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Imaging of Anterior Knee Pain

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Anterior knee pain (AKP) is a common complaint in primary care and orthopedic clinics. In fact, in the sports medicine clinic, up to 25% of patients with knee complaints have symptoms of anterior knee pain [1]. Adolescent females and other young individuals are at particular risk for AKP. In these individuals, symptoms are usually related to increased use, frequently because of increased sports participation [2]. AKP among school-age students has been reported to be 3.3% in the 10- to 19-year age group, and the incidence was 10% among 15 year olds [3]. Symptomatic individuals are more likely to be involved in competitive sports than age-matched controls [4]. Another group with a higher incidence of AKP is older females, and their major risk factors are lack of conditioning, previous trauma, and degenerative changes [5].

ANATOMY

The anatomy of the patellofemoral joint is complex. The patella is the largest sesamoid bone in the body and its articular surface is covered by thick cartilage. The length of the patella is somewhat longer than its articular surface, with the ratio being normally about 1.2 to 1.5. In full extension, the patella lies just proximal to the trochlea, often with a slight lateral position. The patella engages the trochlea at about 10 to 15 degrees of flexion, and stays engaged throughout flexion above 15 degrees [6]. The trochlea is the indentation on the anterior surface of the distal femur, just proximal to the intercondylar notch. It too is covered in cartilage. The sulcus angle is the angle of indentation and is an important factor in patellofemoral joint stability (Fig. 1). This angle increases down the length of the trochlea. The patella is secured in place by the soft tissue structures of the knee. The medial retinaculum and patellofemoral ligaments provide medial restraints. The lateral retinaculum is the confluence of the iliotibial band and the lateral patellofemoral ligament. These structures provide lateral restraint. The quadriceps muscle is made up of the rectus

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Fig. 1. Sulcus angle, *A*.

femoris and vastus muscles. The patella tendon attaches the patella to the tibial tubercle. The patella functions by increasing the mechanical advantage of the quadriceps muscle group [6].

The infrapatellar fad pad, or Hoffa's fat pad, is an extrasynovial but intracapsular structure located posterior to the patellar tendon and joint capsule but anterior to the knee joint synovium. It is directly attached to the anterior meniscal horns inferiorly. Rests of synovial tissue are present within Hoffa's fat pad.

PHYSICAL EXAMINATION

The patient's history and clinical presentation provide initial clues to the cause of AKP. Classic symptoms are pain behind the patella brought on by physical activity such as walking up or down stairs [7]. The physical examination should focus on evaluating alignment, range of motion, bursitis, and effusion. Multiple maneuvers can be performed to check for internal derangement. The patella is examined with the knee in extension. If the examiner can displace the patella laterally by 25% of its diameter or more, it is considered to be "subluxable" [8]. However, the malalignment often is subtle, and physical exam can be difficult and confusing in many patients. Imaging plays an important role in evaluation, not only in searching for malalignment, but for other sources of pain as well.

IMAGING

The standard radiographic evaluation of the knee includes frontal, lateral, and axial (sunrise) views of the knee. The axial view is usually obtained in 30 degrees of flexion. Computed tomography (CT) and MRI are also commonly used to evaluate anterior knee pain, especially in complex or refractory cases. Both of these modalities can be performed using standard protocols. CT is useful for osseous evaluation, such as in trauma or in some cases of possible malalignment. MRI is a more powerful modality, as it can diagnose cartilage and soft tissue abnormalities to greater effect than CT or radiography. Both CT and MRI can be used in dynamic modes, which can be useful for tracking abnormalities of the patella. Nuclear scinitigraphy is somewhat limited in its usefulness for anterior knee pain, however it can have a role, especially in cases of occult fracture and tumors.

DIFFERENTIAL DIAGNOSIS

The differential for AKP is broad. The major differential considerations are listed in Box 1.

SINDING-LARSEN-JOHANSSON SYNDROME

Originally described by Norwegian physician Christian Magnus Falsen Sinding-Larsen and Swedish surgeon Sven Christian Johansson, Sinding-Larsen-Johansson syndrome (SLJS) is defined as "apophysitis of the distal pole of the patella" and is considered one of the osteochondroses [9]. This condition of the distal patella and proximal patellar tendon is quite similar to Osgood-Schlatter disease and primarily affects athletically active adolescents between 10 and 14 years of age with prevalence in boys. This entity typically presents as pain and tenderness with occasional swelling over the inferior pole of the patella brought on by overuse or trauma [10].

Contusion or tendinopathy of the proximal patellar tendon creates a traction phenomenon followed by calcification and ossification, and patellar fracture or

Box 1: Differential Considerations for AKP

Patellar tendon causes

- Tendinopathy/rupture
- Osgood-Slatter
- Sindig-Larsen-Johanssen

Patella

- Chondromalacia
- Patello femoral OA
- Stress fracture
- Bipartite patella
- Osteochondritis

Intra-articular pathology/Hoffa's fat pad

- Meniscal tear/cysts
- Plica syndromes
- Hoffa's syndrome

Bursitis

- Prepatellar
- Pes ancerine

avulsion can produce one or multiple ossification sites. SLJS is most likely to occur in an active adolescent during "growth spurts" when the tendon cannot keep pace with the growing tibia, resulting in a relative shortening and traction on the immature lower pole of the patella. The natural duration of the disease is 3 to 12 months and usually requires only rest and conservative management [11].

Radiographs of the knee are frequently normal with varying calcification and ossification of the lower pole of the patella. Findings of osseous fragmentation of the inferior patella on knee radiography support the diagnosis in a patient with history and physical examination suggestive of SLJS (Fig. 2) [11].

