Skeletal Radiology (2020) 49:823–836
https://doi.org/10.1007/s00256-020-03379-y

REVIEW ARTICLE

Magnetic resonance imaging of impingement and friction syndromes around the knee

Imran Khan[1] · Tanweer Ashraf[2] · Asif Saifuddin[3,4]

Received: 9 October 2019 / Revised: 11 January 2020 / Accepted: 16 January 2020 / Published online: 28 January 2020

Abstract
The knee is a complex joint with its function dependent on a combination of osseous and soft tissue structures. Alteration in the relationship of these tissues, due to either acute or chronic repetitive injury with possible underlying congenital predisposing factors, can result in impingement between the structures resulting in pain, particularly on activity. The purpose of this article is to provide a comprehensive review of the MRI features of various impingement syndromes around the knee.

Keywords Knee · Impingement · Friction syndromes · MRI

Introduction

The knee is a complex joint with movements occurring in different planes and in several different axes. The inside of the joint has an intricate arrangement of soft tissues, which facilitate these movements and enable the knee to withstand varying degrees of stress. These soft tissues may be injured, inflamed, or impinged due to strenuous repetitive activity, or if congenitally predisposed from routine daily activity. Patients with impingement problems present with poorly defined knee pain and without clear physical signs. Static imaging is often reported as normal, making it very difficult to establish a diagnosis. Meticulous interpretation of MRI based on a detailed understanding of the structures and pathology is essential for planning appropriate treatment.

Lower limb impingement syndromes in adults and in children have been previously reviewed, without emphasis on the knee joint [1, 2]. Faletti et al. reported their experience of knee impingement syndromes in a sporting population aged 16–55 years in an article which is now over 20 years old and did not emphasize the role of MRI, while more recently Grando et al. reviewed the MRI findings of common intra-articular extra-synovial impingement syndromes but did not consider extra-articular causes of knee impingement [3, 4]. The aim of this article is to provide a comprehensive update of the commoner impingement syndromes around the knee, and to also describe new and rarer knee impingement syndromes. Conditions which are termed ‘friction syndromes’ are also included, as are syndromes which can result in pain from repetitive trauma to various intra-articular structures such as the synovial plicae although the terms ‘impingement’ and ‘friction’ have not been specifically used to describe them. We have classified knee impingement syndromes into the 4 quadrants of the knee joint (anterior, medial, posterior, and lateral) as previously described, with further subdivision according to intra-capsular or extra-capsular sources of knee pain as shown in Table 1 [3].

✉ Imran Khan
drkhan02@yahoo.com

Tanweer Ashraf
tanweer.ashraf@nhs.net

Asif Saifuddin
asif.saifuddin@nhs.net

1 Department of Radiology, Leicester Royal Infirmary, University Hospitals of Leicester NHS Trust, Leicester, UK

2 Department of Orthopaedics, Royal Orthopaedic Hospital, Birmingham, UK

3 Department of Radiology, Royal National Orthopaedic Hospital, Stanmore, UK

4 Everlight Radiology, Level 6 West, Euston Road, London NW1 3AX, UK

Table 1 Classification of impingement and friction syndromes around the knee

	Quadrant	Location and pathology/source
I	Anterior	A. Extra-capsular 1. Pre-patellar friction syndrome B. Intra-capsular 1. Fat pad a. Hoffa's fat pad b. Pre-femoral fat pad c. Supra-patellar fat pad 2. Supra-patellar plica
II	Medial	A. Extra-capsular 1. Medial tibial crest friction 2. Posteromedial friction syndrome B. Intra-capsular 1. Medial plica syndrome 2. Meniscal/osteomeniscal impingement syndromes
III	Posterior	A. Intra-capsular 1. Peri-cruciate fat pad inflammation
IV	Lateral	A. Extra-capsular 1. Iliotibial band friction syndrome B. Intra-capsular 1. Popliteus tendon impingement

Anterior

Extra-capsular: pre-patellar friction syndrome

In 2003, Dye et al. described the tri-laminar structures of the pre-patellar soft tissues [5]. The superficial layer was orientated transverse to the patella. The intermediate layer, arising from the expansion of the vastus medialis and lateralis with some contribution from the superficial fibres of rectus femoris, was orientated oblique to the patella, while the deep layer was formed by the continuation of the deep fibres of the rectus femoris and was adherent to the underlying bone in a longitudinal orientation. This layer continued inferiorly to become part of the patellar tendon. A small amount of bursal fluid was noted between all three layers, helping to reduce friction. This tri-laminar anatomy is evident on MRI [6].

In 2015, Claes et al. described pre-patellar friction syndrome, an entity observed in a series of 29 surgically operated patients brought on by repetitive motion causing the superficial and intermediate layers to rub against the fixed deep layer [7]. The pathology was seen exclusively in young professional cyclists with anterior knee pain during physical exertion, with or without a history of preceding trauma. There was point tenderness over the superior pole of the patella, mostly at the medial aspect. At surgery, all patients had a defect in the thinnest superficial layer, with or without a further defect in the more robust intermediate layer. The deepest layer only demonstrated inflammation, but no tears. Ultrasound was able to demonstrate the fascial defects, and although the MRI features have not been formally reported, oedematous swelling of the pre-patellar soft tissues would be expected (Fig. 1). It is important to identify this condition on MRI as opposed to simple pre-patellar bursitis, since the condition responds well to partial pre-patellar fasciectomy [7].

Intra-capsular: fat pad impingement

Three distinct areas of adipose tissue called 'fat pads' have been defined in the anterior aspect of the knee joint: the infrapatellar (Hoffa's), the suprapatellar (quadriceps), and the pre-femoral fat pads. These intra-capsular, extra-synovial structures act as protective cushions that accommodate the changing shape and volume of the spaces they occupy during movements of the knee joint [8, 9].

Hoffa's fat pad

Hoffa's fat pad is limited anteriorly by the patellar tendon and joint capsule, superiorly by the inferior pole of the patella, inferiorly by the proximal tibia and the deep infrapatellar bursa, and posteriorly by the joint synovium [10]. It is made up of fat lobules with multiple septa. Hoffa's fat pad is richly innervated via branches of the femoral, common peroneal and saphenous nerves, and therefore, pathology of the fat pad can be a source of anterior knee pain. It is an important structure, as evident by altered patellar biomechanics following its resection [11]. The infrapatellar plica, a remnant of the synovial membranes also known as the ligamentum mucosum, runs through the fat pad between the anterior aspect of the femur and the inferior pole of the patella. It is the most common plica identified on arthroscopy [12]. Pain arising from Hoffa's fat pad is usually secondary to other knee pathology, and may also occur after knee arthroscopy. However, three types of impingement have been described.

The commonest type occurs in the superolateral aspect of the fat pad and is termed patellar tendon-lateral femoral condyle friction syndrome [13, 14]. It is typically seen in young patients with a higher incidence in females, although it can also occur in older individuals [15]. Patients typically present with anterior or anterolateral knee pain which is commonly exacerbated by hyperextension. Physical examination may demonstrate focal point tenderness at the inferior pole of the patella [9]. MRI demonstrates increased signal on T2-weighted fast spin-echo (T2W FSE) or fat-suppressed proton density–weighted fast spin-echo (PDW FSE) images, with corresponding reduced signal on T1-weighted spin-echo (T1W SE) or PDW FSE images (Fig. 2) [14]. The abnormal signal may extend into the central superior aspect of the fat pad, and injection of contrast medium always results in enhancement [16, 17]. A minority of patients may demonstrate appearances of a lobular lesion with fluid/cystic signal change (Fig. 3), and abnormality of the adjacent patellar tendon is not uncommon [14, 18].

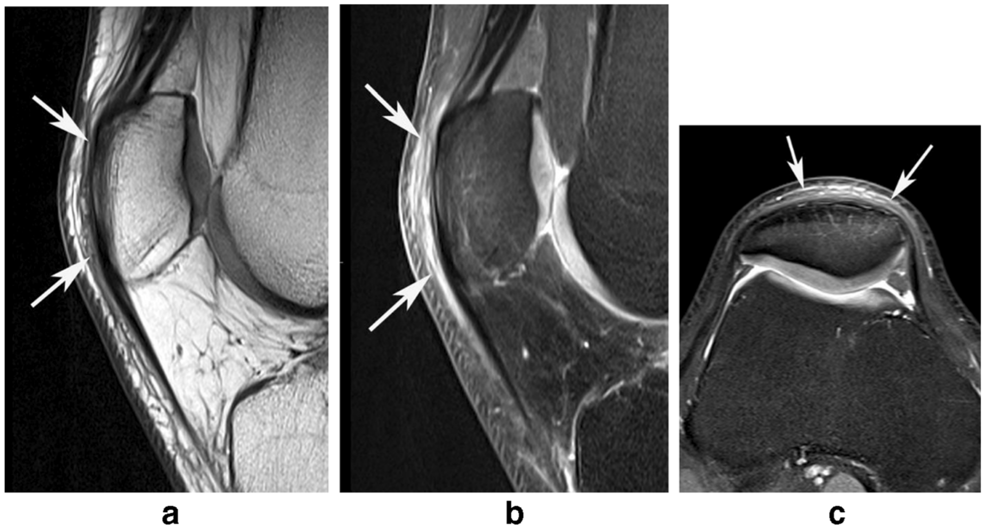


Fig. 1 A 21-year-old male with anterior knee pain following a cycling injury. **a** Sagittal PDW FSE, **b** sagittal STIR, and **c** axial fat-suppressed PDW FSE MR images of the right knee demonstrating oedematous thickening of the soft tissues anterior to the patella, consistent with pre-patellar friction syndrome

Multiple studies have correlated superolateral Hoffa's fat pad oedema with various parameters of patellofemoral maltracking, including patella alta (Insall-Salvati index > 1.3), lateral patellar subluxation (increased tibial tubercle-trochlear groove distance), shallow trochlear depth, sulcus angle, lateral trochlear inclination angle, lateral patellofemoral angle, lateral patellar translation, and the distance between the patellar tendon and the most anterior margin of the adjacent femoral condyle [14, 15, 18–23]. It is important to highlight that while the studies have shown statistically significant differences regarding the various measurements of patellofemoral maltracking between patients with and without oedema in the superolateral aspect of the fat pad, these measurements do not always fall outside the normal range of values described in the literature [21]. Similar signal abnormality can also be seen in asymptomatic patients, particularly in athletes when it may be bilateral. This may still be due to subtle patellofemoral maltracking, but will not require any treatment [17, 24].

