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Tip of the Iceberg Findings: Subtle Radiographic Abnormalities Indicating Significant Pathology in the Knee

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Abstract
Purpose of Review Knee injuries are common and radiographs remain the first line of study in the majority of cases. In many instances, subtle or small radiographic findings actually represent significant underlying pathology that requires expeditious diagnosis and treatment.
Recent Findings By using a mechanistic search strategy, one that applies a comprehensive search for avulsions at ligamentous/tendinous/connective tissue attachments and potential sites of impaction, one may maximize the diagnostic accuracy of radiographic interpretation.
Summary This article will provide a review of important indicators of ligament, tendon, and osseous injuries with an emphasis on their mechanism of injury.

Keywords Knee · Trauma · Fracture · Avulsion · Ligament · Tendon

Introduction

Radiography plays a vital initial role in the evaluation of the knee. It is recommended in patients with acute trauma or twisting injury accompanied by an inability to bear weight, joint effusion, or focal pain by the American College of Radiology [1••]. Radiography is inexpensive, easily obtained, and can quickly exclude fractures and malalignment as causes of pain. Subtle abnormalities with associated soft tissue injuries are important to detect as these patients may require additional imaging with magnetic resonance imaging (MRI). The provided clinical history in the Emergency Department (ED) is often limited, i.e., trauma and/or pain, and a detailed account relating the mechanism of injury may not be readily available. A search pattern utilizing a mechanistic approach maximizes detection of these sometimes subtle fractures.

Biomechanics and Review of Mechanism of Injury

Knee motion is complex. Forces that act on the knee in normal ambulation include direct compression, mediolateral shear, and anteroposterior shear that are resisted by the cruciate ligaments [2]. These forces are generated by the actions of muscles and gravity, and increases by a factor of 2–4 times body weight with walking [3].

Few knee injuries are caused by one single vector. Most are caused by complex injury mechanisms that have a combination of forces [4]. Knee injuries involve at least one of these simple mechanisms: hyperextension, valgus stress, varus stress, posterior tibial translation, and anterior tibial translation, but the majority involves a combination of external rotation and valgus in a flexed knee, flexion with internal rotation and varus, or hyperextension with varus stress and internal rotation [5]. There is a primary resistor for each simple mechanism. In general, unidirectional mechanisms produce instability caused by failure of one or more ligaments, and complex mechanisms typically produce instability caused by failure of multiple ligaments.

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Imaging Technique

There are a number of important radiographic projections available, but most trauma series include at least four views; anteroposterior (AP), lateral, and oblique views. In the AP view, the central beam is directed about 1 cm below the apex of the patella and angled 5° cephalad. In a lateral view, the knee is flexed about 30° and the knee of interest is against the table. A cross-table technique is useful in patients who cannot be moved, and is obtained with the cassette perpendicular to the table, often in between the legs. In an internal oblique view, the leg is internally rotated about 45° and the beam is perpendicular to the cassette. In an external oblique view, the leg is externally rotated about 45°. A notch view is done prone with the cassette in front of a flexed knee, and the tube angled about 40° cephalad. There are a number of different positions to obtain tangential views of the patella. A Merchant view is most common in our institution, obtained with the knees flexed 45° over the table, the cassette perpendicular to the legs, and the beam angle 30° off horizontal and aimed at the cassette.

Femur

Pellegrini–Stieda Disease

Ossification or calcification of the medial collateral ligament (MCL) was first described in 1905 by both Pellegrini and Stieda, and occurs within injured proximal fibers of the ligament. The injury is caused by a valgus force to the knee (Fig. 1) [6]. The etiology of the ossific or calcific deposits remains a source of debate. Pellegrini–Stieda disease radiographically falls into one of the four ossification patterns along the medial femoral condyle on frontal radiographs (Fig. 2): (i) beak-like semilunar ossification tapering inferiorly, (ii) drop-like ossification extending inferiorly, (iii) smooth ossification with superior extension, and (iv) smooth ossification extending both superiorly and inferiorly [7]. When it is visualized superior to the tibial collateral ligament, it likely is the result of periosteal stripping of the distal femoral metaphysis or a concomitant injury to the ischiocondylar portion of the adductor magnus muscle [7, 8].

Ossification has been shown to occur at variable rate but most often develops 2–4 weeks after injury. A similar ossification may be seen in patients with an injury to the medial patellofemoral retinaculum [9]. Pellegrini–Stieda ossification may also be associated with injuries of the posterior cruciate ligament (PCL). Because the radiographic appearance of Pellegrini–Stieda disease is characteristic, further evaluation with MRI is not necessary unless physical findings suggest a coexisting internal derangement.

Posterior Oblique Ligament Avulsion

The posterior oblique ligament (POL) is a distinct structure in the posteromedial corner of the knee. It originates from the adductor tubercle, spans the tibiofemoral joint, and inserts with three points of attachment. The most important component is the central arm, a thickened band of connective tissue that inserts on the posterior tibia near the margin of the articular cartilage. The capsular arm runs between the posterior capsule and oblique popliteal ligament. The distal arm attaches to the semimembranosus sheath. The capsular and distal arms play less significant roles in maintaining stability [10]. The POL, along with the posterior joint capsule, resists posterior tibial translation [11]. A hyperextension-valgus mechanism of injury is usually required to cause this fracture.

Typically, avulsion fractures of the POL manifest as a single osseous fragment arising from the adductor tubercle (Fig. 3). These fractures are readily identified on external oblique radiographs projecting posterior to the femoral metaphysis and proximal to the condyle, but may be occult on the frontal projection [12]. When detected, MRI may be contemplated to further assess the integrity of the MCL, which likely will be injured proximally, although CT may be more optimal for confirming the fracture if the osseous fragment is small. An unusual complication of POL avulsion is displacement of the MCL into the tibiofemoral joint [13].