JUMPER'S KNEE

Although often referred to as patellar tendonitis, a more accurate description of "Jumper's knee," based on histologic studies, is of overuse tendinopathy. This is the most common tendinopathy in skeletally mature athletes, occurring in up to 20% of jumping athletes. Jumper's knee primarily affects the proximal posterior fibers of the patellar tendon and is a cause of significant functional disability in professional and recreational athletes [12]. Biomechanically, to squat and land softly from a jump, the quadriceps muscle lengthens in eccentric contraction and creates high tension on the patellar tendon. Patellar tendinopathy occurs secondary to repetitive microtrauma caused by tendon overload without adequate repair. This overuse can lead to pain, tenderness, swelling, and decreased performance.

Most commonly, an athlete will present with anterior knee pain of insidious onset that is aggravated by activity (jumping, squatting, kneeling, and going down stairs). Symptoms can range from pain after activity to pain that persists

Fig. 2. Sinding-Larsen-Johannsen Syndrome (SLJS). There is fragmentation of the distal aspect of the patella, consistent with SLJ syndrome in the right clinical setting.

throughout an activity. Many individuals experience no decrease in performance, while severely affected individuals may suffer a substantial decrease in athletic ability. On physical examination, localized tenderness over the inferior patella/proximal patellar tendon is commonly found [13].

Imaging of patellar tendinopathy remains somewhat controversial. Radiographs are occasionally useful in identifying ossification of the tendon or associated osseous abnormalities, but ultrasonography and MRI are the modalities of choice for diagnosis. Ultrasonography, the accepted modality in much of Europe, demonstrates lower pole irregularity, fragmentation, chondral changes, and thickening of the tendon insertion at the patella [11]. Ultrasound evaluation of tendinopathy is quite dependent on equipment and operator experience. MRI also demonstrates tendon thickening with increased signal particularly on spin-echo and gradient-echo imaging. T2-weighted imaging best demonstrates partial tears with high signal intensity in the area of injury. Although the exact modality of choice for evaluation of this condition is debatable, ultrasound and MR have both been proven effective (Fig. 3) [13].

PATELLAR AND QUADRICEPS TENDON RUPTURE

Patellar tendon rupture, an overall infrequent occurance, is the third most common injury to the extensor mechanism of the knee after patellar fracture and quadriceps rupture. Rupture usually occurs unilaterally as a result of athletic injury in a patient younger than 40 years of age. Typically, an abrupt eccentric contraction of the quadriceps as the athlete lands with the knee flexed and foot planted will tear the tendon at the osseotendinous junction. In the setting of longstanding systemic inflammatory disease, diabetes mellitus, and chronic renal failure, bilateral rupture can occur [14]. Patellar tendon rupture can also be

Fig. 3. Jumper's knee. T2-weighted fat-saturated image shows increased signal intensity in the proximal patellar tendon.

seen in patients who have had the central third of the tendon used as allograft for repair of the anterior cruciate ligament.

Acute rupture is associated with immediate debilitating pain accompanied by a "pop" or tearing sensation with inability to bear weight. Examination reveals swelling/tenderness of the anterior knee, ecchymosis, hemarthrosis, and patella alta (see later discussion for definition) with a palpable gap in the extensor mechanism [15].

Diagnosis can usually be made by physical exam and radiographs. Contralateral images can be helpful in assessing patellar height. Even if the diagnosis of patellar tendon rupture is clinically obvious, radiographic evaluation is recommended to evaluate for concomitant injury. The classic finding is patella alta on the lateral radiograph. If the diagnosis cannot be made on physical and plain radiographic examination, MRI is the modality of choice and easily demonstrates discontinuity of the tendon fibers, hemorrhage and edema (Fig. 4A) [14].

Quadriceps tendon injury is more often seen on older individuals. This injury can be difficult to diagnose clinically, and misdiagnoses are common [16]. Complete tear is often the result of repetitive microtrauma. MR is useful in demonstrating partial or complete tears. On MR, a complete tear shows discontinuity of the tendon, hemorrhage, and edema, which is manifested as increased signal on T2-weighted sequences [17] (Fig. 4B).

CHONDROMALACIA PATELLAE

As indicated by its Greek and Latin roots, chondromalacia patellae (CP) is a condition characterized by abnormal softening of the cartilage along the

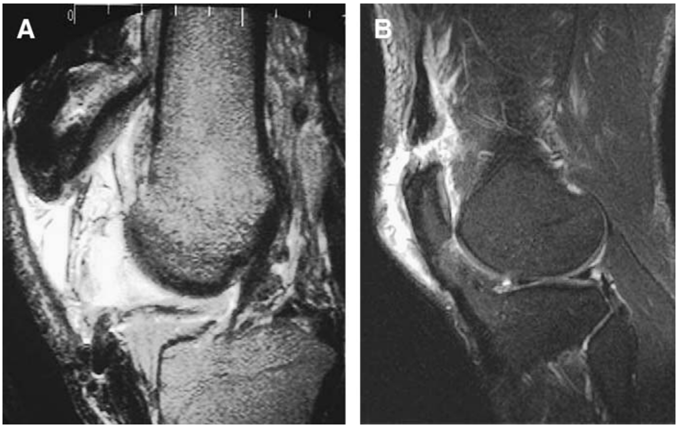

Fig. 4. (*A*) Patellar tendon rupture. T2-weighted sequence shows patella alta with discontinuity of the patellar tendon and associated edema. (*B*) Quadriceps tendon rupture. T2-weighted fat-saturated sagittal image shows discontinuity of the quadriceps tendon with associated edema.

undersurface of the patella. Common causes include trauma, repeated stress, and patellofemoral instability. Also referred to as "runner's knee," this problem is a cause of anterior knee pain and is often seen in young, otherwise healthy individuals. The disorder affects women more often than men and is thought to be a result of anatomical differences in which more lateral force is applied to the female patella. This results in increased lateral tracking of the patella. With proper therapy, early CP can be reversed; however, if left unchecked its changes become advanced, chronic, and may progress to patellofemoral osteoarthritis.

