Learning objectives

The knee joint has numerous tendinous, ligamentous, and meniscal attachments, which make it particularly vulnerable to complex injuries after trauma. The purpose of our study is to present in detail the general mechanisms of avulsion fractures and associated MRI findings with emphasis on the most common injuries.

Background

Eighty-four patients (65 males and 19 females, age range 16-46, mean age 30) who sustained severe injuries of the knee, mainly during sports activity, underwent MRI at 1,5 T between November 2007 and July 2009. The imaging protocol consisted of axial, sagittal and coronal T1-W FSE, fat-suppressed (FS) PD-W FSE, STIR and 3D FS SPGR/3D DESS sequences.

Imaging findings OR Procedure details

ACL Avulsion Fracture

Although most ACL tears involve the midsubstance of the ligament, avulsion of its tibial attachment occurs in a minority of cases and is more common in children than adults. The mechanism often varies between children and adults. In children, this injury usually occurs secondary to forced flexion of the knee with internal rotation of the tibia and is not associated with other knee injuries. In adults, the injury results from severe hyperextension and has a higher prevalence of associated injuries, including "kissing" bone contusions and tears of the medial collateral ligament and PCL. On conventional radiographs, avulsion fractures of the ACL are difficult to recognize. MRI is useful to confirm that the fragment does in fact arise from the tibia and that the entire substance of the ACL is intact, as well as assessing for associated injuries (Fig. 1). The Meyers and McKeever classification system describes four subtypes of tibial spine fractures. Type I injury describes a minimally displaced fragment. Type II injury involves anterior elevation of the fracture fragment, whereas type III and IV injuries demonstrate complete separation of the fragment from the tibia. Although type I injuries are treated conservatively, arthroscopy is recommended for type II-IV lesions because type III and IV injuries require internal fixation.
PCL Avulsion Fracture

Evaluation of the PCL is difficult both clinically and arthroscopically and this fact magnifies the importance of early detection of PCL injuries. Isolated PCL disruption most commonly occurs as avulsion at its tibial insertion (40%-55%), as opposed to its femoral origin or as a midsubstance tear. This injury appears radiographically as focal discontinuity of the posterior tibial articular surface, a finding that is often best appreciated on the lateral view. At MRI, a discrete bone fragment is noted attached to an otherwise intact PCL and separated from the remainder of the tibia (Fig. 2). The mechanisms of injury of the PCL are multiple and include a direct blow to the anterior tibia with the knee flexed or severe hyperextension. Despite the fact that injury to the PCL may be an isolated finding, concurrent damage to the other major stabilizing structures of the knee is common. Additional injuries that are associated with PCL avulsion fracture include disruption of the medial and lateral collateral ligament complexes, medial and lateral meniscal tears, and focal bone contusions of the anterior tibia and lateral femoral condyle. Chronic instability of the knee and early-onset degenerative arthritis lead nowadays to aggressive management of PCL avulsion fractures with surgical reinsertion and fixation.

Conjoined ACL and PCL Avulsion Fracture

This type of lesion is very rare and is attributed to a fracture that extends from anterior to posterior tibial plateau. ACL and PCL fibers are intact but the knee is unstable. MRI clearly demonstrates the fracture line and the insertion point of ACL and PCL (Fig. 3, 4).

Segond fracture

It is the best known avulsion fracture of the knee. It involves cortical avulsion of the tibial insertion of the middle third of the lateral capsular ligament. The pathophysiology of Segond fracture is complex and may involve avulsion of the iliotibial tract and anterior oblique band as well. The mechanism of this injury is often the result of internal rotation of the knee and varus stress, which produces abnormal tension on the central portion of the lateral capsular ligament. The patients present with pain at the lateral joint line and with anterolateral rotational instability. The appearance of this fracture on plain radiographs is an elliptic fragment of bone parallel to the tibia, just distal to the lateral tibial plateau (Fig. 5c). Irregularity of the tibial donor site may be seen. The avulsed fragment is often small and may be appreciated only on the anteroposterior view. MRI demonstrates marrow edema along the lateral tibial rim and in some cases also shows the avulsed fragment (Fig. 5). MRI should be performed in all cases of Segond fracture because of the association of this injury with ACL and meniscal tears.
The reverse Segond fracture involves a fragment similar to that of the Segond fracture except that it is located on the opposite side of the knee, arising from the medial aspect of the proximal tibia. This elliptic fragment represents an avulsion of the deep capsular component of the medial collateral ligament. The mechanism of this injury is also the opposite of the Segond fracture, with external rotation and a valgus stress applied to the knee being the most probable etiology. The reverse Segond fracture appears radiographically as an elliptic bone fragment arising from the medial aspect of the proximal tibia and is associated with PCL and medial meniscus tears.