The second type of impingement is called Hoffa's disease and is related to injury which may be either acute, or chronic and repetitive in nature. First described by Albert Hoffa in 1904, the injury causes haemorrhage and inflammation resulting in hypertrophy of the fat pad and impingement between the tibia and femur during knee extension [13, 25]. Impingement causes further trauma to the fat pad resulting in a continuous cycle of inflammatory response. In the chronic stage, there is fibrosis within the fat pad, with occasional metaplasia resulting in ossification. Patients typically present with pain in the infrapatellar or retro-patellar region, loss of normal hyperextension, and positive Hoffa's test (tenderness on palpation of the fat pad on either side of the patellar tendon as the knee moves from 90° flexion to full extension) [26]. On MRI, acute changes result in hyperintensity within Hoffa's fat pad on fat-suppressed PDW FSE or T2W FSE images, with corresponding hypointensity on T1W SE images [27]. The oedema is more common in the superior or posterior region of the fat pad (Fig. 4), and other MRI features include a fluid-

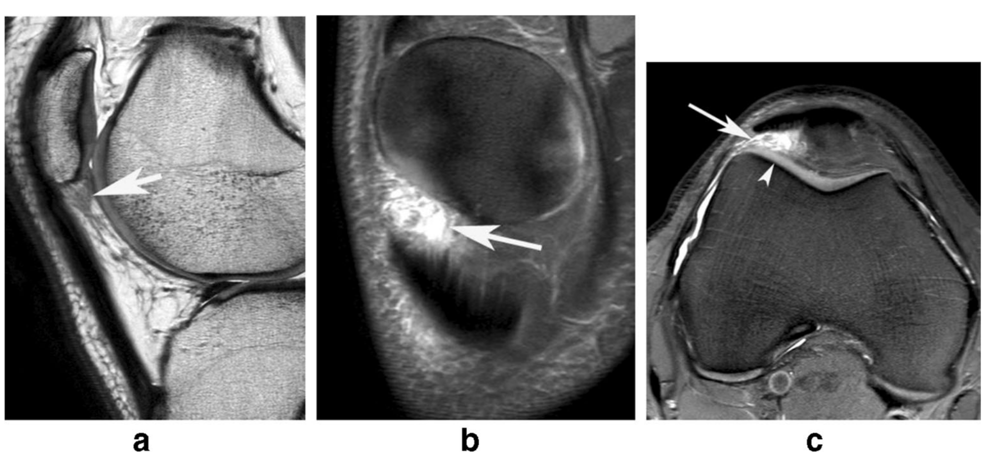


Fig. 2 A 27-year-old male with anterior knee pain. **a** Sagittal PDW FSE, **b** coronal STIR, and **c** axial fat-suppressed PDW FSE MR images of the right knee demonstrating oedema of the superolateral aspect of Hoffa's fat pad (arrows) and prominence of the lateral femoral condyle (arrowhead in **c**), consistent with patellar tendon-lateral femoral condyle friction syndrome

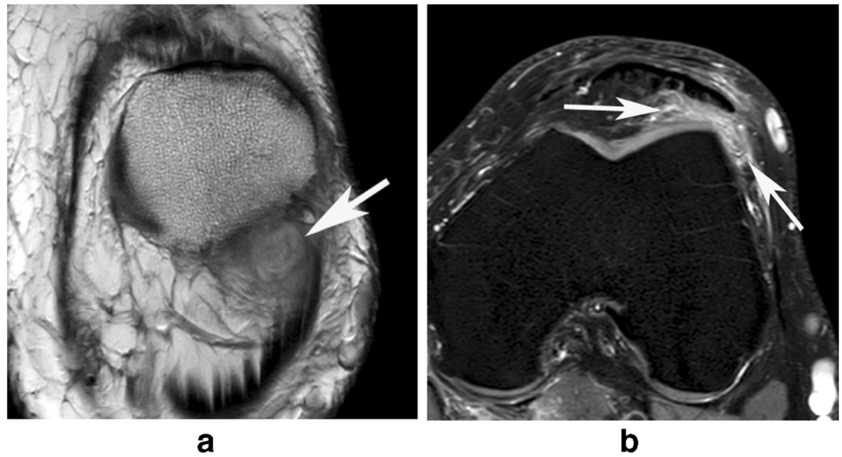


Fig. 3 A 37-year-old male with anterior knee pain. **a** Coronal PDW FSE and **b** axial fat-suppressed PDW FSE MR images of the left knee demonstrating a poorly defined mass in the superolateral aspect of Hoffa's fat pad (arrows) consistent with patellar tendon-lateral femoral condyle friction syndrome

filled deep infrapatellar bursa, non-visualization of vertical and/or horizontal clefts, fibrosis, and calcifications [28]. The fat pad may be enlarged with anterior bowing of the patellar tendon due to mass effect [16]. Chronic cases may show fibrosis with low signal on T1 and T2W images, while radiographs can demonstrate calcification within the fat pad (Fig. 5) [29]. Oedema and scarring of Hoffa's fat pad may also be seen in association with acute and chronic anterior cruciate ligament injury, the resulting knee instability potentially resulting in fat pad impingement which typically involves the region around the ligamentum mucosum [30].

The third type of impingement that may affect Hoffa's fat pad is related to the infrapatellar plica and is termed posterior Hoffa's fat pad impingement. Plicae are normal folds of synovial tissue found in the lining of the knee joint and are (in order of decreasing frequency) the infrapatellar plica (ligamentum mucosum), the suprapatellar plica, the medial (mediopatellar) plica, and the lateral plica [31]. The suprapatellar plica is considered to be a septal remnant between the suprapatellar bursa and patellofemoral cavitation, which is the precursor for the patellofemoral joint space. The infrapatellar plica is a remnant of the septum between the medial and lateral tibiofemoral compartments, but the medial plica is not associated with any distinct compartment [32]. The reported incidence of plica is variable, ranging from 21% for various types of plica to as high as 80% for medial plica, while 11% of the knees may have all 3 main types of plicae and 10% do not have any plicae at all [33, 34]. On MRI, a normal plica is seen as a thin band of low signal intensity within the hyperintense joint fluid, optimally demonstrated on fat-suppressed T2W FSE, PDW FSE, or T2W gradient-echo (GRE) sequences [35]. Plica syndrome is defined as painful knee impairment when the only imaging finding to explain the symptoms is the presence of an abnormal plica [36]. It may be caused by direct injury, repetitive/overuse injury, or a variety of inflammatory conditions. However, most cases of plica syndrome are idiopathic [37].

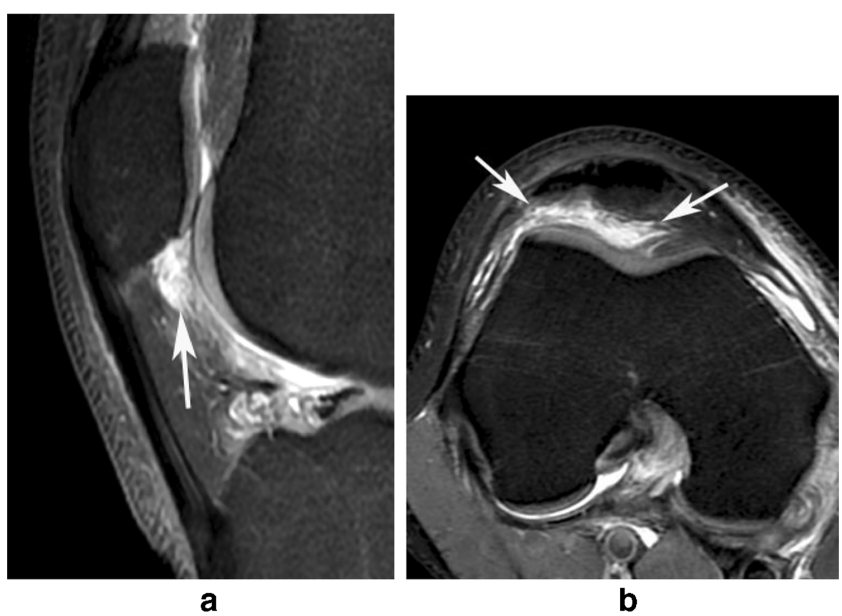


Fig. 4 A 25-year-old male who injured his knee playing football. **a** Sagittal and **b** axial fat-suppressed PDW FSE MR images of the right knee demonstrating oedema in the posterosuperior aspect of Hoffa's fat pad (arrows) consistent with acute Hoffa's disease

