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A systematised MRI approach to evaluating the patellofemoral joint

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Abstract

Knee pain in young patients is a common indication for knee MRI. Many static and dynamic internal derangements of the patellofemoral joint in these patients lead to various secondary MRI findings. This article focuses on how to systematically approach, detect, and emphasize the importance of these findings in the diagnosis of patellofemoral tracking and impingement syndromes with relevant case examples.

Keywords

Patellofemoral; Impingement; Maltracking; MRI

Introduction

Patellofemoral pain syndrome is the leading cause of knee pain in patients younger than 45 years. It may be related to an underlying patellar tracking abnormality or patellofemoral impingement [1]. Therefore, it is important for the radiologist to focus on the patellofemoral joint while evaluating knee MRI in young patients presenting with anterior/anterolateral knee pain and instability for early detection of patellofemoral articular cartilage loss. This article reviews the normal anatomy of the patellofemoral joint and presents a systematic approach to evaluating MRI findings of patellofemoral impingement syndromes and patellar tracking abnormalities.

Anatomy

The patella is the largest sesamoid bone in the body centered within the quadriceps tendon. Although the patellofemoral joint is a part of the knee joint, it is functionally distinct from the tibiofemoral articulation. It shields the tibiofemoral joint and increases the mechanical advantage of the quadriceps muscle by extending its effective lever arm and centering the divergent pull of the different quadriceps muscle components [1]. The patellar articular cartilage is the thickest in the body, measuring 4–6 mm in young healthy adults, correlating with the significant mechanical stresses placed on the joint [2]. The superior three-quarters of the posterior patellar surface articulates with the femoral trochlear sulcus. The lateral femoral condyle has a greater anteroposterior dimension than the medial condyle, which acts to prevent lateral translation of the patella. The patella has a convex medial facet and a concave lateral facet, which is usually longer than the medial facet. A hypoplastic medial

facet has been shown to be more commonly associated with patellar maltracking disorders [3,4]. There are three distinct fat pads around the patella: Hoffa's fat pad, the quadriceps fat pad, and the prefemoral fat pad (Fig. 1). Edema of the superolateral aspect of Hoffa's fat pad (SHFPE) is the more frequent finding in patellofemoral disorders than involvement of other fat pads (Fig. 2).

Patellofemoral disorders and MRI technique

Patellofemoral maltracking refers to abnormal medial–lateral translation with respect to the trochlear groove, while patellofemoral impingement refers to abnormal contact of the patella with the femur. Both conditions commonly occur in association rather than in isolation. Kinematic MRI and CT studies exploit these dynamic patellofemoral relationships by imaging patients in varying degrees of knee flexion and extension [5–7]. However, these studies demand pre-performance optimization, patient cooperation, and significant interpreter skill. On the other hand, since articular congruence of the patellofemoral joint is the most important static stabilizer against patellar maltracking and impingement, it is essential to assess the various anatomic parameters of the patellofemoral joint on routine extended position MRI examinations in evaluating these disorders [8–11]. It should also be understood that the practice of medicine is regional and that the radiologist's orthopedic and clinical colleagues will likely rely on a specific set of criteria or measurements that are unique to their practice. In other words, the measurements we are about to present represent a regional snapshot based on the available literature and our experience.