Multiple imaging modalities and techniques can be used to evaluate the patient with suspected chondromalacia patellae. Conventional radiography, CT arthrography, MR arthrography, and conventional MRI are available options. Conventional radiographs are relatively insensitive in evaluating for cartilage loss, except when it is severe. CT arthrography may demonstrate fissuring and foci of cartilage loss, but this technique is invasive and involves ionizing radiation. MR arthrography has also been shown to be sensitive and specific, but like CT arthrography, it is invasive [18]. Conventional MRI can show focal cartilage surface irregularities, as well as provide excellent soft tissue differentiation and reveal deeper internal cartilaginous derangement [19]. However, some studies have also shown relative insensitivity of conventional MRI in detecting early changes of CP [20]. Although invasive, MR arthrography with spoiled gradient recalled acquisition (SPGR) has demonstrated the high sensitivity for detecting early stage CP in multiple studies [21,22]. The MR findings typically show focal signal abnormalities or focal contour defects along the patellar cartilage on T2WI. These abnormalities can progress to patellofemoral osteoarthritis (PO) if left untreated (Fig. 5). A useful four-level grading scheme for CP based on arthroscopic and MRI appearance is presented in Box 2 and Fig. 5B.

PATELLOFEMORAL OSTEOARTHRITIS

Patellofemoral osteoarthritis is an extremely common cause of anterior knee pain. This is encountered primarily in older individuals, but can be seen in younger patients with accelerated degenerative changes brought on by comorbidities such as obesity. The classic radiographic features of PO include loss of articular cartilage with joint space narrowing, subchondral sclerosis and/or cyst formation, and osteophyte formation along the posterior margin of the patella. The symptoms commonly seen with PO include morning knee joint stiffness, loss of mobility, pain with ambulation (particularly walking up an incline or along a flight of stairs), and weakness about the knee joint.

Early clinical signs and symptoms may precede detectable conventional radiographic abnormalities. MRI, however, is especially sensitive to soft tissue and bone abnormalities. Fast spin echo T2 fat-saturated sequences are sensitive and specific for focal cartilage abnormalities [23]. MR findings in PO include cartilage surface thinning and irregularity, fine delineation of focal articular cartilage loss, or cartilage fissuring. Osteophytes are also common. There may be high T2 signal changes in the patella if there is significant marrow edema (Fig. 6).

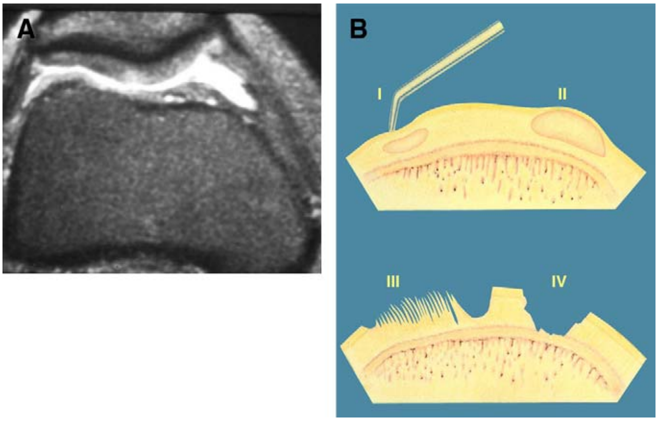

Fig. 5. Chondromalacia patella. (*A*) T2-weighted image shows focal abnormal high signal within the patellar cartilage. (*B*) Diagram of CP grading scheme, pathologic findings. (*From* Conway WF, Hayes CW, Loughran T, et al. Cross-sectional imaging of the patellofemoral joint and surrounding structures. Radiographics 1991;11:195–217; with permission.)

PREPATELLAR AND PES ANSERINE BURSITIS

The term "bursa" is Latin for "pouch" and is a synovium-lined sac that helps lubricate structures that move along one another. Bursae facilitate motion by reducing friction, and they can become symptomatic when inflamed, damaged, or infected. Prepatellar and pes anserine bursitis are commonly encountered causes of anterior knee pain.

The prepatellar bursa is a superficial bursa located between the skin and the anterior patella. Inflammation of this structure, also known as "Housemaid's knee," results in prepatellar bursitis and is a common cause of AKP in those individuals who frequently kneel or spend large amounts of time on their knees

Box 2: Grading of Chondromalacia Patella (modified Shahriaree) [60]

Grade 1. Arthroscopic findings: Softening of articular cartilage; T1-weighted MR findings: Partial width focal decreased signal areas of patellar cartilage on T1-weighted sequences, not extending to cartilage surface.

Grade 2. Arthroscopic findings: ''Blistering'' of articular cartilage with surface abnormality; T1-weighted MR findings: Focal area of sharply marginated decreased signal extending to the articular surface.

Grade 3. Arthroscopic findings: Cartilage fibrillation; T1-weighted MR findings: Indistinct focal areas of decreased signal extending to the articular surface.

Grade 4. Arthroscopic findings: Full thickness cartilage ulceration; T1 weighted MR fingings: Full-thickness decreased signal abnormalities with associated subchondral bone low signal changes.