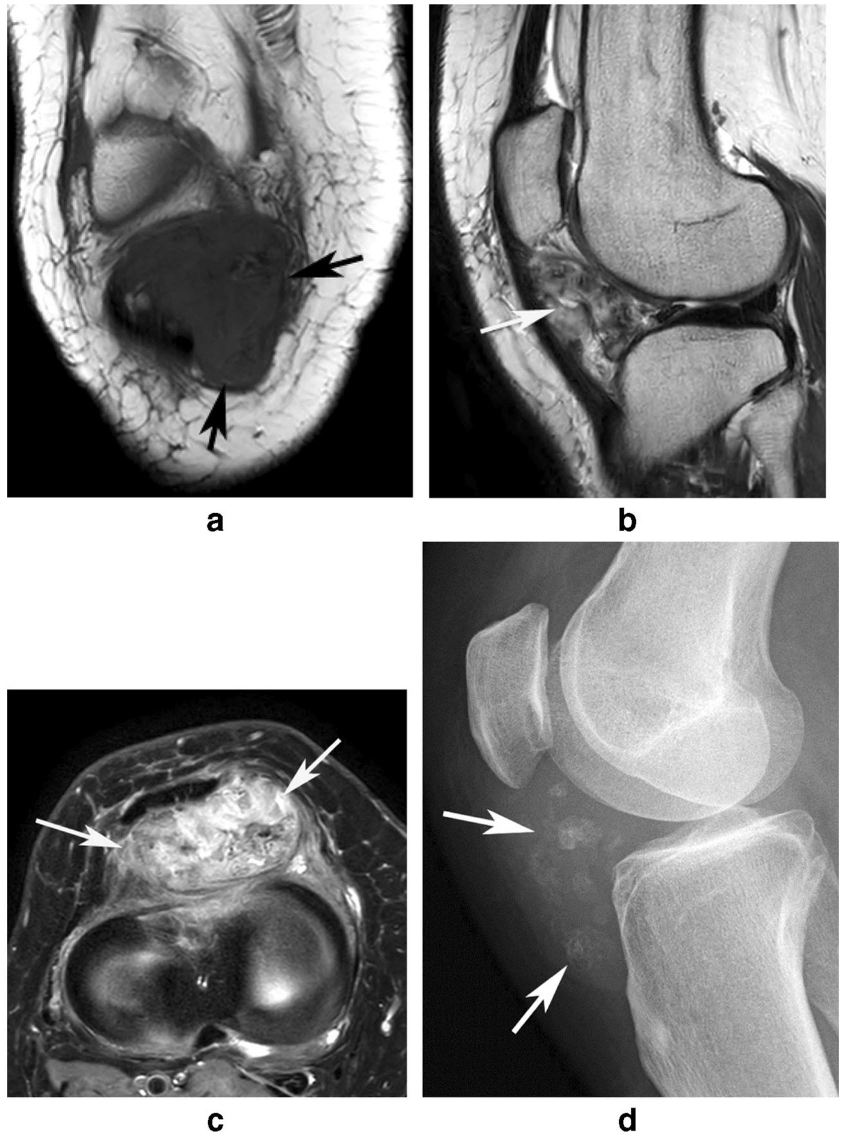


Fig. 5 A 58-year-old female with a chronically swollen and painful right knee. **a** Coronal T1W SE, **b** sagittal T2W FSE, and **c** axial SPAIR MR images show a large oval heterogeneous mass in Hoffa's fat pad (arrows), which has heterogeneous signal intensity and is resulting in anterior bowing of the patellar tendon. **d** Lateral radiograph showing multiple areas of ossification within the mass (arrows), the features being consistent with chronic Hoffa's disease. The diagnosis was confirmed on biopsy

The infra-patellar plica may undergo thickening and fibrosis and become symptomatic, causing anterior knee pain and restriction of movement by impinging at the intercondylar notch and trochlea [38]. On MRI, there is high signal on fat-suppressed PDW FSE or T2W FSE images along the expected course of the infrapatellar plica, with chondromalacia occurring at the superior aspect of the intercondylar notch and on the patellofemoral sulcus [39, 40]. Similar to Hoffa's disease, the abnormality is related to either acute injury or repetitive trauma, and there may be clinical and imaging overlap with Hoffa's disease [13, 41, 42]. It is therefore considered a diagnosis of exclusion.

Pre-femoral fat pad

The pre-femoral fat pad, also known as the posterior suprapatellar fat pad, is located anterior to the distal femur and superior to the trochlea, being separated from the quadriceps fat pad by the suprapatellar bursa [43]. Two different patterns of oedema have been described within the pre-femoral fat pad. One occurs at the superior aspect close to the midline and is believed to be caused by impingement of the fat pad due to a prominent suprapatellar osteophyte. Scalloping of the anterior femur and fibrous or cartilaginous metaplasia may also be seen (Fig. 6) [43]. The second occurs in the inferolateral part of the fat pad and is found to be associated with patellar tendon-lateral femoral condyle friction syndrome, with impingement of the fat pad occurring between the superior aspect of the patella and the distal femur [9, 14, 19]. MRI shows oedema and enlargement of the fat pad with high signal on fat-suppressed PDW FSE or T2W FSE images and low signal intensity on T1W SE images (Fig. 7) [44]. Some consider the association between pre-femoral fat pad oedema and

Fig. 6 A 71-year-old female with chronic anterior knee pain. Sagittal PDW FSE MR image showing advanced patellofemoral osteoarthritis with an osteophyte at the superior pole of the patella (arrow) causing scalloping of the anterior femoral cortex (arrowheads) and impingement of the pre-femoral fat pad (thin arrow)

anterior knee pain to be controversial, as it can also be an asymptomatic finding in high-level athletes [9, 45].

Quadriceps fat pad

The quadriceps (suprapatellar) fat pad is a small triangular structure located superior to the patella, deep to the quadriceps tendon, and separated from the pre-femoral fat pad by the suprapatellar bursa [43]. Oedema within the suprapatellar fat pad is a common finding on MRI, although its association with anterior knee pain is controversial. Enlargement of the quadriceps fat pad has been demonstrated in 12% of knee MRI studies (Fig. 8a, b), with signal alteration in 54%. A significant association with anterior knee pain and an enlarged fat pad has been suggested [46]. However, a larger retrospective review of 879 knee MRI studies reported an incidence of suprapatellar fat pad enlargement of 13.8% of cases which was rarely associated with anterior knee pain, and there was also no association with patellofemoral malalignment [8]. Finally, Shabshin et al. identified quadriceps fat pad oedema with mass effect in 4.2% of 770 consecutive knee MRI examinations, also demonstrating that symmetrical oedema may be seen in the contralateral knee and that the fat pad enhances following contrast (Fig. 8c) [47].

While the term impingement has been used for suprapatellar fat pad oedema, based on histological changes and the higher incidence in young males, it is considered to be similar to Hoffa's disease representing an overuse injury causing oedema and haemorrhage in the suprapatellar fat pad, rather than being due to impingement [8, 47]. More recently, an association between suprapatellar fat pad oedema and mass effect with subsequent knee osteoarthritis, particularly at the patellofemoral joint, has been identified [48, 49].

Intra-capsular: suprapatellar plica

The suprapatellar plica has also been described as the superior plica, plica synovialis suprapatellaris, superomedial plica, or medial suprapatellar plica [31]. It is located in the suprapatellar region and runs from the synovium at the anterior aspect of the femoral metaphysis to the posterior aspect of the quadriceps tendon, inserting above the patella. It is the most common type of plica, being found in approximately 90% of knees, with various classifications ranging from 4 to 10 different morphological appearances [31, 50–52]. The plica may not demonstrate a septum, but if present, the septum can be complete or incomplete. When complete, the intact septum separates the knee joint cavity from the suprapatellar bursa.

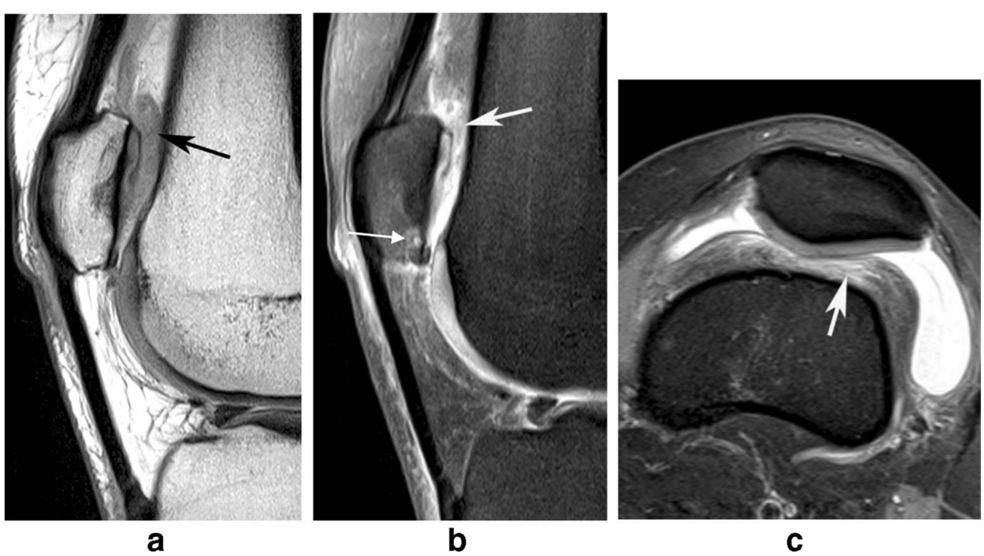


Fig. 7 A 34-year-old female with knee pain. **a** Sagittal PDW FSE, **b** sagittal STIR, and **c** axial fat-suppressed PDW FSE MR images show oedematous thickening of the fat in the lateral aspect of the upper patella-femoral joint (arrows), consistent with pre-femoral fat impingement. This is predisposed to by the presence of patella alta and trochlear dysplasia. Grade 4 chondromalacia is also noted in the inferior patellar articular surface (thin arrow in **b**)