Systematic approach

The radiologist should begin with an analysis of patella alta/infer (baja) on the midline sagittal image. The lower third of the patella articulates with the trochlear surface of the femur in a relaxed, extended knee during routine MR examinations. The normal patellar length should be similar to the length of the patellar tendon (patellar ligament). In our experience, patella alta is the most common association with patellofemoral maltracking and impingement disorders (Figs. 3, 4). It has also been reported to be the most consistent physical examination finding in patients with patellar instability [12,13]. The Insall–Salvati (IS) ratio has been widely used to define patellar position. Using this method, the ratio of the patellar tendon length to the maximal diagonal length of the patella is calculated, with normal values derived from radiography ranging from 1.02 ± 0.13 . Traditionally, two standard deviations above or below normal lead to the diagnosis of patella alta or infera (baja) respectively [14]. It should also be noted that patella alta might be underestimated because of the extended position of the leg during MRI scanning. There are many ways to measure patella alta on MRI [15–17]. Similar to the radiographic measurement, patellar height can be reliably assessed on sagittal MR imaging using the patellar tendon:patella height ratio [17]. On sagittal MR imaging, patella alta is suggested at values greater than 1.3 (1.1+2 SD). Shabshin et al. have suggested that the upper and lower limits of normal should be defined as 1.5 and 0.74 respectively, to more accurately reflect differences in measurement technique on MRI versus radiography, and the asymmetric distribution of measurements about the mean. However, this study was limited by a lack of normal controls and clinical correlation [18]. Other findings related to patellofemoral derangement that can be easily made on sagittal images include evaluation of superolateral Hoffa's fat pad edema (SHFPE), prefemoral fat pad edema, and trochlear articular cartilage abnormalities. SHFPE is easiest to detect on far lateral sagittal (the last 2–4) images of a fluid-sensitive sequence. It is prudent to compare the far medial sagittal images and vary window width and levels during the image evaluation to increase the sensitivity for the detection of this finding. In addition, the fat pad should be evaluated for enlargement, which may result from worsening edema or hypertrophy related to chronic friction changes (Figs. 2b,4). An enlarged Hoffa's

fat pad may be seen extending farther laterally beneath the lateral patellar retinaculum, or causing anterior bowing of the patellar tendon. Isolated signal abnormalities in the superolateral aspect of Hoffa's fat pad should be differentiated from "Hoffitis," which primarily results from recurrent shear injuries leading to hemorrhage and edema of the central posterior aspect of Hoffa's fat pad, with consequent fibrosis in the chronic stages [8]. This can also be a source of persistent anterior knee pain (Fig. 5). The remaining measurements are best made on axial images.

Second, the radiologist should investigate the overall relation of the patella to the femoral trochlear groove on axial images. One should look for patellar translation relative to the femur, which occurs more commonly laterally rather than medially. A fine balance between medial and lateral stabilizers control patellar tracking. Of these, the vastus medialis obliquus (VMO) and vastus lateralis obliquus (VLO) form the two most important dynamic restraints. The VMO holds the patella flush against the femur in extension and neutralizes the lateral pull of the VLO [19]. Subluxation/translation is measured as the distance between perpendicular lines drawn on an axial image from the medial edge of the patella through the most anterior point of the medial condyle [20], with 2 mm being the top normal distance (Fig. 6a), [9,21,22]. It can also be inferred from the distance between perpendicular lines drawn from the median ridge of the patella and the apex of the trochlear sulcus, which should roughly match if there is no translation (Fig. 6b). It should be remembered that the presence of a joint effusion in itself might cause or exaggerate patellar subluxation. The translation or subluxation can be further classified as mild (<5 mm), moderate (5–10 mm), or severe (>10 mm), with worsening subluxation seen more commonly in female patients than in their male counterparts [5]. There is a high percentage of bilateralism in patellar subluxation—up to 55% of cases [5].

Third, the radiologist should look for abnormal patellar tilt, which may be present with or without patellar translation. Abnormal lateral tilt is more frequently symptomatic than mere subluxation [23,24]. Abnormal tilt without lateral translation has been referred to as excessive lateral pressure syndrome (ELPS). In fact, ELPS may be associated with medial subluxation. ELPS is usually caused by a tight lateral retinaculum, which may need to be released if there is failure of conservative treatment (Figs. 7,8). In cases of ELPS, lateral retinaculum laxity should be carefully evaluated as its presence may mitigate against lateral retinacular release [19]. Again, there are many ways to measure patellar tilt [20,21,24–28]. The patellofemoral angle is a valid and easy measurement between the lines drawn along the bony lateral patellar facet and the tangent to the anterior femoral condyles. It is measured at the level of the patellar midpoint as referenced on sagittal imaging. In general, the patellofemoral angle measures more than 8° and opens laterally. Medial opening or an angle less than 8° qualifies as abnormal tilt [9]. Alternatively, Grelsamer et al. and Wittstein et al. have used the angle between the line joining the medial and lateral facets of the patella and the line tangent to the posterior femoral condyle to quantify patellar tilt, a method more analogous to the clinical examination [13,24]. It may be difficult to measure the angle using this technique, as the two respective lines forming the angle are generally visualized on two different axial images because of the changing slope and size of the femoral condyles.