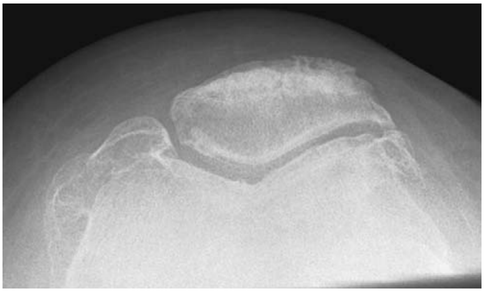

Fig. 6. Patellofemoral osteoarthritis. Radiograph demonstrates osteophytes at the PF articulation.

such as gardeners and carpet layers. Radiography may show prepatellar soft tissue swelling. Symptoms and physical exam findings may include pain that increases with ambulation or kneeling, decreased range of motion, and erythema/edema along the lower pole of the patella. MRI will usually show a prepatellar fluid collection with low T1/high T2 signal.

Pes anserine bursitis is an inflammation of the conjoined insertion of the sartorius, gracilis, and semitendinosus muscle tendons along the proximal medial aspect of the tibia [24]. This entity is commonly associated with degenerative joint disease of the knee, but can also be seen in younger, active individuals who engage in sports requiring frequent side-to-side movements. The most specific physical exam finding is pain over the proximal anterior medial tibia where the conjoined tendons insert. On T1WI, there is usually a low intensity fluid collection in the region of the pes anserinus along the medial tibial metaphysis, which shows relatively high homogeneous signal on T2WI (Fig. 7).

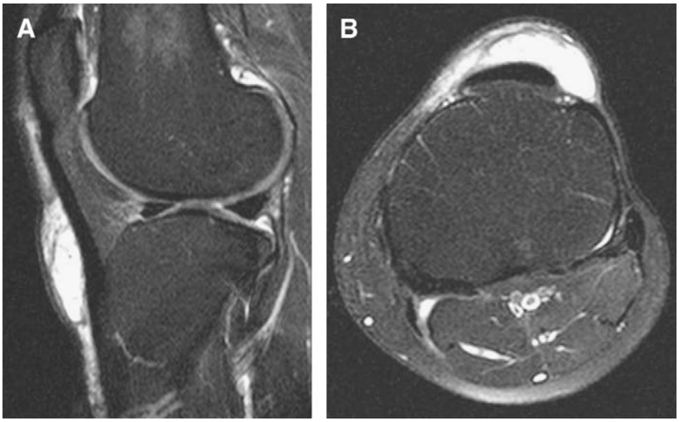

Fig. 7. (*A,B*) Prepatellar bursitis. T2-weighted images demonstrates fluid signal intensity superficial to the patellar tendon, consistent with prepatellar bursitis.

BIPARTITE PATELLA AND PATELLAR STRESS FRACTURE

The patella is normally one bone, but in approximately 1% to 2% of the population the patella develops as two unfused ossification centers. This condition, known as bipartite patella, is a variant of normal and affects men more than women. These two bones are not separate, but are connected by thick fibrous tissue. The patient with a bipartite patella is usually asymptomatic but can experience pain with standing or jumping. The classic bipartite patella appears as a small unfused fragment of the upper outer margin of the larger, main patellar fragment. On radiographs, inexperienced physicians can mistake the bipartite patella as a patellar fracture. Sometimes stress fracture superimposed on bipartite patella can occur and is a potentially difficult clinical entity to recognize (Fig. 8). MRI can aid with diagnosis by showing increased signal within the marrow on fat-suppressed T2WI compatible with marrow edema in cases of stress fracture.

Rest and strengthening exercises are usually sufficient treatment for uncomplicated knee pain in patients with bipartite patella; however, if there is avulsion at the fibrous connection, or a stress fracture, immobilization may be necessary.

ACUTE PATELLAR DISLOCATION

Acute lateral patellar dislocation can occur as a result of knee trauma and is most often seen in young athletes. The dislocation often reduces spontaneously without treatment, and the patient may not be aware that it has occurred. After such an event, the clinical examination is nonspecific, and as many as 75% of patients are misdiagnosed on initial physical exam and radiographs [25]. MR has been useful for diagnosis as several specific findings have been described. These include hemarthrosis/effusion, lateral femoral condyle and medial patellar facet bone contusions, osteochondral injury, and medial retinacular injury. The medial patello-femoral ligament, which has been identified as the major

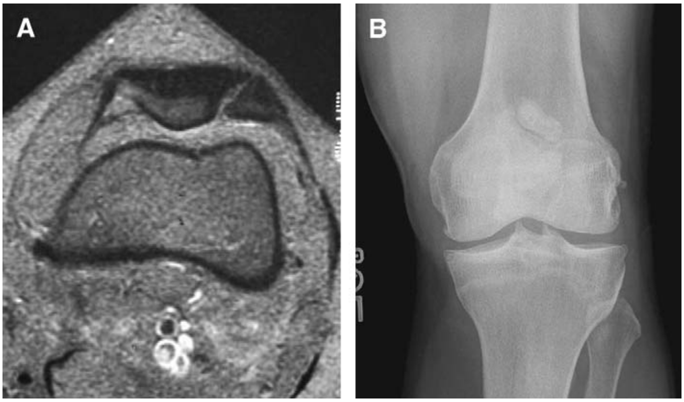

Fig. 8. Bipartite patella. (*A*) Gradient echo MR image shows cleft in the superior lateral patella without evidence for edema. Corticated margins suggest the diagnosis. (*B*) Radiograph bipartite patella.

restraint to lateral dislocation of the patella, is often injured when patellar dislocation occurs (Fig. 9) [26].