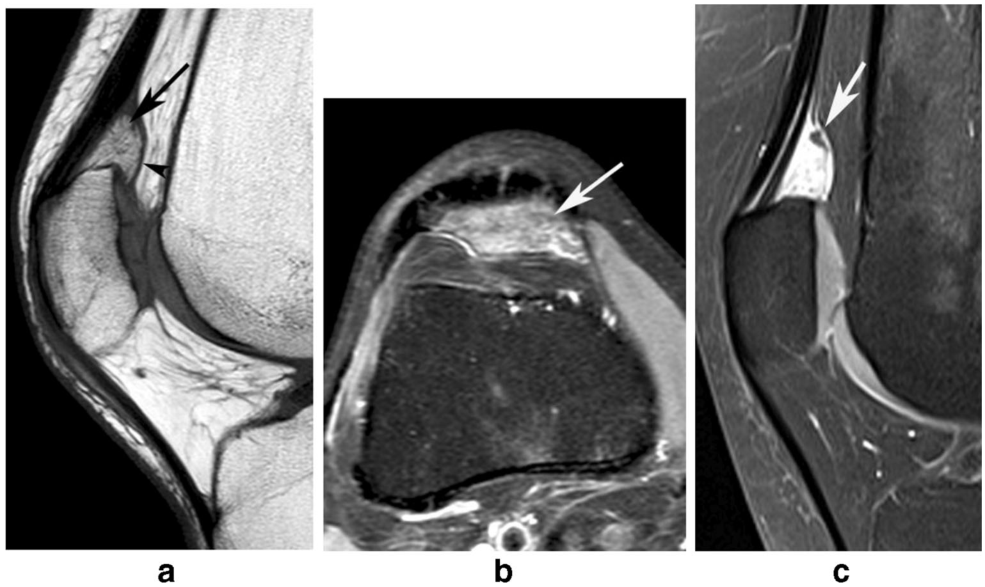


Fig. 8 A 48-year-old female with knee pain. **a** Sagittal PDW FSE and **b** axial fat-suppressed PDW FSE MR images show an oedematous swollen supra-patellar fat pad (arrows), consistent with supra-patellar fat impingement. **c** A 35-year-old female with knee pain and hypermobility. Sagittal post-contrast fat-suppressed T1W SE MR image showing diffuse enhancement of the swollen supra-patellar fat pad (arrow)

A symptomatic suprapatellar plica is a rare occurrence, associated with inflammation which may be triggered by either acute or repetitive injury [53]. Patients present with dull knee pain aggravated by prolonged standing and/or squatting, with point tenderness at the superior pole of the patella [50, 54]. A plica with a complete septum is typically symptomatic. MRI shows a low signal intensity band-like structure in the retro-patellar space, optimally seen on sagittal images (Fig. 9). The abnormal plica can become compressed between the quadriceps tendon and femoral condyle during flexion, resulting in impingement with secondary chondromalacia at the patellofemoral joint [55]. MRI is helpful in identifying the abnormal plica, as well as excluding other underlying causes.

Medial

Extra-capsular: medial tibial crest friction

Medial tibial crest friction was first described in 2013, the condition being seen predominantly in young adults with a high level of physical activity, particularly athletes [56]. Patients typically complained of pain and tenderness approximately 2.5 cm below the medial joint line. It is suggested that prominence of the medial tibial crest due to a reduced medial tibial crest angle results in friction between the tibial collateral ligament and the adjacent bone, causing bone and soft tissue oedema. MRI demonstrates hyperintense signal on fat-suppressed PDW FSE images at the medial tibial crest and

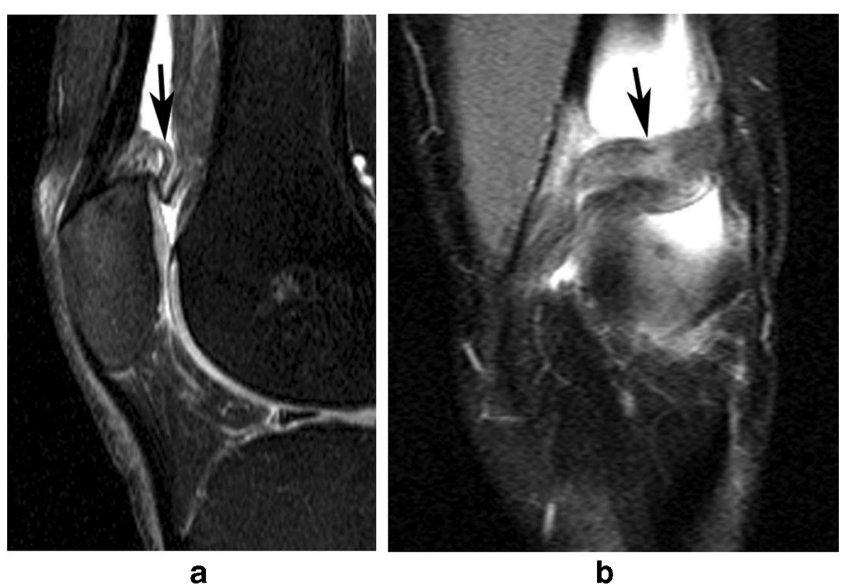


Fig. 9 A 28-year-old male with chronic anterior knee pain. **a** Sagittal STIR and **b** coronal fat-suppressed T2W FSE MR images show oedematous thickening of the supra-patellar plica (arrow in **a**) which extends for the whole transverse width of the supra-patellar pouch (arrow in **b**), the features being consistent with supra-patellar plica syndrome

adjacent soft tissue in all patients, the oedema occurring where the tibial collateral ligament contacts the proximal tibia (Fig. 10). The medial tibial crest angle calculated on the coronal images demonstrated a difference of 8.1° between patients (151.3° ± 9/3°) and controls (159.4° ± 7.2°) [56].

Extra-capsular: posteromedial friction syndrome

Posteromedial friction syndrome is thought to be due to approximation of the posteromedial femoral condyle and the adjacent sartorius and gracilis tendons, although other factors such as concomitant lateral friction syndromes may contribute [57]. Patients complain of medial joint pain which may mimic a meniscal tear, with positive McMurray's test reported in 21% of cases. MRI demonstrates a significantly reduced space between the posteromedial femoral condyle and the adjacent sartorius and gracilis tendons, and a varying degree of oedema of the fat between the condyle and the adjacent tendons (Fig. 11). The oedema is usually deep to both tendons, less commonly deep only to gracilis, and rarely deep only to sartorius. Bone marrow oedema may also be visible in the non-weight-bearing portion of the posteromedial femoral condyle. Lateral-sided friction syndrome is present in approximately 25% of cases, patellar tendon-lateral femoral condyle friction syndrome being the commonest. The condition may respond well to local anaesthetic and steroid injection [58].

Intra-capsular: medial plica syndrome

The medial plica is the most commonly symptomatic plica [31]. Four types of medial plica are described. Types A and B do not cover the medial patellofemoral articular surface, while types C and D extend to cover the articular surfaces and are therefore more likely to be symptomatic. Typically, pain is experienced medial to the patella with clinical signs such as crepitation, pseudo-locking, and effusion-mimicking symptoms of a meniscal tear or patellar maltracking. Oedema and inflammation result in loss of normal elasticity of the plica, causing it to become thickened and fibrotic [59]. Symptoms may be related to the thickened oedematous plica itself, or from impingement on the cartilage at the medial femoral condyle in extension and medial patellar facet in flexion [35]. MRI demonstrates a thickened irregular plica, covering the medial aspect of the patellofemoral joint (Fig. 12). Associated cartilage defects are seen in the medial patellofemoral joint in 30% of patients [60, 61].

Intra-capsular: meniscal impingement syndromes

Various types of meniscal impingement have been described, predominantly related to the medial meniscus. These are due to either variations of underlying bone morphology, increased joint mobility, or peripherally displaced meniscal tears. Some conditions described in the orthopaedic literature cannot be demonstrated on routine knee MRI, and are therefore not included.

Morphological factors may predispose to meniscal impingement and tears. In a retrospective analysis of 160 knee MRI studies of 150 patients, medial and lateral tibial slope, medial tibial plateau depth, and medial and lateral femoral condylar offset ratio were measured and correlated with the presence and location of meniscal tears. A significant association was shown between reduced medial tibial slope and tears in the posterior third of the medial meniscus, the combination of shallow medial tibial slope, and the relatively immobile posterior third likely contributing to meniscal impingement on knee flexion. A significant association was also identified between tears of the anterior third of the lateral meniscus and a shallow lateral tibial slope [62].