Fourth, the trochlear sulcus should be evaluated for hypoplasia/dysplasia. As a consequence of abnormal trochlear morphology, the lateral bony border, which normally acts as a restraint against the lateral pull of the VLO, may be missing. Thus, the patella is unable to engage properly and tends to sublux laterally with extension and early flexion movements of the knee. MRI is proven to be better than conventional radiography in the characterization of trochlear sulcus shape as the measurement on the skyline radiograph evaluates only the lower part of the trochlear sulcus, which is not representative of actual trochlear morphology [3,17,29–31]. Various authors have assessed trochlear morphology by measuring trochlear

sulcus depth, lateral trochlear inclination, trochlear height, as well as the sulcus angle [21,29,30,32,33]. Pfirrmann et al. have reported that trochlear dysplasia can be diagnosed with a sensitivity of 100% and specificity of 96%, if the trochlear sulcus measures 3 mm or less at 3 cm above the tibiofemoral articulation [29]. However, it should be understood that the measurements may vary from patient to patient because of differences in the size of the knee and the proximal extent of the trochlear cartilage. Also, measurements vary if trochlear cartilage versus bone is referenced for measurement of the sulcus angle [32]. It is prudent to use bony landmarks for measurement purposes to avoid the variability related to the cartilage thickness. We measure the sulcus angle as well as the depth in suspected cases of trochlear hypoplasia. A sulcus angle greater than 144° indicates hypoplasia [31]; depth less than 5 mm indicates hypoplasia and less than 3 mm confirms dysplasia (Figs. 8,9; see also Figs. 12c,13b). These abnormalities can be corrected with trochleoplasty. This procedure usually entails surgical remodeling of the trochlear groove, which reduces the ventral prominence of the trochlear floor. Recently, encouraging results have been reported using this procedure in reducing symptoms associated with patellofemoral malalignment [34,35].

Fifth, the tibial tuberosity–trochlear groove (TT–TG) distance should be obtained in suspected patellofemoral derangement. It is the maximum distance taken from the lines drawn perpendicular to the deepest area of the trochlear groove and the center of the patellar tendon insertion on the tibial tuberosity on axial images (Fig. 10a, b), similar to the method proposed by Wittstein et al. [13]. More than 15 mm of tibial tubercle deviation indicates lateralization/transposition [13, 36, 37]. Lateralization of the patellar tendon/tibial tuberosity leads to an increased lateral pull of the quadriceps femoris muscle on the patella, potentiating patellofemoral disorders [25, 38, 39]. This lateralization may lead to friction between the quadriceps tendon and the anterior femur, and edema/adventitial bursa formation of the superolateral Hoffa's fat pad (Fig. 10c), also referred to as excessive lateral friction syndrome (ELFS) [40]. The TT–TG distance measurement is essential for patients being considered for tibial tuberosity osteotomy and re-fixation. It may be viewed as a CT/MRI surrogate of the quadriceps (Q) angle measured on physical examination. The Q angle is clinically measured between a line drawn from the anterior superior iliac spine to the center of the patella, and a line from the center of the patella to the tibial tuberosity. Normal measurements for men are $14^\circ (\pm 3)$, and for women $17^\circ (\pm 3)$. Similar observations are possible on sequential coronal MR images as well (Fig. 11). Clinically, measurement of the Q angle is a useful indicator of patellofemoral malalignment [1], but it can be underestimated because of lateral patellar maltracking. It was recently reported that clinical measurement of the TT–TG distance may also be unreliable [37]. Therefore, the TT–TG distance obtained on MRI is a more valid indicator of lateralization/transposition. It should be noted that there may be other underlying contributing factors to increased TT–TG distance, such as femoral neck anteversion, external tibial torsion, and subtalar pronation.