Avulsion of the Lateral Epicondyle

The lateral epicondylar portion of the femur is the site of origin of the lateral collateral ligament (LCL). When a fracture occurs in this location, it may indicate an injury to the LCL or the popliteus tendon, which has its attachment slightly more posteriorly. The mechanism of injury is usually a unidirectional varus force that subsequently distracts the lateral joint and compresses the medial joint, although it may also occur with a combination of hyperextension and varus forces. Femoral avulsion of the LCL is rare; one retrospective study of pediatric and adolescent knees detected only 2 of 51 knees with isolated collateral ligament injuries [14]. It often requires high-energy trauma. The characteristic appearance of a lateral epicondyle avulsion fracture is a biconcave bone fragment with or without displacement on frontal knee radiographs (Fig. 4). Associated injuries may include tears the popliteus tendon and posterior cruciate ligament [15, 16].

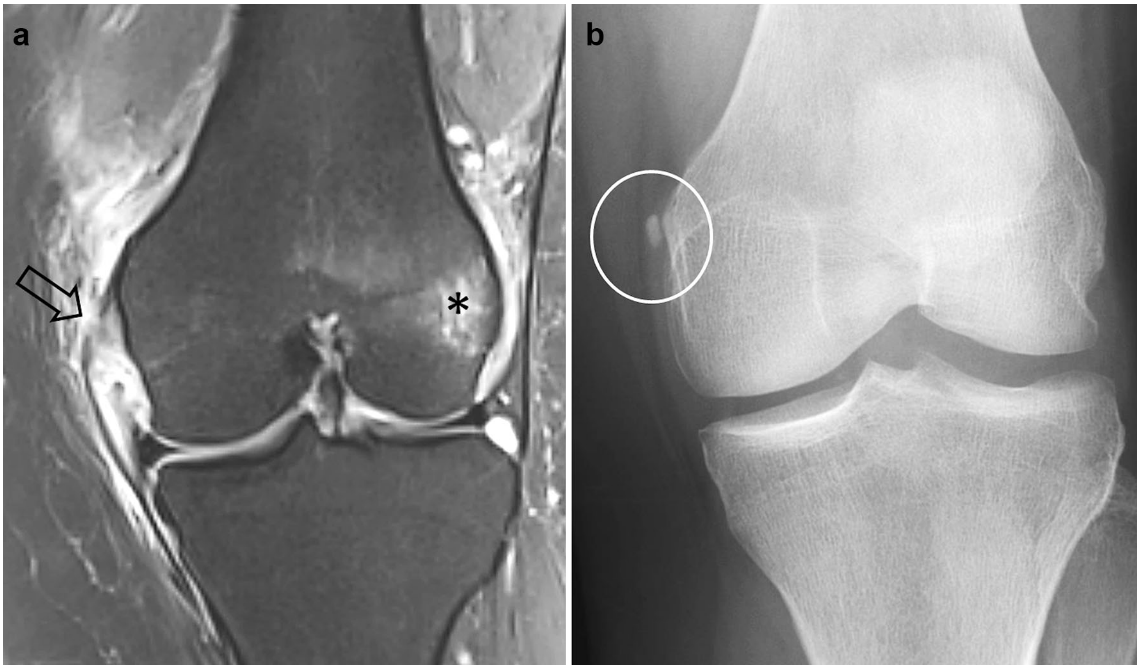

Fig. 1 Pellegrini–Stieda disease. **a** Coronal T2-weighted MR image shows a focal disruption in the MCL (arrow) with surrounding perifascicular edema. Note that the bone contusion in the lateral femoral condyle (asterisk) is indicative of a valgus injury. **b** Frontal radiograph performed 1 year later shows a drop-like, ovoid ossification in the proximal MCL (circle)

Fig. 2 Pellegrini–Stieda disease. **a** Beak-like ossification arises from the epicondylar portion of the medial femoral condyle and extends inferiorly. **b** Smooth curvilinear ossification originating in the proximal MCL extends superiorly above the level of the epicondyle. **c** Note that these ossific densities extend both inferiorly within proximal MCL and superiorly above the epicondyle

Popliteus Tendon Avulsion

The popliteus tendon inserts within the fossa in the lateral aspect of the lateral femoral condyle, just inferior and deep to the LCL origin. The tendon descends inferiorly along the joint, with connections to the posterior horn of the lateral meniscus and fibula, and distally, the muscular belly attaches on the posterior surface of the proximal tibia, superior to the soleus line [17]. Most avulsion fractures of the popliteus tendon insertion occur in the setting of a varus force, but may also occur with dashboard injuries and external rotation of the flexed knee [18]. An isolated avulsion fracture is a rare injury, occurring more commonly in skeletally immature people [19, 20].

On frontal radiographs, the fracture appears as a small ovoid osseous fragment adjacent to the lateral femoral condyle that is accentuated on external oblique views, but many are radiographically occult (Fig. 5). It is important to note that owing to tensile forces, the avulsed fragment may displace anywhere along the expected course of the