Osteomeniscal impingement, also termed osteomeniscal impact oedema (OIE), is a distinct entity manifest by a peripherally displaced flap tear of the medial meniscus with adjacent reactive bone marrow oedema [63, 64]. Patients typically complain of medial knee pain, particularly with knee flexion and valgus stress, as a result of impingement of the meniscal

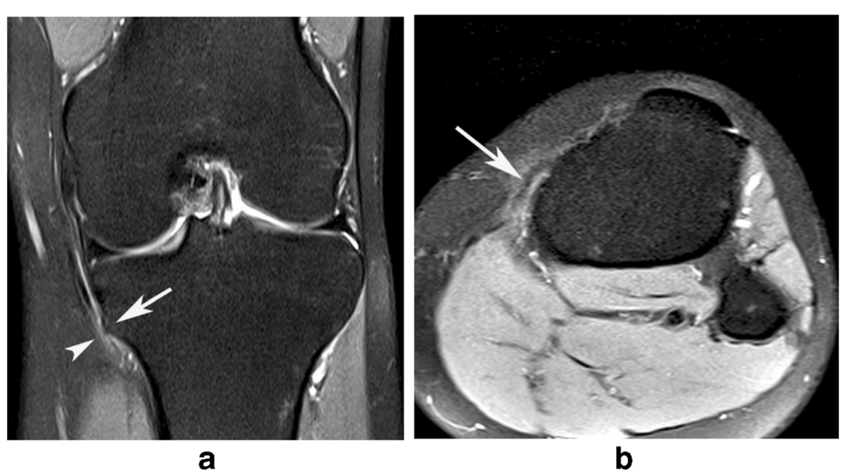


Fig. 10 A 22-year-old female with anteromedial knee pain. **a** Coronal fat-suppressed PDW FSE MR image showing a prominent tibial crest (arrow) with oedematous overlying soft tissue (arrowhead). **b** Axial fat-suppressed PDW FSE MR image showing thickening of the tibial collateral ligament (arrow), the features being consistent with medial tibial crest friction syndrome

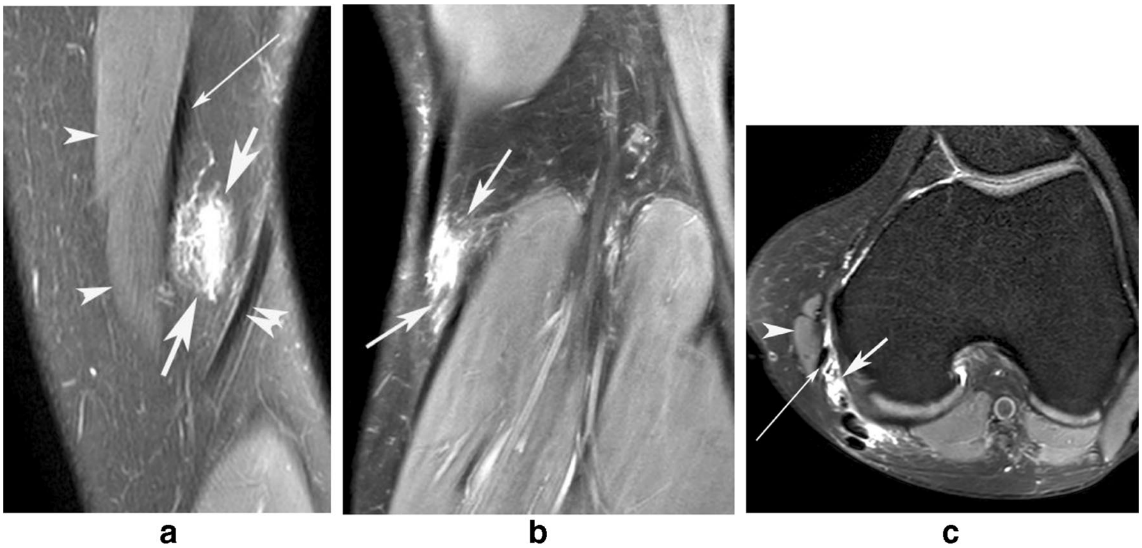


Fig. 11 A 25-year-old male with posteromedial knee pain. **a** Sagittal, **b** coronal, and **c** axial fat-suppressed PDW FSE MR images showing soft tissue oedema (arrows) between the medial femoral condyle and sartorius (arrowheads in **a** and **c**), gracilis (thin arrows in **a** and **c**), and anterior to semitendinosus (double arrowhead in **a**), consistent with posteromedial impingement syndrome

fragment against the bone under an intact medial collateral ligament [65]. Displacement into the inferior medial gutter (Fig. 13a) is more common compared with superior displacement (Fig. 13b). Apart from identifying the displaced meniscal fragment and adjacent oedema, MR may also demonstrate focal bone depression. It is important to identify flap tears with osteomeniscal impingement, as patients may respond well to arthroscopic debridement of the displaced meniscal fragment [63, 66].

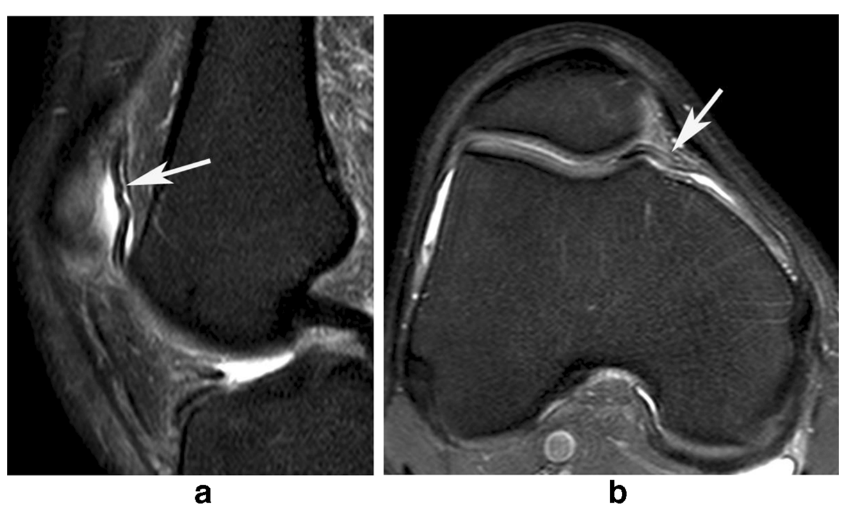
Posterior

Intra-capsular: peri-cruciate fat pad inflammation

The peri-cruciate fat pad is a triangular-shaped structure located in the intercondylar fossa above the posterior cruciate ligament and posterior fibres of the anterior cruciate ligament. It is an intra-capsular, extra-synovial structure which is best identified on sagittal MR images [67].

Peri-cruciate fat pad inflammation presents as non-specific posterior knee pain, predominantly in young patients with a high level of physical activity. Impingement of the fat pad in knee flexion has been proposed as a possible mechanism of injury/inflammation. MRI demonstrates a poorly defined oedema in the peri-cruciate fat pad on fluid-sensitive fat-suppressed sequences, best appreciated on sagittal and axial images (Fig. 14). The oedematous fat pad will enhance following contrast. The condition is a diagnosis of exclusion, which can be suggested when no other pathology is demonstrated to account for the patient's symptoms.

Fig. 12 A 46-year-old male with knee pain. **a** Sagittal and **b** axial fat-suppressed PDW FSE MR images showing a thickened, irregular, and oedematous mediopatellar plica (arrows) extending into the patellofemoral joint, consistent with plica syndrome



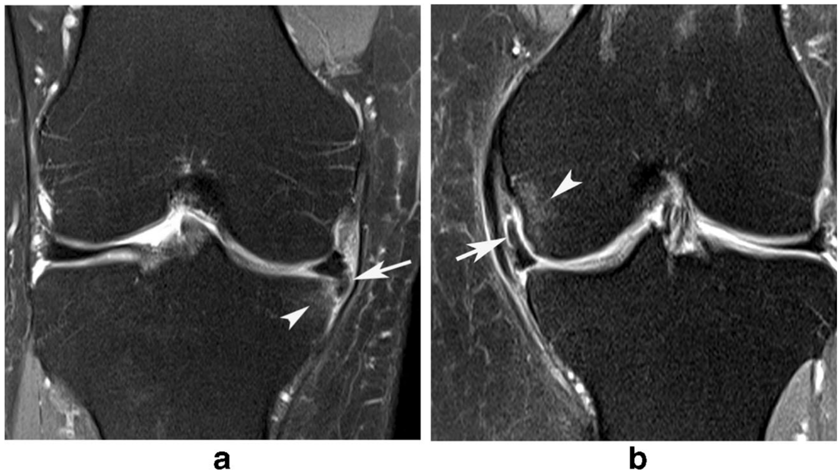


Fig. 13 Osteomeniscal impingement. **a** A 43-year-old male with medial knee pain. Coronal fat-suppressed T2W FSE MR image showing a peripherally displaced meniscal fragment (arrow) adjacent to the medial tibial plateau with associated bone erosion and bone marrow oedema (arrowhead). **b** A 49-year-old female with medial knee pain following prolonged walking. Coronal fat-suppressed T2W FSE MR image showing a peripherally displaced meniscal fragment (arrow) adjacent to the medial femoral condyle with associated bone marrow oedema (arrowhead)

Lateral

Extra-capsular: iliotibial band friction syndrome

The iliotibial band is a tri-laminar structure consisting of superficial, intermediate, and deep layers which merge together at the level of the greater trochanter receiving fibres from the gluteus maximus and tensor fascia lata muscles [68, 69]. In the distal thigh, it runs close to the lateral femoral condyle, attaching to the intermuscular septum and supracondylar tubercle of the femur proximal to the knee joint. Distally, it inserts into Gerdy's tubercle on anterolateral tibia. The space between the iliotibial band and the lateral femoral condyle contains fatty and vascular connective tissue [70]. Contrary to the earlier suggestion of the band moving forwards and backwards in flexion and extension respectively, Fairclough et al. have shown that the band is compressed against the epicondyle in 30° of flexion and moves laterally on extension [71].