Sixth, the radiologist should evaluate the soft tissue structures around the patellofemoral joint, particularly the distal quadriceps tendon, the patellar tendon, the distal vastus lateralis and medialis muscles, along with their oblique components (VLO and VMO), and the patellar retinaculae. These should be assessed for tendinosis, tears, and atrophy. Traction-related chronic enthesopathic changes of the anterosuperior and anteroinferior aspects of the patella are frequently identified on radiographs. However, MRI may sometimes show their acute manifestation as partial quadriceps tendon stripping from the anterior aspect of the patella (Fig. 12). Subluxation may result from tightening of the VLO or abnormal laxity of the VMO. Re-tearing of the retinaculum may also be seen following surgical repair (Fig. 13). The patellar tendon should be evaluated for jumper's knee (Fig. 14) and remote Osgood–Schlatter disease (Fig. 15) [38].

Finally, one should look for complications of patellofemoral maltracking, such as patellar chondrosis and early onset/selective osteoarthritis of the patellofemoral joint (Figs. 7c, 8b, 9c, 12b, 13d, 14b, c, 15b, 16, 17b). The patellar cartilage is best assessed in the axial plane, and trochlear cartilage in the sagittal plane [19]. Cases of early patellofemoral arthritis show areas of cartilage softening as well as surface fibrillation. In our experience, the trochlear cartilage surface fibrillation can be subtle and is commonly seen at the site of impingement, usually in the area of the apex of the trochlear sulcus and the adjacent lateral trochlea on the sagittal images. Other secondary findings may include edema and synovial proliferation/adventitial bursa formation of the fat pads (Fig. 17), and traction-related cystic changes of the patellar insertions of the medial and lateral retinaculæ [40]. Superolateral Hoffa's fat pad edema is the most frequent finding relating to patellar maltracking and impingement syndromes and it may be associated with prefemoral fat pad edema. The adventitial bursa should be differentiated from the more commonly and incidentally seen Hoffa's fat pad ganglion. The adventitial bursa related to patellofemoral derangement is characteristically located in the superolateral Hoffa's fat pad, while the Hoffa's fat pad ganglion is frequently seen adjacent to the transverse meniscal ligament (Fig. 18). We have infrequently seen prefemoral fat pad edema as an isolated finding in patellofemoral derangements (Fig. 19). Rarely, there may be synovitis/adventitial bursa formation of the prefemoral fat pad, especially in cases following anterior cruciate ligament graft repair (Fig. 20). However, these abnormalities in the prefemoral fat pad may be related to underlying patellar maltracking or patellofemoral impingement and require further scrutiny of the patellofemoral joint. Frequently, edema may also be seen in the quadriceps fat pad. In our experience, it is seen in all age groups as a common unrelated finding. Sometimes it is seen with distal quadriceps tendinosis. Shabshin et al. postulated that quadriceps fat pad edema might be a manifestation of impingement of the suprapatellar pouch in patients presenting with anterior knee pain [41]. Roth et al. found the prevalence of mass effect of the quadriceps fat pad on the suprapatellar recess in 12% of knee MRI examinations, although there was no significant association between quadriceps fat pad abnormalities and various indicators of potential patellar maltracking [42].

Stepwise systematic approach summary

1. Assess for patella alta/baja on the midline sagittal image. Evaluate anterior fat pads, especially the superolateral Hoffa's fat pad, and trochlear cartilage on the other sagittal views before moving on to the axial images.
2. Evaluate lateral patellar translation and grade as mild, moderate, or severe. Assess for medial translation (which may be seen with ELPS).
3. Evaluate patellar tilt using patellofemoral angle.
4. Evaluate for trochlear sulcus hypoplasia/dysplasia using trochlear sulcus angle and depth.
5. Evaluate TT–TG distance, particularly if there is suspected lateralized tibial tuberosity/patellar tendon transposition (which may be seen with ELFS).
6. Assess for soft tissue abnormalities in relation to the patellar tendon, the quadriceps muscles and tendon, the patellar retinaculæ, and the fat pads.