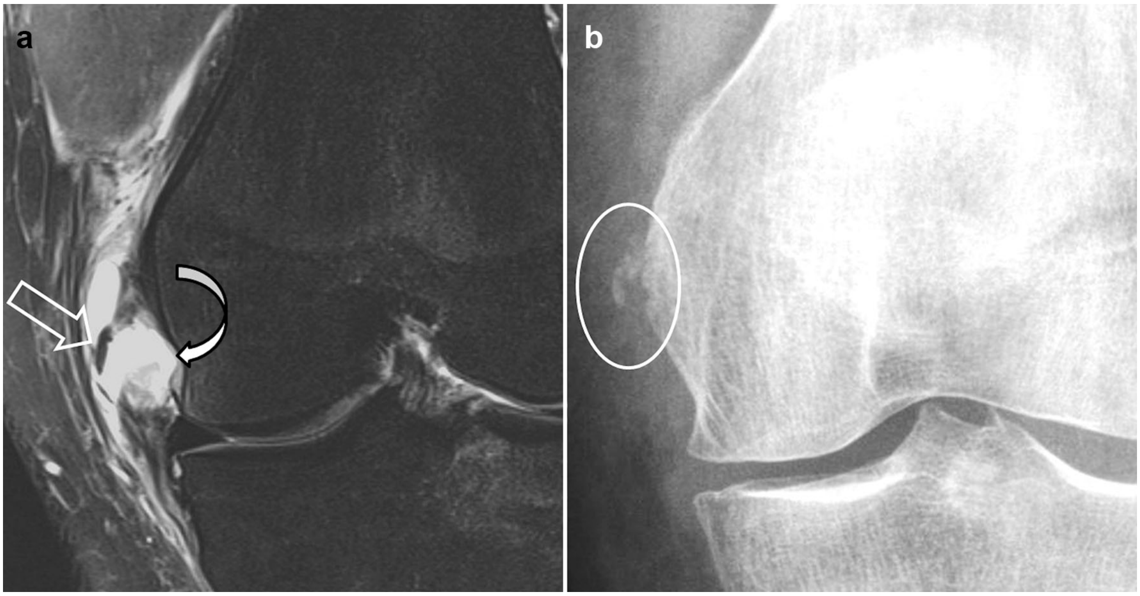

Fig. 3 Posterior oblique ligament avulsion fracture. **a** Coronal T2-weighted MR image shows a tear in the posterior oblique ligament (arrow) as well as the meniscotibial component of the MCL (curved arrow). **b** The frontal radiograph shows subtle irregular ossific densities medial to the medial femoral condyle (oval) and surrounding soft tissue swelling

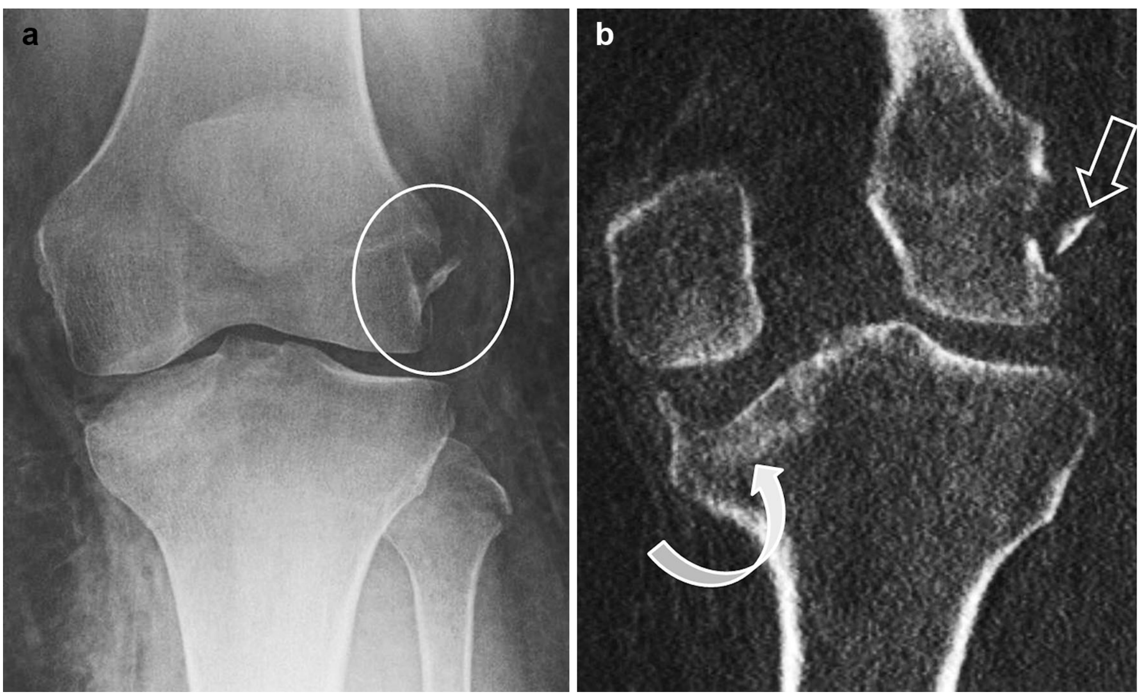

Fig. 4 Lateral collateral ligament avulsion fracture. **a** Frontal radiograph shows a linear ossification adjacent to the fossa of the popliteus tendon in the lateral femoral condyle (oval). **b** The coronal reformatted CT image shows the avulsion fracture (arrow) arising from the lateral epicondylar region of the lateral femoral condyle and a depressed fracture of the medial tibial plateau (curved arrow) indicative of a varus mechanism of injury

popliteus tendon. Therefore, it is important to not dismiss the finding as an intra-articular body, particularly in patients with osteoarthritis, but to critically analyze the margins of the bone fragment. If necessary, MRI can assess the femur for acute bone marrow edema, as well as for associated injuries to the PCL, LCL, and lateral meniscus.

Deep Sulcus (Lateral Notch) Sign

There are several mechanisms of injury responsible for a complete tear of the anterior cruciate ligament (ACL), but the most commonly observed mechanism is a pivot shift injury. With this mechanism, the femur externally rotates against a fixed tibia, and a valgus force distracts the medial knee and compresses the lateral knee. When the tibia translates anteriorly, the lateral condylopatellar sulcus, or lateral notch, a natural depression in the lateral femoral condyle that separates the patellar articulating surface anteriorly from the tibial articulating surface posteriorly, may impact on the posterolateral tibia [21]. If the valgus force is sufficient, it can result in an impaction fracture of the lateral notch which deepens the sulcus depth, a finding referred to a *deep notch* sign (Fig. 6) [22].

The depth of the sulcus is ascertained by drawing a tangential reference line across the lower articular surface of the lateral femoral condyle on the lateral view of the knee, and then measuring a perpendicular line at the deepest point (Fig. 7) [23]. A deep sulcus is depicted as a concave defect that is > 2 mm. A depth of 1.5 mm is a sensitive measurement in predicting an ACL tear, but a depth of 2.0 mm was found to be 100% specific, and demonstrated a 100% positive predictive value for ACL tears [21]. MRI is recommended when a *deep notch* sign is observed because it not only correlates to an ACL injury, but also to cartilage abnormalities of the condylopatellar sulcus and lateral meniscal tears.