DISEASES OF HOFFA'S FAT PAD

A variety of disease entities can affect this structure and cause AKP, including impingement syndromes, postarthroscopy changes, plica syndromes, and mass lesions [27–30].

Hoffa's Fat Pad Syndrome

Acute or repetitive trauma to Hoffa's fat pad can result in edema and hemorrhage. The resultant changes of enlargement put the fat pad at risk for impingement between the femur and tibia. Fibrosis and anterior knee pain can result [27]. This is called Hoffa's disease or syndrome. Acutely, there is high T2 signal and mass effect with the fat pad. Chronically, fibrosis appears dark on both T1- and T2-weighted images [27].

Plica Syndromes

A possibly related entity to Hoffa's fat pad syndrome is an abnormal infrapatellar plica. The infrapatellar plica is a synovial fold that runs parallel to the anterior cruciate ligament (ACL) in the intercondylar notch. It travels over and through the superior aspect of the Hoffa's fat pad. Normally it shows low signal similar to that of ligaments. This structure can be injured, resulting in abnormal signal in both the plica and the superior aspect of Hoffa's fat pad. Injury to this plica is logically associated with injury to the fat pad, and thus the two entities may appear together and have some similar imaging findings. Clinical differentiation may also be difficult [31].

Other plica syndromes, including medial, lateral, and suprapatellar, are described. The mediopatellar plica is most often symptomatic. It extends from the medial joint wall to the synovium covering Hoffa's fat pad (Fig. 10). When it is prominent, it can be impinged upon by the medial condyle of the

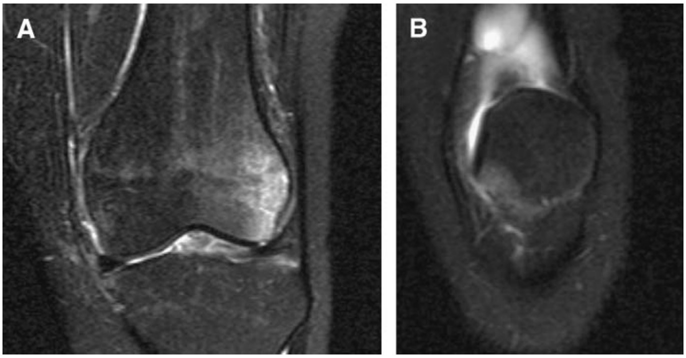

Fig. 9. Transient patellar dislocation. T2-weighted fat-saturated images of the knee show marrow edema in the lateral femoral condyle (*A*) and the medial patellar facet (*B*).

Fig. 10. Medial patella plica. T2-weighted sagittal image shows a low signal band in the suprapatella bursa consistent with a medial plica.

femur and the patella. This can result in chronic irritation and injury, with an increase in thickening, edema, and further impingement. The plica can then become fibrotic and cause damage to the articular cartilage and synovitis. Symptoms range from crepitation and swelling to joint pain medial to the patella [32].

Patellar Tendon Lateral Femoral Condyle Friction Syndrome

Patellar tendon lateral femoral condyle friction syndrome, so named by Chung and colleagues [33], is related to the clinical disease known as fat pad impindgement syndrome. Patients present with anterior knee pain, more pronounced at the inferior aspect of the patella. Abnormal increased T2 signal is seen in the inferolateral aspect of the patellofemoral joint and with possible involvement of the lateral fat pad. Cystic changes in the fat pad and enhancement may occur.

Mass Lesions

Several symptomatic mass lesions can occur in Hoffa's fat pad that may cause symptoms. Localized nodular synovitis is the localized form of PVNS. It most commonly occurs outside the knee, but can occur in Hoffa's fat pad. MR shows a mass-like lesion with variable signal characteristics. Hemosiderin will often be present with its associated artifacts on gradient echo sequences [28]. Para-articular chondroma arises from connective tissue due to cartilaginous metaplasia and most commonly occurs in or near Hoffa's fat pad. The MR appearance is that of a lobulated mass obliterating the normal high T1 signal fat pad inferior to the patella. The lesion shows increased T2 signal and will enhance after IV gadolinium administration. Primary intra-articular sarcoma has been reported but is extremely rare. Imaging appearances are often nonspecific and biopsy is often required for diagnosis [34].

Postsurgical Changes

The major portals used in arthroscopy are anterolateral, anteromedial, and medial and all of these can cause fibrosis within Hoffa's fat pad [28]. The fibrosis appears as well-defined strands of low signal (on T1 and T2 sequences) tissue coursing through the high-signal fat. Artifact from metallic fragments can also be seen after arthroscopy [27]. These changes on MR are not usually thought of as a cause of pain, but are important to recognize and not be misdiagnosed.

Patient's who have undergone ACL repair may present with a postoperative fibrotic complication known as localized anterior arthrofibrosis, or "Cyclops" lesion. This complication can result in pain and limited extension of the knee and is thought to occur from impingement of the anterior intercondylar notch on a graft that has been positioned too far anterior. The MR appearance is a low to intermediate signal intra-articular structure anterior to the graft. MRI has been shown to be sensitive for detection of the lesion [35].

PATELLOFEMORAL PAIN SYNDROME

Patellofemoral pain syndrome has been suggested as a diagnosis of exclusion reserved for patients with anterior knee pain without one of the conditions described above. Causes of this variety of anterior knee pain are somewhat controversial. Fulkerson points out that there are six main tissues to consider when looking for the etiology of patellofemoral pain. These include subchondral bone, synovium, retinaculum, skin, muscle, and nerve. He believes that the most common causes of pain from an orthopedic standpoint are overuse, patellofemoral malalignment, and trauma [36].