Conclusion

It is important for the radiologist to understand normal patellofemoral joint MRI anatomy and the key imaging features of patellofemoral maltracking and impingement syndromes. The differentiation among these lesions is important to direct appropriate patient management and prevent patellofemoral articular cartilage loss.

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Fig. 1.
a Sagittal proton density-weighted (PDW) and **b** axial T2-weighted fat-saturated (T2Wfs) images demonstrate a normal quadriceps fat pad (*Q*), a prefemoral fat pad (*P*), Hoffa's fat pad (*H*), and a superolateral Hoffa's fat pad (*SL*)

Fig. 2.

A 25-year-old woman with anterolateral knee pain. **a** Sagittal T2Wfs and **b** axial T2Wfs images demonstrate superolateral Hoffa's fat pad edema (*large arrows*). Also notice the hypertrophy of the SL fat pad extending far beyond the lateral retinaculum and causing anterior bowing of the patellar tendon (*small arrows*)

Fig. 3.
a Sagittal T2fs and **b** axial T2Wfs images showing an abnormal Insall–Salvati ratio of 1.5 (patellar length [*P*] to patellar tendon [*T*] ratio) in a 19-year-old woman with anterolateral knee pain. Notice superolateral Hoffa's fat pad edema (*arrow*) on the axial T2Wfs (**b**)

Fig. 4.

a Sagittal T2Wfs, **b** axial T2Wfs, and **c** axial PDW images in another case of patella alta with superolateral Hoffa's fat pad edema (*long arrows*). Notice Hoffa's fat pad enlargement with abnormal bowing of the patellar tendon (*small arrows*)

Fig. 5. Traumatic Hoffitis in a 27-year-old woman with a history of a motor vehicle accident. **a** Initial sagittal PDWfs and **b** sagittal PDW images 2 years before at the time of the insult demonstrate a shearing injury to Hoffa's fat pad with diffuse edema and irregular contour. **c**, **d** Persistent anterior knee pain led to another MRI, which demonstrated posterior superior Hoffa's fat pad fibrosis (*arrows*) as focal hypointensity on sagittal PDWfs (**c**) and sagittal PDW (**d**) images. No other internal derangement was identified

Fig. 6.

a Normal patellar location with patellar apex congruent to femoral trochlear sulcus and less than 2 mm distance between lines drawn along the medial patellar facet (*short line*) and medial femoral trochlea (*longer line*; axial T2Wfs image). **b** Another patient with abnormal lateral patellar translation (axial T2Wfs image). Also notice superolateral Hoffa's fat pad hypertrophy extending below the lateral retinaculum (*arrow*)

Fig. 7.

A 27-year-old man with anterolateral knee pain walking upstairs. **a** Sagittal T2Wfs and **b, c** axial T2Wfs images demonstrate superolateral Hoffa's fat pad edema (*long arrows*). Notice abnormal patellar tilt (**c**) with relatively decreased lateral patellofemoral joint space, and the patellofemoral angle measured 5° . Also note the full thickness chondral fissure at the median ridge with subchondral edema (*thick arrow*)

Fig. 8.

A 20-year-old woman with bilateral anterolateral knee pain. **a, b** Axial T2Wfs images of both knees demonstrate findings of excessive lateral pressure syndrome (ELPS) and abnormal lateral patellar tilt without lateral translation. There was bilateral superolateral Hoffa's fat pad edema (not shown). Also note the underlying trochlear sulcus hypoplasia and loose cartilaginous body from the median ridge of the left patella (*arrow*)

Fig. 9. Axial T2Wfs images. **a** Normal trochlear sulcus (sulcus angle measuring $<144^{\circ}$). **b** Hypoplastic sulcus (sulcus angle measuring $= 168^{\circ}$) and **c** dysplastic sulcus (absent sulcus with abnormal trochlear convexity)

Fig. 10.