Tibia

Tibial Eminence Fractures

Tibial eminence fractures are relatively uncommon but are important because they may affect the distal attachments of the cruciate ligaments. Generally, these fractures are more common in pediatric patients than adults [24]. MRI is generally recommended in these types of fractures. About 90% of fractures involve the anterior tibial eminence and are associated with intrasubstance damage to the ACL in 41% [25]. Posterior tibial eminence fractures are associated with intrasubstance damage to the PCL in about 14% of cases. Tears of the MCL, patellar retinaculum, and posterolateral corner ligaments occur in about 30–40% of cases. Meniscal tears may be seen in 20–30% of cases [25, 26•]. Occult osseous injuries and cartilaginous defects are frequent observations as well [27]. CT may be useful to further characterize the morphology of the fracture.

Less than 1% of ACL injuries involve the anterior tibial eminence [28•]. High impact trauma producing hyperextension or rapid deceleration is recognized as the causes of these types of fractures; while a pivot shift mechanism in skeletally immature patients can also produce anterior tibial eminence avulsion fractures [29]. Fractures of the anterior tibial eminence may be observed on both AP and lateral radiographs and have a varying appearance depending on the size of the fracture fragment as well as on the degree of displacement. In nondisplaced fractures, there

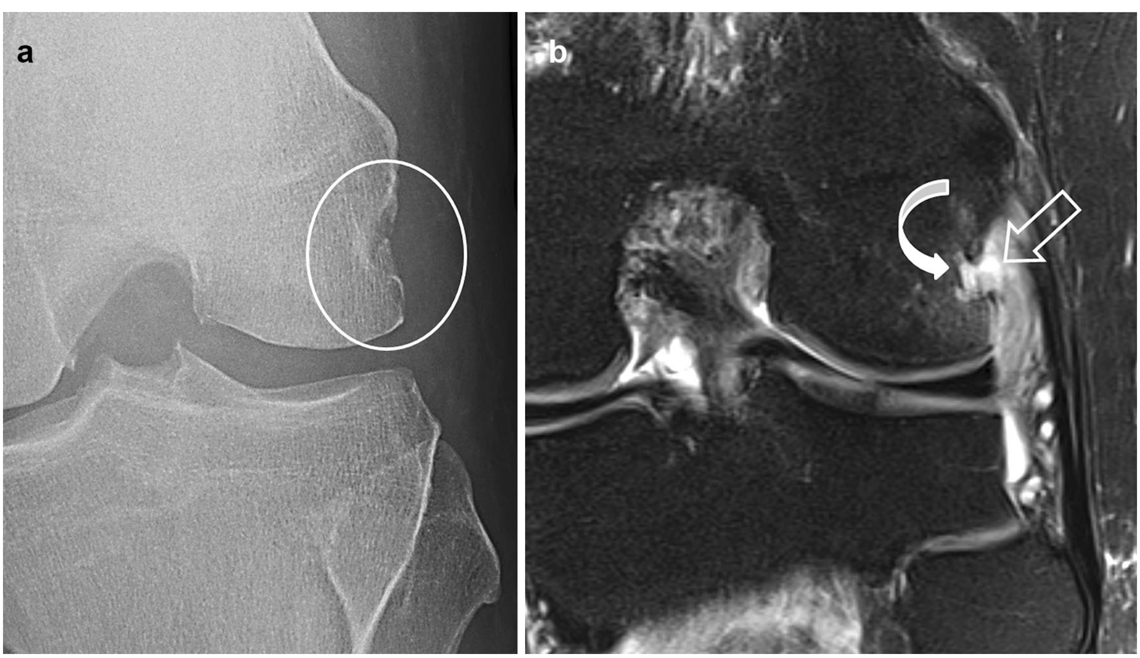

Fig. 5 Popliteus tendon avulsion fracture. **a** Frontal radiograph shows a small irregular ossicle lying within the fossa of the popliteus tendon (oval). **b** Coronal T2-weighted MR image shows an avulsion of the popliteus tendon (arrow) and an adjacent defect in the lateral cortex of the lateral femoral condyle (curved arrow) with surrounding bone marrow edema

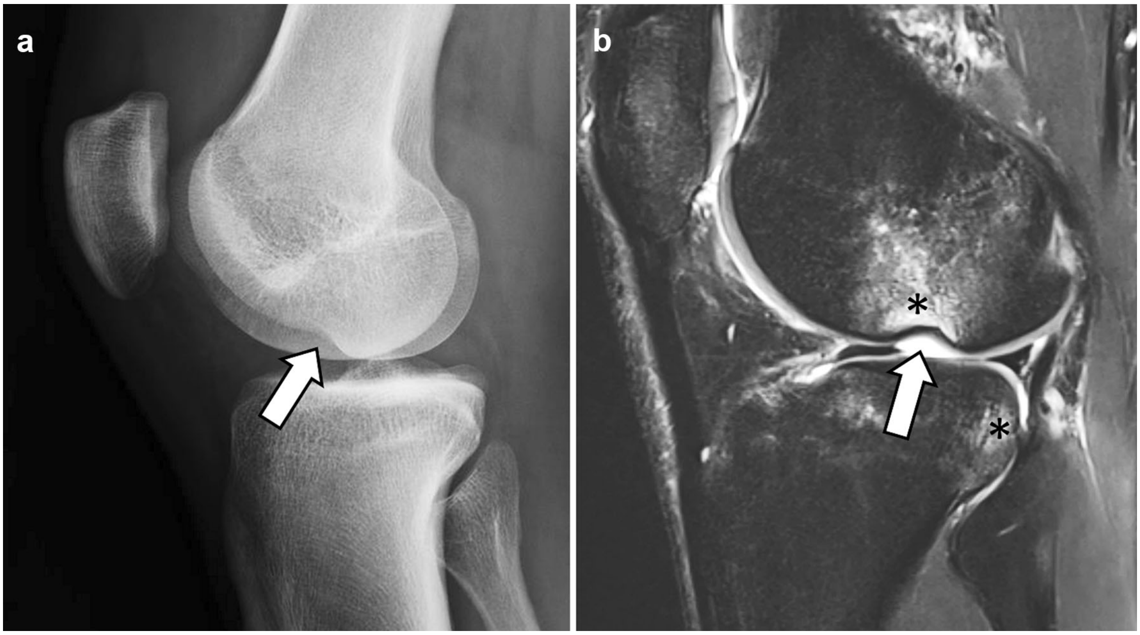

Fig. 6 Deep sulcus sign. **a** Lateral radiograph shows a deep depression in the region of the lateral condylopatellar sulcus in the articular surface of the lateral femoral condyle (arrow). **b** Sagittal T2-weighted MR image shows the deepening of the sulcus (arrow) with thinning of the overlying cartilage. Note the bone contusions in the lateral femoral condyle and posterolateral tibia (asterisk) consistent with a pivot shift mechanism of injury