MALALIGNMENT EVALUATION—TRADITIONAL INDICES

Several measurements obtained from the axial, or sunrise, view have traditionally been used to evaluate for malalignment. There are three main radiographic patterns of malalignment (described with CT). These include subluxation of the patella with and without tilt, and tilt without subluxation [37]. Conditions that lead to malalignment and influence patellofemoral stability, such as depth of the trochlea, can be measured with imaging. The most common indices described in the literature are the lateral patellofemoral angle (tilt), the congruence angle, and lateral patellar displacement [38–40]. Other measurements that have been shown to potentially have merit are the Q angle and the trochlear-tubercle distance [41,42].

The lateral PF angle is calculated on an axial radiograph obtained at 20 degrees of flexion by measuring the angle of the lateral patellar facet compared with a line drawn across the femoral condyles. A study by Laurin and colleagues [40] showed that 97% of normal patellae open laterally. If the angle opens medially, or is parallel, then the patella is tilted (external rotation) (Fig. 11) [43]. Lateral patellar displacement is measured by comparing the medial margin of the patella on an axial view to the medial femoral condyle. If is more than 1 mm lateral in relation to the medial condyle apex, it is considered subluxed (Fig. 12) [39,43].

The congruence angle, as described by Merchant [38], is measured from a 45 degree of flexion axial film. The measurement is made by bisecting the sulcus angle to create a zero reference line. Then a line is drawn from the lowest point on the patella to the sulcus angle point. The angle created is then measured. The "normal" value is -6 ± 11 degrees. Values outside this range are an

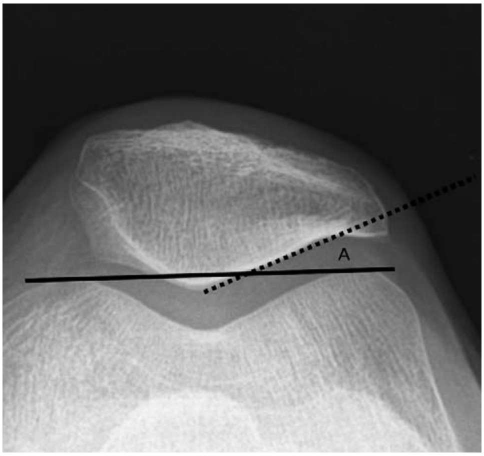

Fig. 11. Lateral patellofemoral angle. The angle of the lateral patellar facet compared with a line drawn across the femoral condyles. Angle *A* is the lateral patellofemoral angle.

indicator of patellar subluxation (Fig. 13) [37]. These values may also be obtained with CT and MR.

The Q angle is a measure of the angle formed between a line drawn from the tibial tubercle and a line drawn from the middle of the patella and anterior superior iliac spine. The normal value is 15 degrees [42]. An increased Q angle implies that the tibial tubercle is more lateral than normal. Thus, the patella experiences a lateral force with contraction of the quadriceps, predisposing it to lateral subluxation or dislocation. The Q angle can be measured by scout CT image or physical exam.

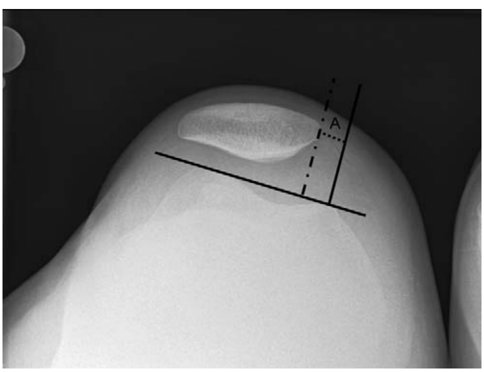

Fig. 12. Lateral patellar displacement. This is measured by comparing the medial margin of the patella on an axial view to the medial femoral condyle. The distance *A* is lateral patellar displacement.

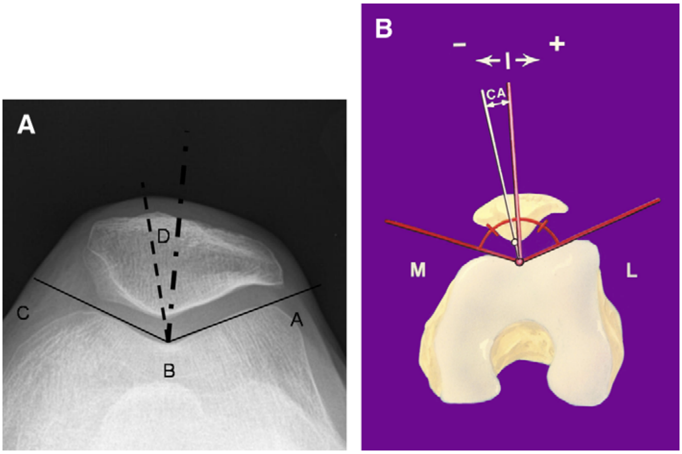

Fig. 13. Congruence angle. (*A*) The measurement is made by bisecting the sulcus angle to create a zero reference line. Then a line is drawn from the lowest point on the patella to the sulcus angle point. The angle created (D) is then measured. (*B*) CA = congruence angle.

The tibial tubercle distance (T-T distance) can be measured with axial imaging, and can substitute for the Q angle. This is a measure of the tibial tubercle in relation to the trochlear nadir. Two sagittal lines are drawn, one through the tibial tubercle, the other through the bottom of the trochlear groove. The lines' difference in position in the axial plane is the T-T distance. One study showed high specificity for maltracking if the tibial tubercle distance was 2 cm or greater [41].