A 43-year-old woman with excessive lateral friction syndrome (ELFS). **a, b** Notice increased TT–TG distance measuring 2.3 cm depicted on sequential axial PDW images superimposed on each other. **c** Also note the subtle superolateral Hoffa's fat pad edema on a sagittal T2Wfs image (*arrow*)

Fig. 11.

A 36-year-old woman with excessive lateral friction syndrome (ELFS) due to lateralized patellar tendon (*marker*) depicted on **a–d** sequential coronal T1W images with an abnormal Q angle equivalent (**d**). Notice **e** superolateral Hoffa's fat pad edema on the sagittal T2Wfs image (*arrow*) and **f** the abnormally located patellar tendon on axial T2Wfs image (*arrow*)

Fig. 12.

A 50-year-old woman who had suffered from nontraumatic anterior knee pain for many months. **a, b** Sagittal PDWfs, **c** axial PDWfs and **d** sagittal PDW images show acute partial quadriceps tendon stripping of the anterior patella (*curved arrows in a,c*), superolateral Hoffa's fat pad edema (*long arrow in b*), and subchondral edema of the lateral facet of the patella related to chondrosis (*arrowhead in b*). There is underlying trochlear sulcus hypoplasia (**c**). **d** Also note the chronic enthesopathic change in the superior patella (*short arrow*)

Fig. 13.

An 18-year-old boy with persistent knee pain, status post-medial retinacular repair. **a, c** Sagittal PDWfs and **b, d** axial PDWfs images show susceptibility artifacts from the surgery (*arrow in a*), persistent lateral subluxation and tilt of the patella and trochlear sulcus dysplasia (**b**), patella alta with subtle superolateral Hoffa's fat pad edema (*arrow in c*). There is partial re-tearing of the patellar insertion of the medial retinaculum (*arrow in d*) and median ridge patellar chondrosis

Fig. 14.

A 35-year-old man with chronic jumper's knee. **a, b** Sagittal PDWfs and **c** axial PDWfs images show focally thickened proximal patellar tendon (*arrow* in **a**). Notice superolateral Hoffa's fat pad edema as well as lateral trochlear (*arrow* in **b**) and lateral facet patellar chondrosis with subchondral cystic change and edema (*arrow* in **c**)

Fig. 15.

A 35-year-old man with Osgood–Schlatter disease. **a** Sagittal PDW and **b, c** axial PDWfs images show a thickened distal patellar tendon (*arrow in a*). Notice lateral facet patellar chondrosis (*arrow in b*) and superolateral Hoffa's fat pad edema (*arrow in c*)

Fig. 16.

A 30-year-old woman with anterior knee pain. **a** Sagittal T2Wfs and **b, c** axial T2Wfs images show patella alta (**a**), dysplastic sulcus (**b**), and laterally transposed patellar tendon in keeping with excessive lateral friction syndrome (ELFS; **c**). Notice secondary patellofemoral osteoarthritis (*arrows*)

Fig. 17.

A 48-year-old man with long-standing anterior knee pain. **a** Sagittal T2Wfs, **b** axial T2Wfs, **c** coronal T1W, and **d** coronal T2Wfs images demonstrate synovitis and early adventitial bursa formation of the superior Hoffa's fat pad (*arrows in a, c, d*). Notice the underlying shallow trochlear sulcus and abnormal patellar tilt with secondary patellar chondrosis (*short arrow in b*)

Fig. 18.

a Sagittal PDWfs and **b** PDW images. The infrapatellar fat pad is one of the most common locations for a ganglion cyst of the knee (*arrows*). This should not be confused with adventitial bursa formation due to Hoffa's fat pad impingement

Fig. 19.

A young girl with anterior knee pain. **a** Sagittal PDWfs, **b** axial PDW, and **c** axial PDWfs images show patella alta (**a**) and isolated prefemoral fat pad edema related to impingement (*arrows*)

Fig. 20.

A 42-year-old man s/p anterior cruciate ligament graft with persistent knee pain. The graft was intact. **a** Sagittal PDWfs and **b** axial PDWfs images show impingement-related adventitial bursa formation of the prefemoral fat pad (*arrows*). Minimal patella alta (Insall–Salvati ratio 1.3) was also present