Fig. 7 Measuring the lateral sulcus depth. To measure the depth of the lateral sulcus on a lateral radiograph, draw a tangential reference line across the lower articular surface of the lateral femoral condyle (dashed line), and then place a perpendicular line at the deepest point of the sulcus (solid line)

is often a semilunar lucency depicting the fracture at the base of the eminence. If the fragment is distracted anteriorly from tension by the ACL, a trapdoor appearance on the lateral view may be observed with an intact posterior hinge (Fig. 8). Complete detachment, comminution, and rotation are indicative of increased severity. With increasing displacement of fracture fragments, there is a greater risk of meniscal entrapment [30]. Fractures of the anterior tibial eminence are most often classified by the revised Meyers and McKeever classification. In this classification, type 1 is a nondisplaced to < 3 mm displaced fragment; type 2 is a trapdoor fracture with anterior elevation but with an intact posterior hinge; type 3 is completely separated and displaced, and type 4 is a either comminuted or rotated with or without displaced fragments [31, 32].

The PCL inserts upon the posterior tibial eminence, and avulsion fractures in this area are less common [33]. The most common mechanism of injury is high-energy trauma to a flexed or hyperflexed knee, or a dashboard injury [34•]. Hyperextension and falls on a flexed knee with plantar flexion of the foot are other potential mechanisms [35]. The fracture fragment is best depicted on the lateral radiograph appearing as irregular crescentic or triangular fragment of bone adjacent to the posterior tibia, with or without displacement (Fig. 9). Isolated bundle avulsions rather than osseous PCL avulsion may occasionally occur [36]. Occasionally, posterior tibial subluxation may be evident radiographically.

Segond Fracture

Since its original description in 1879, the anatomy of the Segond fracture has been a subject of study [37••, 38•, 39••, 40•]. Cadaveric dissections indicated that numerous structures insert on the lateral tibia. The iliotibial band inserts on

Fig. 8 Anterior tibial eminence fracture. **a** Frontal radiograph shows a fracture involving the medial tibial spine in the anterior aspect of the tibial eminence (circle). **b** Lateral radiograph shows a boat-shaped bone fragment (arrow), but it is difficult to determine if the fracture is complete. **c** Coronal T1-weighted MR image shows superior displacement of the fragment (oval) and a bone contusion in the lateral femoral condyle (asterisk). **d** Sagittal T2-weighted MRI image shows that the edematous bone fragment is attached to the ACL. The fragment was attached posteriorly (arrow) indicating a trap-door morphology

Gerdy's tubercle, but also has fibers inserting posteriorly with the anterior oblique band of the lateral collateral ligament [41]. More recently, another fibrous structure has been defined as the anterolateral ligament (ALL) and observed in 45–97% of cadaveric knees [37••, 39••]. The origin is at the prominence of the lateral femoral epicondyle slightly anterior to the origin of the lateral collateral ligament (LCL), although these may be connected. It courses obliquely and attaches on the anterolateral tibia midway between Gerdy's tubercle and the tip of the fibular

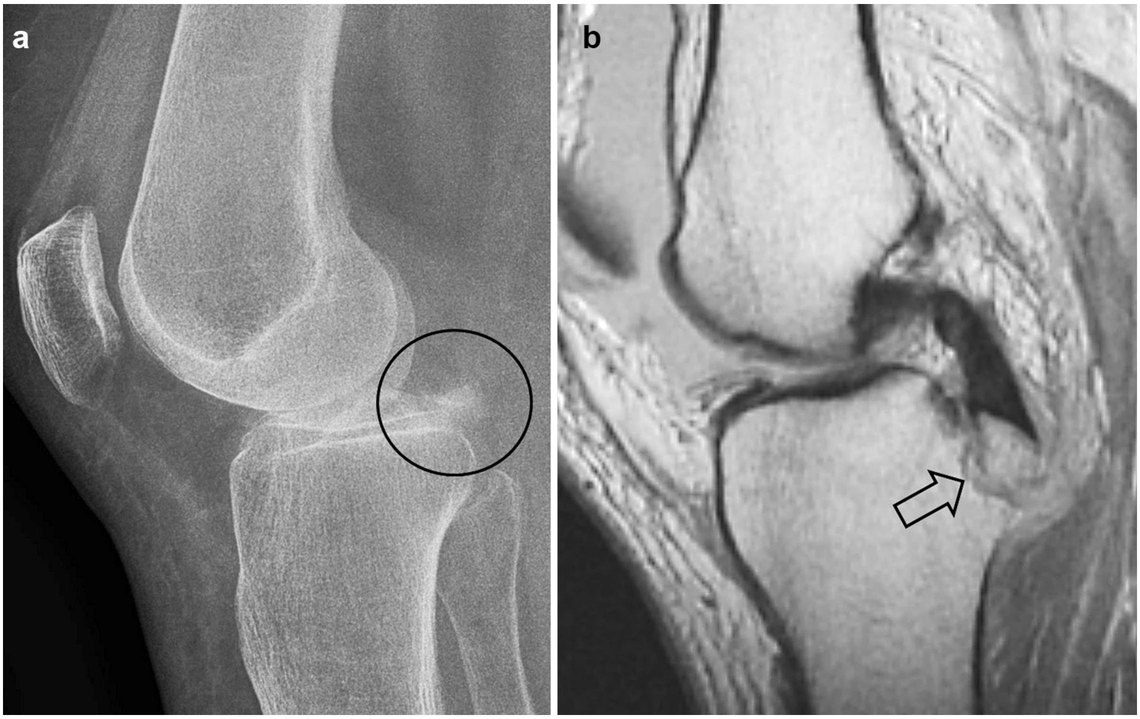

Fig. 9 Posterior tibial eminence fracture. **a** Lateral radiograph shows a displaced fracture fragment arising from the posterior tibial eminence (circle). Note that the tibia is posteriorly subluxed. **b** Sagittal proton-density MR image shows that the bone fragment involves the attachment of the PCL (arrow)

head, separate from the ITB. It is a rotational stabilizer by preventing internal rotation.