LATERAL RADIOGRAPHS OF THE KNEE

Recently, several studies have described the limitations of the axial view for patellar alignment evaluation. Walker and colleagues [44] questioned the value of the axial view and compared the axial view with CT of the patellofemoral joint. They found that these two modalities often give conflicting results and concluded the axial view to be of limited value due to lack of sensitivity, as "even florid examples [of maltracking] must be missed." Many researchers now advocate using the lateral view of the knee, in various degrees of flexion, to evaluate for alignment at the patellofemoral joint. The basis of this argument rests on the fact that in most knees, the patella is fully engaged in the trochlea by 30 degrees of flexion. Many patients with mild subluxation or tilt are not diagnosed on axial images as their abnormally aligned patellae have corrected at the angle the axial images are obtained. It is not possible to obtain an axial image at less than 20 degrees of flexion; special equipment and elaborate technique is required to obtain these images at angles less than 30 degrees.

Maldague and Malghem [45] have shown how the lateral radiograph can be used to evaluate for malposition of the patella. Dupont and Guier [46] added to their grading scheme (Fig. 14). There is a technical advantage to this technique. A true lateral view can be obtained in full extension or in varying degrees of

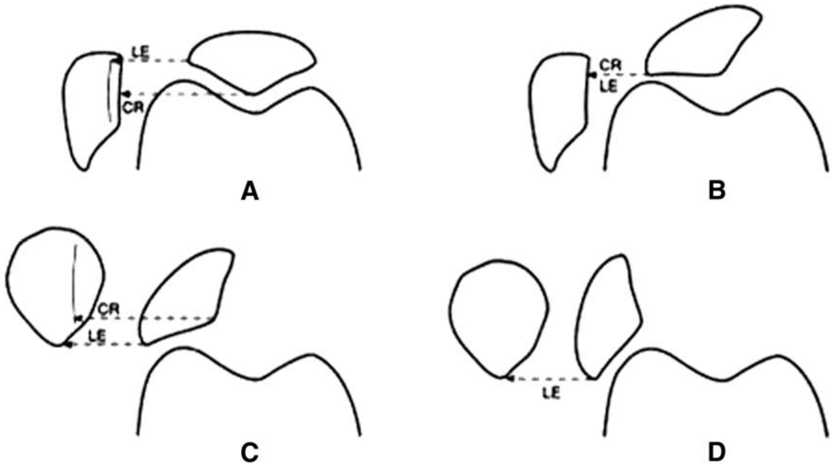

Fig. 14. Schematic representation of patellar position on lateral views, according to the degree of external rotation (tilt), modified Maldague-Malghem's classification in 4 stages. (*A*) Stage 1 (normal position): both lines (central ridge, CR; lateral edge, LE) are concave posteriorly and separated by 5 to 10 mm. The anterior line is the lateral edge, the posterior line the central ridge. (*B*) Stage 2 (false lateral profile as described by Maldague and Malghem, or minor lateral patellar subluxation): both lines are superimposed. Only one straight line is visible. (*C*) Stage 3 (overwhelming lateral profile, or pronounced lateral subluxation): the anterior line is the central ridge, the posterior line is the lateral aspect of the patella and is convex. (*D*) Stage 4. The central ridge is no longer visible. The patella often covers the anterior cortex of the femoral metaphysis and appears ovoid in shape [46]. (*From* Dupont JY, Guier CA. Comparison of three standard radiologic techniques for screening of patellar subluxations. Clin Sports Med 2002;21(3):389–401; with permission.)

flexion to the point where the patella engages the trochlea. Murray and colleagues [47] compared lateral radiographs (taken in 15 to 30 degrees of flexion) of the knee with axial views and found the lateral films had increased sensitivity and specificity for correlation to patellofemoral pain, previous dislocation, and malalignment. Similar results were obtained by Dupont and Guier [46].

The lateral radiograph can also allow assessment of the condition of the trochlea and patellar height. The assessment of patella height is important as patella alta is associated with an increased risk for dislocation. A simple method is the modified Insall-Salvati method, which takes into account the wide variety of patellar shapes that are encountered [48]. This method is highly reproducible and does not rely on exact positioning. The patellar articular surface is compared with the length of the patellar tendon from the tibial tubercle to the most inferior aspect of the patellar articular surface. This ratio of patellar tendon/patellar length is measured and a normal value is less than 2 (Fig. 15). Trochlear depth, accurately measured by the lateral knee radiograph, is an important factor in patellar malalignment. A shallow trochlea places one at risk for dislocation and subluxation. Malghem and Maldague [49] demonstrated that a depth in the proximal trochlea of less than 5 mm increases the risk of instability.

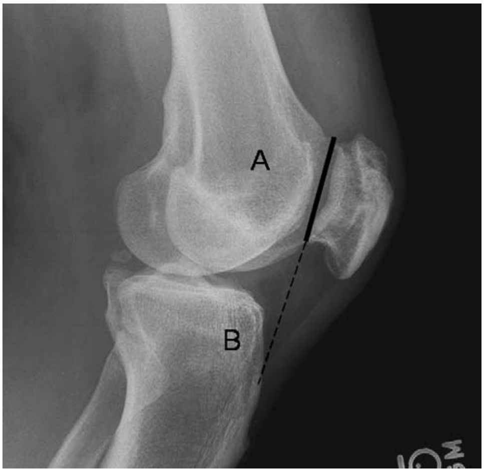

Fig. 15. Modified Insall-Salvati method to determine patellar height. The ratio of B/A should normally be less than 2.