Iliotibial band friction syndrome was first described in 1975 in military personnel presenting with lateral knee pain, being subsequently reported in athletes a few years later [72, 73]. The incidence of iliotibial band friction syndrome ranges from 1.6 to 12% [74]. Various aetiologies have been proposed, including friction induced by the band as it moves over the lateral epicondyle of the femur, and compression of the fat and connective tissue between the band and adjacent condyle [74].

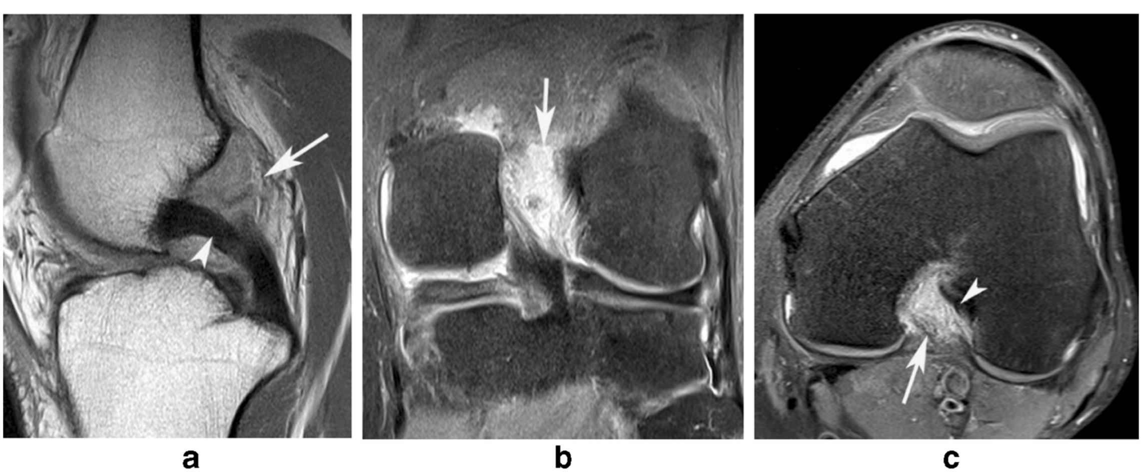


Fig. 14 A 43-year-old male with knee pain. **a** Sagittal PDW FSE, **b** coronal fat-suppressed PDW FSE, and **c** axial fat-suppressed PDW FSE MR images showing a swollen, oedematous peri-cruciate fat pad (arrows) posterosuperior to the PCL (arrowhead in **a**) and medial to the posterior fibres of the ACL (arrowhead in **c**), consistent with peri-cruciate fat pad inflammation

Fig. 15 A 39-year-old female who developed lateral knee pain 4 weeks after mountain climbing. **a** Coronal and **b** axial fat-suppressed PDW FSE MR images showing oedema of the fat (arrows) between the iliotibial band and the lateral femoral condyle, consistent with iliotibial band friction syndrome

Structural abnormalities have also been implicated, including gait abnormality, leg length discrepancy, and varus deformity of the knees [74, 75].

The diagnosis of iliotibial band friction syndrome is based on history and clinical symptoms, with tenderness over the lateral aspect of the knee, inferior to femoral condyle but above the joint line [76]. However, other conditions such as lateral meniscal tears, lateral collateral ligament sprain, and popliteus tendon strain may mimic symptoms of iliotibial band friction syndrome [77]. Therefore, MRI is helpful in making the appropriate diagnosis. The most common MRI finding is an ill-defined area of hyperintense signal on fat-suppressed PDW FSE/ T2W FSE coronal and axial images deep to the iliotibial band and lateral, proximal, or distal to the femoral condyle (Fig. 15). The signal abnormality can also be seen posterolaterally between by the femur and the anterior margin of biceps femoris. Oedema superficial to the iliotibial band is uncommon in friction syndrome being typically associated with acute trauma, and there is usually no thickening of the band itself [75, 78]. Rarely, oedema-like marrow signal may be seen in the adjacent lateral femoral condyle (Fig. 16) [79]. A circumscribed fluid collection may be observed deep to the iliotibial band and separate from the suprapatellar pouch in approximately 30% of patients, which can be as large as 5 cm in keeping with adventitial bursitis as a result of chronic inflammation [70].

Intra-capsular: popliteus tendon impingement

The popliteus musculotendinous unit is a major stabilizer of the posterolateral knee [80]. The muscle originates from a strong intra-capsular tendon at the lateral condyle of the femur, coursing inferomedially within the popliteal fossa and inserting into the posterior surface of the tibia above the soleal line. The popliteofibular ligament anchors the popliteus to the fibular head, and the tendon has variable attachments to the lateral meniscus.

Impingement of the popliteus tendon is an extremely rare cause of lateral knee pain, typically occurring secondary to osteophyte formation at the lateral femoral condyle

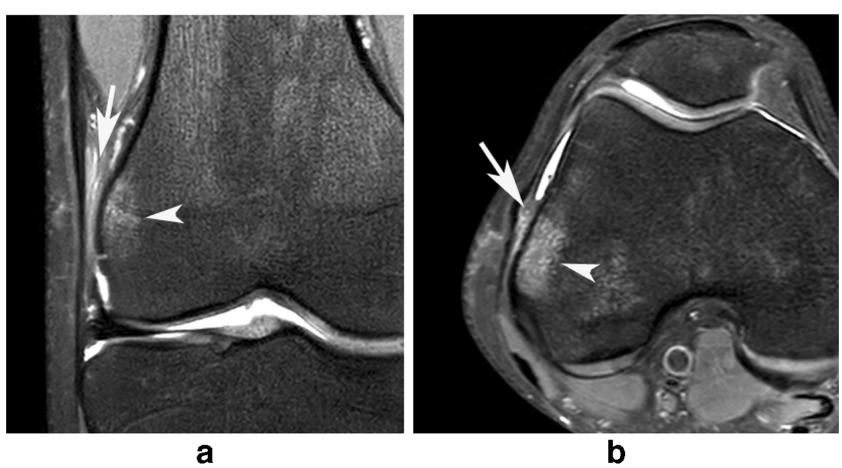


Fig. 16 A 21-year-old female with lateral knee pain. **a** Coronal and **b** axial fat-suppressed PDW FSE MR images showing oedema of the fat (arrows) between the iliotibial band and the lateral femoral condyle, with adjacent oedema-like marrow signal (arrowheads)

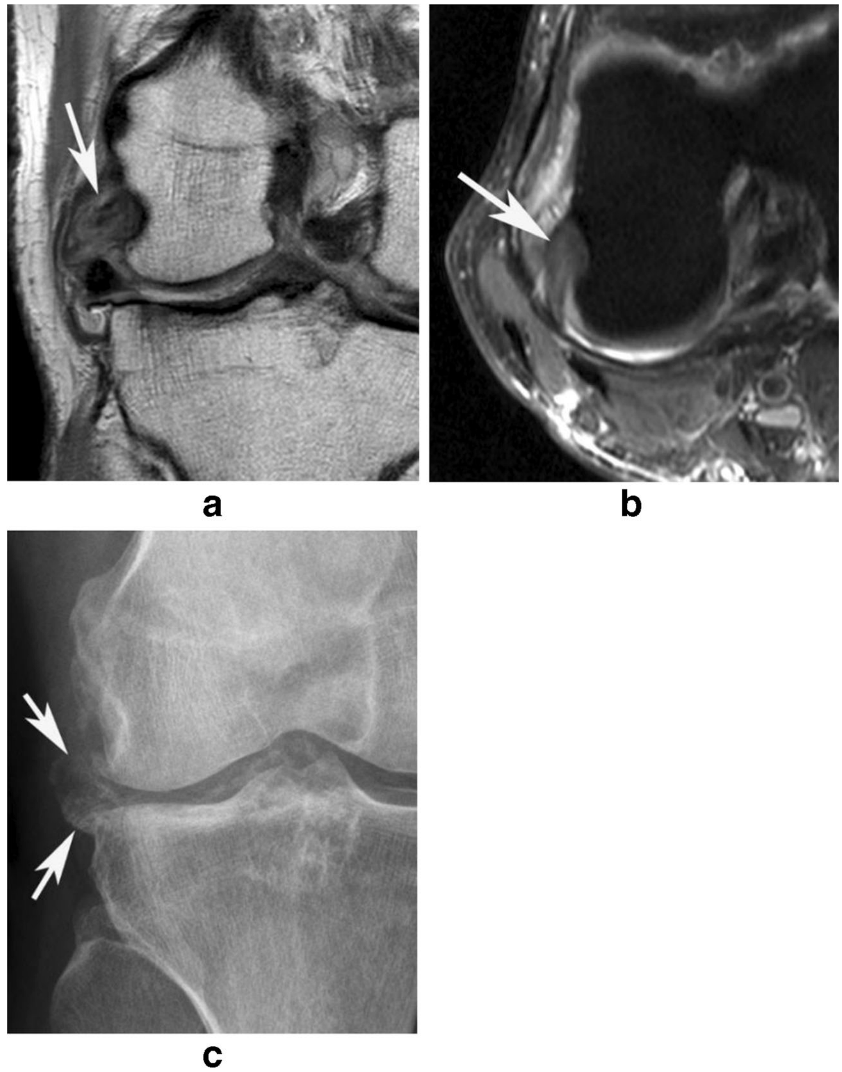


Fig. 17 A 71-year-old male with lateral knee pain. **a** Coronal PDW FSE and **b** axial fat-suppressed PDW FSE MR images showing a thickened, oedematous popliteus tendon insertion (arrows) with adjacent soft tissue oedema. **c** AP radiograph demonstrates large osteophytes at the lateral joint margin (arrows), the features being consistent with intra-articular popliteus tendon impingement

[81]. The pain is typically related to physical activity causing an abnormal movement of the popliteus tendon against the osteophyte. The tendon may appear thickened and inflamed at arthroscopy, which also allows direct visualization of the tendon impinging on the osteophyte. MRI demonstrates swelling and hyperintensity of the tendon to its insertion at the lateral femoral condyle consistent with tendinosis, and oedema of the surrounding soft tissues (Fig. 17).