Segond fractures result from combined internal rotation and varus stress upon the knee [42]. Historically, regarded as an avulsion fracture of the anterolateral capsule of the knee, it has recently been attributed to an avulsion of the ALL complex or the posterior fibers of the ITB [38•, 40•, 41]. Frontal radiographs of the knee reveal an ovoid or linear osseous fragment oriented vertically along the lateral tibial plateau with or without displacement (Fig. 10). The bone fragment has a remarkable consistency in size and shape owing to the specifically involved structures. ACL tears, meniscal tears, chondral defects, and ITB injuries have been associated with the presence of a Segond fracture, so further evaluation with MRI is recommended.

Medial (Reverse) Segond Fracture

An isolated avulsion fracture of the meniscotibial component of the MCL from its tibial insertion was coined a reverse Segond fracture in 2002. It is the result of high-energy trauma associated with valgus stress and external rotation [43]. It is a rare finding but has a higher prevalence in patient with complete knee dislocations (Fig. 11) [44, 45]. The fracture appears as a small bone fragment along the medial rim of the tibial plateau on frontal radiographs measuring only a few millimeters in length. The importance of this fracture is its association with PCL tear and medial meniscal tears, often occurring at the root, and posterior oblique ligament tears [45, 46]. More recent associated findings include with both ACL and PCL avulsion fractures, occult anterior tibial rim fractures, and lateral meniscal tears [44, 47]. Therefore, when detected, a medial Segond fracture is highly suggestive of internal derangement and requires further investigation with MRI.

Iliotibial Band Avulsion Fracture

The ITB serves as a lateral stabilizer of the knee. It is the distal continuation of the fascia of the tensor fascia lata. Avulsion fractures can be caused by both direct and indirect trauma. The most common mechanism of injury relates to a direct varus force [48]. Radiographically, this avulsion injury appears as a triangular-shaped fragment displaced from its tibial donor site (Fig. 12). Depending on the size of the avulsed fragment, there may be associated lipohemarthrosis [49]. MRI is recommended because there are several associated abnormalities that may occur including tears of the ACL, MCL, and LCL [50].

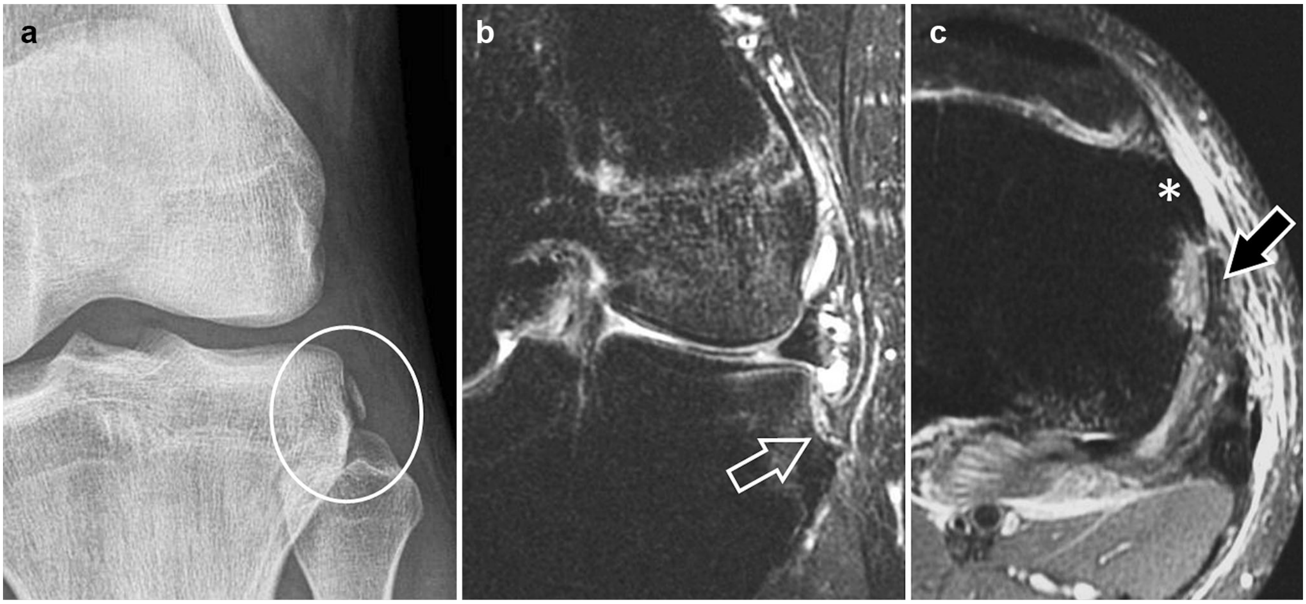

Fig. 10 Segond fracture. **a** Frontal radiograph shows a vertically oriented fracture with a linear fragment arising from the lateral aspect of the proximal tibia just distal to the articular surface (oval). **b** Coronal T2-weighted MR image shows an avulsed anterior lateral ligament and a defect in the lateral tibial cortex surrounded by bone marrow edema (arrow). **c** Axial T2-weighted MR image shows that the displaced fragment (arrow) is located in between Gerdy's tubercle (asterisk) and the fibular head (not shown)