CT and MR

MR and CT can both be used to study the patellofemoral articulation and each has intrinsic advantages and disadvantages. Both modalities have the advantage of being able to study the knee directly in degrees of flexion less than 30 degrees, without overlapping structures adding confusion. A static study involves acquiring axial images at a fixed degree of flexion, usually less than 20 degrees. Kinematic studies acquire images while the knee moves from flexion to extension, and the images acquired can be viewed in a cine mode. These modalities may be useful in patients with symptoms that suggest malalignment but without evidence of the diagnosis by radiographs or physical exam [50,51].

Schutzer and colleagues [37] in 1986 evaluated the patellofemoral joint with CT. They described three malalignment patterns. These include subluxation without tilt, subluxation with tilt, and tilt without subluxation. Their study demonstrated that in asymptomatic normal controls, the patella is either centered or slightly medially displaced by 10 degrees of flexion. Therefore, a patella is considered subluxed if the congruence angle is greater than 0 with the knee in 10 degrees or more of flexion. The patellar tilt angle in asymptomatic controls always was greater than 8 degrees and usually was more than 15 degrees. The authors conclude that 8 degrees is the lower limit of normal tilt on CT [37].

Static MR techniques, such as the one described by Koskinen and colleagues [52], can be used to obtain accurate traditional patellofemoral indices such as lateral patellar tilt, lateral patellofemoral angle, lateral patellar displacement, sulcus angle, and congruence angle. The advantages of static MR over CT include its ability to characterize the status of the soft tissues of the knee. Patellar height can also be assessed reliably with MR. Miller and colleagues [53] compared sagittal MR images and lateral radiographs, and found good correlation between the two modalities. They compared patellar tendon length to patellar length ratios of lateral knee radiographs and midline sagittal MR images. CT sagittal reconstructions theoretically could provide similar information. Pfirrmann and colleagues [54] compared MR and lateral knee radiographs to demonstrate that MR is a reliable test for trochlear dysplasia.

Kinematic MR and CT

The goal of kinematic studies is to better evaluate patellar tracking and to image the PF joint in a manner that more closely mimics physiologic conditions. Advances in fast imaging technology have allowed the development of practical kinematic techniques [50]. Earlier kinematic studies were performed with passive movement of the knee while images were obtained at different degrees of flexion. More recently, active movement kinematic studies let the patient move the knee through quadriceps contraction while being imaged [55]. Active contraction kinematic studies can identify malalignment and maltracking in patients who otherwise would appear normal. Shellock and colleagues [56] demonstrated the advantages of stressing the patellofemoral joint with "loaded" kinematic MR studies. This was accomplished by the patient performing quadriceps contraction against resistance supplied by weights. Their study showed improved ability to identify alignment abnormalities compared with unloaded active kinematic exams.

McNally and colleagues [51] described a useful loaded kinematic MR technique in their study comparing static and kinematic MR. With this technique, the patient was placed supine in the magnet with the knees strapped loosely together at about 30 degrees of flexion. Images were obtained while the patient extended the knee against a balloon, which provided resistance (loading). Multiple fast gradient echo sequences were acquired while extension took place. The imaging took about 2 minutes, with the balloon controlling the rate of extension. The axial slices closest to the center of the patella were selected and compiled for a cine loop. This loop was viewed on a PACS station and subjectively quantified. In the study, the authors rated the observed subluxation (as defined by the lateral movement of the patella in relation to the trochlea) as grade 1 (mild), grade 2 (moderate), or grade 3 (severe). They then compared the given grade of subluxation to multiple patellofemoral measurements, including femoral sulcus angle, sulcus depth, lateral patellar angle, patellar lateralization, and patella-patellar tendon ratio near extension. Their study showed that with increasing grade of maltracking there was a progressive worsening of the above patellofemoral indices, suggesting their simple subjective grading method's utility.

In a separate study, O'Donnell and colleagues [57] compared tracking patterns in 50 patients with anterior knee pain to 50 asymptomatic controls using the protocol described by McNally and coworkers. They demonstrated that increasing degrees of patellar lateralization relate to increasing severity of symptoms in patients. They also showed that many normal controls show mild lateralization near full extension, and thus conclude that this phenomenon is likely a normal variant rather than pathologic.

Fulkerson and colleagues [8] described a technique for unloaded (non-weighted) kinematic CT of the patellofemoral joint obtained at various degrees of flexion. This technique allowed for the evaluation of tilt and subluxation at various degrees of flexion. Tilt was measured by comparing the posterior condylar line to the lateral patellar facet. Congruence angle was used to measure subluxation. The examination was performed in about 20 minutes and at a cost similar to standard knee radiography. The values obtained were compared with the guidelines set forth by Schutzer and colleagues [37].

Competing Viewpoints

Dye [58] has challenged the idea that malalignment (without subluxation) by itself causes patellofemoral pain, and has questioned some of the measurements that have been traditionally used to evaluate patients with anterior knee pain. In his study there was no statistical difference in Q angle and congruence angle in patients with patellofemoral pain and asymptomatic controls. He also concluded that osseous landmarks on radiography often do not match the contour of the underlying cartilage, which challenges the concept of patellar tilt. Ninety percent of patients with a diagnosis of malalignment improve with conservative treatment even though their malalignment is not surgically addressed. Many patients with bilateral patellar tilt have symptoms in only one knee. Therefore, Dye asserts that loss of tissue homeastasis, which is the root cause of patellofemoral pain, is likely due to "supraphysiologic" overload [58]. Other authors, such as Thomee and colleagues, have also pointed out problems with the theory of malalignment as the cause of anterior knee pain [43,59].

SUMMARY

A variety of entities may be responsible for AKP. A combination of patient history, physical examination, and appropriate use of imaging may, in most instances, result in a reliable diagnosis in most individuals affected by this disorder.

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