Summary

A wide variety of impingement and friction syndromes can occur around the knee, mimicking meniscal and ligamentous conditions in the setting of acute and chronic sports injuries. Knowledge of the MRI appearances is essential to allow correct diagnosis and management.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Consent and ethics Not applicable

References

1. De Maeseneer M, Wuertzer S, De Mey J, Shahabpour M. The imaging findings of impingement syndromes of the lower limb. Clin Radiol. 2017;72(12):1014–24.
2. Aydingoz U, Maras Ozdemir Z, Gunes A, Ergen FB. MRI of lower extremity impingement and friction syndromes in children. Diagn Interv Radiol. 2016;22(6):566–73.
3. Faletti C, De Stefano N, Giudice G, Larciprete M. Knee impingement syndromes. Eur J Radiol. 1998;27(Suppl 1):S60–9.
4. Grando H, Chang EY, Chen KC, Chung CB. MR imaging of extrasynovial inflammation and impingement about the knee. Magn Reson Imaging Clin N Am. 2014;22(4):725–41.

5. Dye SF, Campagna-Pinto D, Dye CC, Shifflett S, Eiman T. Soft-tissue anatomy anterior to the human patella. J Bone Joint Surg Am. 2003;85(6):1012–7.
6. Flores DV, Mejía Gómez C, Pathria MN. Layered approach to the anterior knee: normal anatomy and disorders associated with anterior knee pain. Radiographics. 2018;38(7):2069–101.
7. Claes T, Claes S, De Roeck J, Claes T. Prepatellar friction syndrome: a common cause of knee pain in the elite cyclist. Acta Orthop Belg. 2015;81(4):614–9.
8. Tsavalas N, Karantanas AH. Suprapatellar fat-pad mass effect: MRI findings and correlation with anterior knee pain. Am J Roentgenol. 2013;200(3):W291–6.
9. Jarraya M, Diaz LE, Roemer FW, Arndt WF, Goud AR, Guermazi A. MRI findings consistent with peripatellar fat pad impingement: how much related to patellofemoral maltracking? Magn Reson Med Sci. 2018;17(3):195–202.
10. Draghi F, Ferrozzi G, Urciuoli L, Bortolotto C, Bianchi S. Hoffa's fat pad abnormalities, knee pain and magnetic resonance imaging in daily practice. Insights Imaging. Springer Berlin Heidelberg. 2016;7(3):373–83.
11. Bohnsack M, Wilharm A, Hurschler C, Rühmann O, Stukenborg-Colsman C, Wirth CJ. Biomechanical and kinematic influences of a total infrapatellar fat pad resection on the knee. Am J Sports Med. 2004;32(8):1873–80.
12. Kim SJ, Min BH, Kim HK. Arthroscopic anatomy of the infrapatellar plica. Arthroscopy. 1996;12(5):561–4.
13. Saddik D, McNally EG, Richardson M. MRI of Hoffa's fat pad. Skelet Radiol. 2004;33(8):433–44.
14. Chung CB, Skaf A, Roger B, Campos J, Stump X, Resnick D. Patellar tendon-lateral femoral condyle friction syndrome: MR imaging in 42 patients. Skelet Radiol. 2001;30(12):694–7.
15. Widjajahakim R, Roux M, Jarraya M, Roemer FW, Neogi T, Lynch JA, et al. Relationship of trochlear morphology and patellofemoral joint alignment to superolateral Hoffa fat pad edema on MR images in individuals with or at risk for osteoarthritis of the knee: the MOST study. Radiology. 2017;284(3):806–14.
16. LLopis E, Padrón M. Anterior knee pain. Eur J Radiol. 2007;62(1):27–43.
17. De Smet AA, Davis KW, Dahab KS, Blankenbaker DG, del Rio AM, Bernhardt DT. Is there an association between superolateral Hoffa fat pad edema on MRI and clinical evidence of fat pad impingement? AJR Am J Roentgenol. 2012;199(5):1099–104.
18. Campagna R, Pessis E, Biau DJ, Guerini H, Feydy A, Thevenin FS, et al. Is superolateral Hoffa fat pad edema a consequence of impingement between lateral femoral condyle and patellar ligament? Radiology. 2012;263(2):469–74.
19. Subhawong TK, Eng J, Carrino JA, Chhabra A. Superolateral Hoffa's fat pad edema: association with patellofemoral maltracking and impingement. Am J Roentgenol. 2010;195(6):1367–73.
20. Jibri ZA, Kamath S. Maltracking and impingement of superolateral Hoffa's fat pad. Am J Roentgenol. 2011;197(6):W1164–W4.
21. Matcuk GR, Cen SY, Keyfes V, Patel DB, Gottsegen CJ, White EA. Superolateral hoffa fat-pad edema and patellofemoral maltracking: predictive modeling. AJR Am J Roentgenol. 2014;203(2):W207–12.
22. Jarraya M, Guermazi A, Felson DT, Roemer FW, Nevitt MC, Torner J, et al. Is superolateral Hoffa's fat pad hyperintensity a marker of local patellofemoral joint disease? - the MOST study. Osteoarthr Cartil. 2017;25(9):1459–67.
23. Li J, Sheng B, Yu F, Guo C, Lv F, Lv F, et al. Quantitative magnetic resonance imaging in patellar tendon-lateral femoral condyle friction syndrome: relationship with subtle patellofemoral instability. Skeletal Radiol. Springer Berlin Heidelberg. 2019;48(8):1251–9.
24. Mehta K, Wissman R, England E, D heurle A, Newton K, Kenter K. Superolateral Hoffa's fat pad edema in collegiate volleyball players. J Comput Assist Tomogr. 2015;39(6):945–50.
25. Hoffa A. The influence of the adipose tissue with regard to the pathology of the knee joint. JAMA. 1904;XLIII(12):795.
26. Kumar D, Alvand A, Beacon JP. Impingement of infrapatellar fat pad (Hoffa's disease): results of high-portal arthroscopic resection. Arthroscopy. 2007;23(11):1180–1.
27. Larbi A, Cyteval C, Hamoui M, Dallaudière B, Zarqane H, Viala P, et al. Hoffa's disease: a report on 5 cases. Diagn Interv Imaging. 2014;95(11):1079–84.
28. von Engelhardt LV, Tokmakidis E, Lahner M, Dàvid A, Haage P, Bouillon B, et al. Hoffa's fat pad impingement treated arthroscopically: related findings on preoperative MRI in a case series of 62 patients. Arch Orthop Trauma Surg. 2010;130(8):1041–51.
29. Jacobson JA, Lenchik L, Ruhoy MK, Schweitzer ME, Resnick D. MR imaging of the infrapatellar fat pad of Hoffa. RadioGraphics. 1997;17(3):675–91.
30. Abreu MR, Chung CB, Trudell D, Resnick D. Hoffa's fat pad injuries and their relationship with anterior cruciate ligament tears: new observations based on MR imaging in patients and MR imaging and anatomic correlation in cadavers. Skelet Radiol. 2008;37(4):301–6.
31. Dupont JY. Synovial plicae of the knee. Controversies and review. CSM. 1997;16(1):87–122.
32. Ogata S, Uhthoff HK. The development of synovial plicae in human knee joints: an embryologic study. Arthroscopy. 1990;6(4):315–21.
33. Jouanin T, Dupont JY, Halimi P, Lassau JP. Les plicae. Etude anatomique portant sur la dissection de 200 genoux. Anat Clin. 1982;4(1):47–53.
34. Nakayama A, Sugita T, Aizawa T, Takahashi A, Honma T. Incidence of medial plica in 3,889 knee joints in the Japanese population. Arthroscopy. 2011;27(11):1523–7.
35. García-Valtuille R, Abascal F, Cerezal L, García-Valtuille A, Pereda T, Canga A, et al. Anatomy and MR imaging appearances of synovial plicae of the knee. RadioGraphics. 2002;22(4):775–84.
36. Ewing J. Plica: pathologic or not? J Am Acad Orthop Surg. 1993;1(2):117–21.
37. Lee PYF, Nixion A, Chandratreya A, Murray JM. Synovial plica syndrome of the knee: a commonly overlooked cause of anterior knee pain. Surg J (N Y). 2017;3(1):e9–e16.
38. Kim S-J, Kim J-Y, Lee JW. Pathologic infrapatellar plica. Arthroscopy. 2002;18(5):E25.
39. Cothran RL, McGuire PM, Helms CA, Major NM, Attarian DE. MR imaging of infrapatellar plica injury. Am J Roentgenol. 2003;180(5):1443–7.
40. Ozcan M, Copuroğlu C, Ciftdemir M, Turan FN, Calpur OU. Does an abnormal infrapatellar plica increase the risk of chondral damage in the knee. Knee Surg Sports Traumatol Arthrosc. 2011;19(2):218–21.
41. Demirag B, Ozturk C, Karakayali M. Symptomatic infrapatellar plica. Knee Surg Sports Traumatol Arthrosc. 2006;14(2):156–60.
42. Radu A, Discepola F, Volesky M, Munk PL, Le H. Posterior Hoffa's fat pad impingement secondary to a thickened infrapatellar plica: a case report and review of the literature. J Radiol Case Rep. 2015;9(3):1–7.
43. Lapègue F, Sans N, Brun C, Bakouche S, Brucher N, Cambon Z, et al. Imaging of traumatic injury and impingement of anterior knee fat. Diagn Interv Imaging. 2016;97(7–8):789–807.