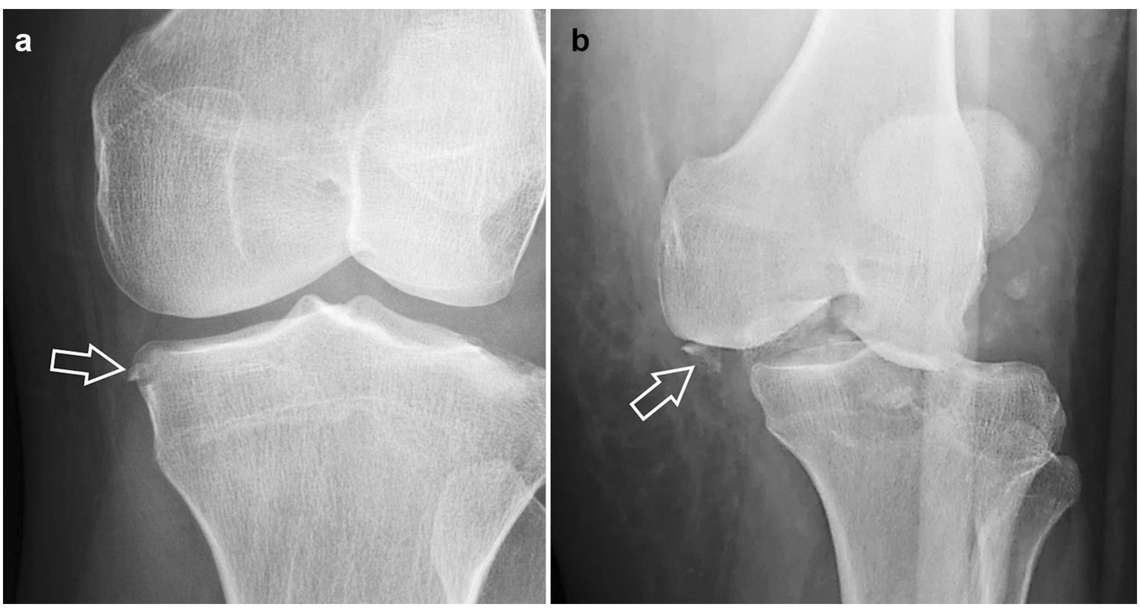

Fig. 11 Medial Segond fracture. **a** Frontal radiograph shows a small avulsion fracture at the medial corner of the proximal tibia (arrow) after sustaining a rotational injury. **b** Frontal radiograph in another patient shows a complete posterolateral knee dislocation and a displaced avulsion fracture arising from the medial aspect of the proximal tibia (arrow)

Fibula

Arcuate Sign

Shindell et al. described the *arcuate* sign in the setting of posterolateral instability in 1983 [51]. The posterolateral corner of the knee is complex and has been characterized both by imaging and by cadaveric studies [52, 53]. The arcuate ligament is a Y-shaped structure originating from the fibular styloid with two limbs, medial and lateral. The medial limb attaches to the posterior capsule, while the lateral limb attaches to the lateral joint capsule. The popliteofibular ligament connects the popliteus tendon to the fibular styloid [53]. The fabellofibular ligament also

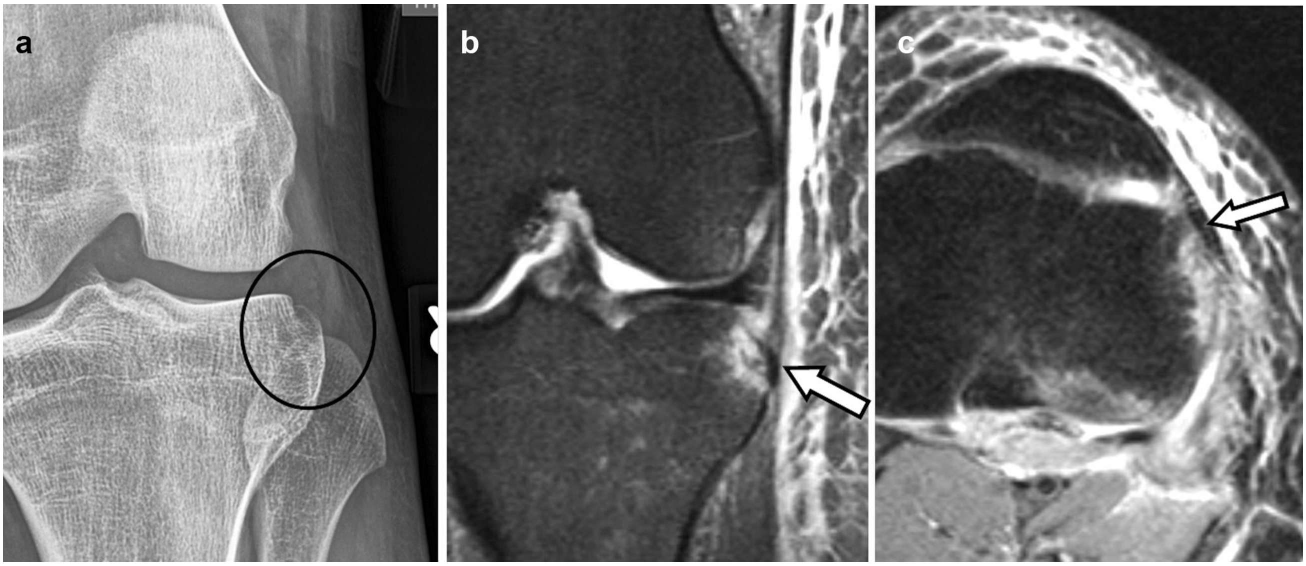

Fig. 12 Iliotibial band avulsion fracture. **a** Frontal radiograph shows a lucent defect in the lateral aspect of the proximal tibia with a small curvilinear density within the defect (oval). **b** Coronal T2-weighted MR image shows that the bone fragment (arrow) is attached to the iliotibial band, which is surrounded by perifascicular edema. Note the bone marrow edema in the tibial defect. **c** Axial T2-weighted MR image shows detachment of the iliotibial band (arrow) and bone marrow edema in Gerdy's tubercle

attaches to the fibular styloid. The *arcuate* sign represents an avulsion fracture of the fibular styloid process caused by a combined hyperextension-varus force imparted upon the knee. The radiographic appearance of this fracture is characteristic; a transverse lucency through the fibular styloid process resulting in a small osseous fragment, at most several millimeter in length (Fig. 13). This fragment may maintain close proximity with the fibular head, or may displace proximally and medially.

The *arcuate* sign is an important indicator of posterolateral instability [54]. A concomitant tear of the ACL or PCL has both been recognized as associated injuries. If unrecognized or left untreated, reconstruction of an ACL ligament is likely to fail; therefore, MRI is recommended when this fracture is detected. It recently has been described in patients who have sustained complete knee dislocations [55].

Fibular Head Avulsion Fracture

The fibular insertion of the lateral collateral ligament and the biceps femoris tendon converge to a single insertion point upon the lateral aspect of the fibular head. Isolated avulsion of the fibular head is rare. When varus forces are sufficient, the fibular head can avulse *en bloc,* although the fracture occurs more commonly with a complete knee dislocation [56, 57]. Radiographically, the fragment is larger than that seen in the *arcuate* sign, and the vertically or obliquely oriented line of the fracture is located more laterally and inferiorly (Fig. 14). Displacement is often greater with avulsion of the fibular head owing to the traction related to the biceps femoris at its insertion, producing the characteristic ribbon-like deformity of the LCL on MRI [53].

Patella

Avulsion of Medial Patellofemoral Ligament

The medial constraining structures of the patella are frequently injured in the setting of lateral patellar dislocation. Predisposing factors for patellar instability include trochlear dysplasia, increased rotation between the femoral neck and the tibial tuberosity, and patella alta [58]. The knee is at greatest risk for transient dislocation when flexed between 0 and 30 [59]. Three different patterns of medial patellofemoral ligament (MPFL) injury have been described; ligament disruption, osseous avulsion from the patella, and osseous-cartilaginous avulsion of the patella [60•]. Avulsion fractures of the MPFL on radiographs are well demonstrated on merchant view and manifest as small linear osseous fragments displaced from the medial patellar facet (Fig. 15). Pure cartilaginous injuries are radiographically occult. Imaging with MRI is therefore necessary to assess the integrity of the MPFL and medial patellar retinaculum, but to also detect potential injuries of the articular cartilage and possible displaced intra-articular chondral fragments.

Fig. 13 Fibular styloid avulsion fracture. **a** Oblique radiograph shows a transverse fracture through the tip of the fibular styloid process resulting in a small distracted bone fragment (oval) consistent with an arcuate sign. **b** Sagittal T2-weighted MR image shows bone marrow edema (asterisk) surrounding and within the fragment, and ribbon-like redundancy of the detached arcuate ligament (arrow)

Fig. 14 Fibular head avulsion fracture. **a** Oblique radiograph shows an obliquely oriented fracture through the lateral aspect of the fibular head with minimal superior displacement of the fragment (oval). **b** Coronal T1-weighted MR image shows that the bone fragment is attached to the conjoined tendon (arrow), which comprises the distal LCL and biceps femoris tendon

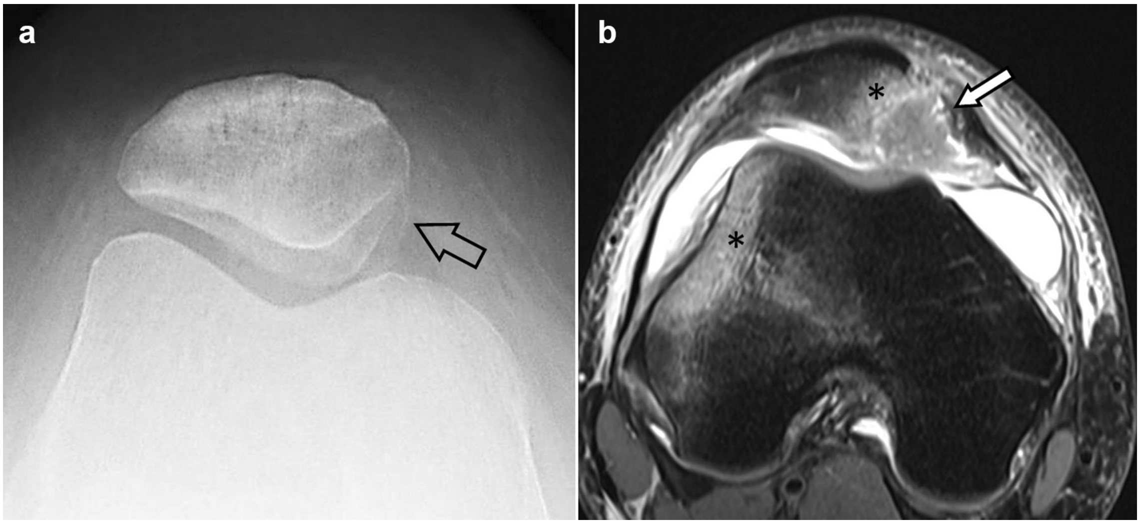

Fig. 15 Medial patellofemoral ligament avulsion fracture. **a** Axial patellar radiograph shows a subtle, very thin curvilinear density adjacent to the medial aspect of the patella (arrow) with adjacent soft tissue swelling. **b** Axial T2-weighted MR image shows significant soft tissue swelling and displacement of a thin low signal intensity abnormality (arrow) that corresponds to the bone fragment. The medial patellofemoral is disrupted and there is a classic bone contusion pattern (asterisk) of a prior lateral patellar dislocation

Conclusion

Recognition of subtle fractures of the knee is important because in the setting of acute knee trauma, they may herald significant underlying abnormalities of the ligaments, menisci, capsule, tendons, and bones. An understanding of the mechanisms of injury that contribute to these fractures can increase the diagnostic acumen when interpreting radiographs in patients with symptoms, thus adding value to the role of the radiologist in caring for these patients in the ED. Prompt utilization of MRI is essential in revealing other associated injuries, initiating prompt treatment, and optimizing patient outcome.

Compliance with Ethical Guidelines

Conflict of interest Jason D. Lather declares no potential conflicts of interest. Joseph S. Yu is a section editor for *Current Radiology Reports*.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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Recently published papers of particular interest have been highlighted as:
- • Of importance
- •• Of major importance

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