44. Borja MJ, Jose J, Vecchione D, Clifford PD, Lesniak BP. Prefemoral fat pad impingement syndrome: identification and diagnosis. Am J Orthop (Belle Mead NJ). 2013;42(1):E9–11.
45. Soder RB, Mizerkowski MD, Petkowicz R, Baldisserotto M. MRI of the knee in asymptomatic adolescent swimmers: a controlled study. Br J Sports Med. 2012;46(4):268–72.
46. Roth C, Jacobson J, Jamadar D, Caoili E, Morag Y, Housner J. Quadriceps fat pad signal intensity and enlargement on MRI: prevalence and associated findings. Am J Roentgenol. 2004;182(6):1383–7.
47. Shabshin N, Schweitzer ME, Morrison WB. Quadriceps fat pad edema: significance on magnetic resonance images of the knee. Skelet Radiol. 2006;35(5):269–74.
48. Wang J, Han W, Wang X, Pan F, Liu Z, Halliday A, et al. Mass effect and signal intensity alteration in the suprapatellar fat pad: associations with knee symptoms and structure. Osteoarthr Cartil. 2014;22(10):1619–26.
49. Schwaiger BJ, Mbapte Wamba J, Gersing AS, Nevitt MC, Facchetti L, McCulloch CE, et al. Hyperintense signal alteration in the suprapatellar fat pad on MRI is associated with degeneration of the patellofemoral joint over 48 months: data from the Osteoarthritis Initiative. Skelet Radiol. 2018;47(3):329–39.
50. Akao M, Ikemoto T, Takata T, Kitamoto K, Deie M. Suprapatellar plica classification and suprapatellar plica syndrome. Asia Pac J Sports Med Arthrosc Rehabil Technol. 2019;17:10–5.
51. Dandy DJ. Anatomy of the medial suprapatellar plica and medial synovial shelf. Arthroscopy. 1990;6(2):79–85.
52. Zidorn T. Classification of the suprapatellar septum considering ontogenetic development. Arthroscopy. 1992;8(4):459–64.
53. Al-Hadithy N, Gikas P, Mahapatra AM, Dowd G. Review article: plica syndrome of the knee. J Orthop Surg (Hong Kong). 2011;19(3):354–8.
54. Bae DK, Nam GU, Sun SD, Kim YH. The clinical significance of the complete type of suprapatellar membrane. Arthroscopy. 1998;14(8):830–5.
55. Kim SJ, Shin SJ, Koo TY. Arch type pathologic suprapatellar plica. Arthroscopy. 2001;17(5):536–8.
56. Klontzas ME, Akoumianakis ID, Vagios I, Karantanas AH. MR imaging findings of medial tibial crest friction. Eur J Radiol. 2013;82(11):e703–6.
57. Simeone FJ, Huang AJ, Chang CY, Smith M, Gill TJ, Bredella MA, et al. Posteromedial knee friction syndrome: an entity with medial knee pain and edema between the femoral condyle, sartorius and gracilis. Skelet Radiol. 2015;44(4):557–63.
58. Simeone FJ, Kheterpal A, Chang CY, Palmer WE, Bredella MA, Huang AJ, et al. Ultrasound-guided injection for the diagnosis and treatment of posteromedial knee friction syndrome. Skeletal Radiol. Springer Berlin Heidelberg. 2019;48(4):563–8.
59. Boles CA, Martin DF. Synovial plicae in the knee. AJR Am Roentgen Ray Soc. 2001;177(1):221–7.
60. Kan H, Arai Y, Nakagawa S, Inoue H, Hara K, Minami G, et al. Characteristics of medial plica syndrome complicated with cartilage damage. Int Orthop. 2015;39(12):2489–94.
61. Liu YW, Skalski MR, Patel DB, White EA, Tomasian A, Matcuk GR. The anterior knee: normal variants, common pathologies, and diagnostic pitfalls on MRI. Skelet Radiol. 2018;47(8):1069–86.
62. Khan N, McMahon P, Obaid H. Bony morphology of the knee and non-traumatic meniscal tears: is there a role for meniscal impingement? Skelet Radiol. 2014;43(7):955–62.
63. Krych AJ, Wu IT, Desai VS, Kennedy NI, Littrell LA, Collins MS, et al. Osteomeniscal impact edema (OMIE): description of a distinct MRI finding in displaced flap tears of the medial meniscus, with comparison to posterior root tears. J Knee Surg. 2019.
64. Bordalo-Rodrigues M, Cavalcanti C, Almeida A, Hernandez A, Camanho G, Cerri G. Osteo-meniscal impingement: MRI findings. Skelet Radiol. 2014;43:1343. https://doi.org/10.1007/s00256-014-1937-z.
65. Herschmiller TA, Anderson JA, Garrett WE, Taylor DC. The trapped medial meniscus tear: an examination maneuver helps predict arthroscopic findings. Orthop J Sports Med. 2015;3(5):2325967115583954.
66. Lecas LK, Helms CA, Kosarek FJ, Garret WE. Inferiorly displaced flap tears of the medial meniscus: MR appearance and clinical significance. Am J Roentgenol. 2000;174(1):161–4.
67. Skaf AY, Hernandez Filho G, Dirim B, Wangwinyuvirat M, Trudell D, Haghigi P, et al. Pericruciate fat pad of the knee: anatomy and pericruciate fat pad inflammation: cadaveric and clinical study emphasizing MR imaging. Skelet Radiol. 2012;41(12):1591–6.
68. Huang BK, Campos JC, Michael Peschka PG, Pretterklieber ML, Skaf AY, Chung CB, et al. Injury of the gluteal aponeurotic fascia and proximal iliotibial band: anatomy, pathologic conditions, and MR imaging. RadioGraphics. 2013;33(5):1437–52.
69. Flato R, Passanante GJ, Skalski MR, Patel DB, White EA, Matcuk GR. The iliotibial tract: imaging, anatomy, injuries, and other pathology. Skeletal Radiol. Springer Berlin Heidelberg. 2017;46(5):605–22.
70. Muhle C, Ahn JM, Yeh L, Bergman GA, Boutin RD, Schweitzer M, et al. Iliotibial band friction syndrome: MR imaging findings in 16 patients and MR arthrographic study of six cadaveric knees. Radiology. 1999;212(1):103–10.
71. Fairclough J, Hayashi K, Toumi H, Lyons K, Bydder G, Phillips N, et al. The functional anatomy of the iliotibial band during flexion and extension of the knee: implications for understanding iliotibial band syndrome. J Anatomy. 39 ed. John Wiley & Sons, Ltd (10.1111). 2006;208(3):309–16.
72. Renne JW. The iliotibial band friction syndrome. J Bone Joint Surg Am. 1975;57(8):1110–1.
73. Orava S. Iliotibial tract friction syndrome in athletes–an uncommon exertion syndrome on the lateral side of the knee. Br J Sports Med. 1978;12(2):69–73.
74. Strauss EJ, Kim S, Calcei JG, Park D. Iliotibial band syndrome: evaluation and management. J Am Acad Orthop Surg. 2011;19(12):728–36.
75. Vasilevska V, Szeimies U, Stäbler A. Magnetic resonance imaging signs of iliotibial band friction in patients with isolated medial compartment osteoarthritis of the knee. Skelet Radiol. 2009;38(9):871–5.
76. Lavine R. Iliotibial band friction syndrome. Curr Rev Musculoskelet Med. 2010;3(1–4):18–22.
77. Noble CA. Iliotibial band friction syndrome in runners. Am J Sports Med. SAGE Publications. 1980;8(4):232–4.
78. Mansour R, Yoong P, McKean D, Teh JL. The iliotibial band in acute knee trauma: patterns of injury on MR imaging. Skelet Radiol. 2014;43(10):1369–75.
79. Isusi M, Oleaga L, Campo M, Grande D. MRI findings in iliotibial band friction syndrome: a report of two cases. Radiologia. 2007;49(6):433–5.
80. Jadhav SP, More SR, Riascos RF, Lemos DF, Swischuk LE. Comprehensive review of the anatomy, function, and imaging of the popliteus and associated pathologic conditions. RadioGraphics. 2014;34(2):496–513.
81. Gaine WJ, Mohammed A. Osteophyte impingement of the popliteus tendon as a cause of lateral knee joint pain. Knee. 2002;9(3):249–52.