**Arcuate Complex Avulsion Fracture**

Injuries to the arcuate complex and posterolateral corner of the knee have been increasingly discussed in recent radiology literature. The arcuate complex provides posterolateral stabilization of the knee and consists of the lateral (fibular) collateral ligament, biceps femoris tendon, popliteus muscle and tendon, popliteal meniscal and popliteal fibular ligaments, oblique popliteal, arcuate, and fabellofibular ligaments and lateral gastrocnemius muscle. Recognition of this injury by radiologists is crucial because physical examination findings are usually subtle. The patient may experience only mild swelling and tenderness after the injury and frequently remains physically active. Furthermore, failure to recognize injuries to the posterolateral corner of the knee is a likely cause of failure after ACL and PCL reconstruction, as well as chronic knee instability. These findings reaffirm the need to diagnose avulsion fractures of the arcuate complex prospectively. On conventional radiographs the avulsed bone fragment has a characteristic appearance as an elliptic piece of bone arising from the fibular styloid process with its long axis oriented horizontally on the anteroposterior knee radiograph. MRI is useful to confirm the exact origin of the fracture fragment, either by direct visualization or by identification of marrow edema in the head of the fibula and adjacent soft-tissue swelling (Fig. 6). The mechanism of injury is related to trauma to the anteromedial tibia with the knee extended, varus force to the externally rotated tibia, or sudden hyperextension. Avulsion fractures of the arcuate complex and posterolateral corner of the knee are frequently associated with damage to many of the other stabilizing structures of the knee, such as cruciate ligaments, lateral capsular ligament, medial and lateral collateral ligaments, iliotibial band, popliteus muscle, and menisci.

**Biceps Femoris Tendon Avulsion Fracture**

The biceps femoris tendon consists of two heads and courses along the posterolateral aspect of the knee, just deep to the iliotibial tract. The long head inserts onto the posterolateral aspect of the fibular head, while the short head inserts just medially to the long head. This distal insertion frequently forms a conjoined tendon along with the insertion of the lateral collateral ligament. The conjoined tendon formed from the biceps femoris and lateral collateral ligament attaches to the lateral margin of the fibular head,
as opposed to the arcuate complex, which inserts on the fibular styloid process. Often, it is difficult to distinguish an avulsion fracture of the fibular head from that of the arcuate sign on conventional radiographs alone, although the arcuate sign tends to have a more characteristic appearance as an elliptic fragment with its axis oriented horizontally on anteroposterior views. Avulsion fracture of the biceps femoris tendon appears simply as an irregular bone fragment arising from the fibular head. MRI is useful to confirm the exact etiology of the avulsed fragment and in most cases clearly demonstrates avulsion of the insertion of the biceps femoris tendon. This type of avulsion injury is associated with disruption of the lateral collateral ligament, Segond fracture, and damage to the popliteal musculotendinous unit.

Pellegrini-Stieda disease

Ossification of the femoral epicondylar or proximal attachment of medial collateral ligament (MCL) is thought to be the result of chronic trauma and is referred to as Pellegrini-Stieda disease. Areas of ossification in Pellegrini-Stieda disease may demonstrate marrow fat signal intensity or may be hypointense if sclerotic. Calcification has low-signal-intensity on T1- and T2-W images (Fig. 7). Thickened ligamentous healing may be demonstrated at the same time calcification or periarticular ossification is detected. Ossification may affect the MCL, the adductor magnus tendon or both. Finally, it is important to notice that grade III MCL tears may also be associated with avulsed cortical fragments from the attachment site at the femoral epicondyle (Fig. 8).

Sinding-Larsen-Johansson Syndrome

A spectrum of entities are involved in injury to the inferior aspect of the patella and the proximal patellar tendon, including "jumper's knee," patellar sleeve avulsion, and Sinding-Larsen-Johansson syndrome. The patellar tendon is usually only a few centimeters long, arising from the inferior patella and inserting distally at the tibial tuberosity. Jumper's knee is a pain syndrome involving the proximal or distal insertion of the patellar tendon and resulting from chronic stress and inflammation, commonly seen in young athletes. Thickening of the patellar tendon is often identified without definite evidence of tear or avulsion. Patellar sleeve avulsion involves a cartilaginous injury to the lower pole of the patella. At conventional radiograph, a small bone fragment is usually identified arising from the inferior patella. Further evaluation with MRI is necessary to distinguish this entity from Sinding-Larsen-Johansson syndrome, which has a similar radiographic appearance and represents a pure osseous injury without the extensive cartilaginous involvement seen with patellar sleeve avulsion. The mechanism of injury in all three entities is similar and is believed to be due to forceful contraction of the quadriceps against resistance, particularly in adolescent male athletes. This injury tends to occur in isolation and has no known associations with damage to other major stabilizing structures of the knee. Further evaluation with MRI is useful in differentiating Sinding-
Larsen-Johansson syndrome from patellar sleeve avulsion, as only a bone avulsion at the proximal patellar insertion is identified in the former entity (Fig. 9), while the latter demonstrates extensive cartilaginous injury in addition to the osseous deformity (Fig. 10). Distinguishing between these entities is important with regard to patient treatment, as minimally displaced fractures such as those seen with Sinding-Larsen-Johansson syndrome are often managed conservatively and nonoperatively, whereas displaced patellar sleeve avulsion fractures are treated with open reduction and possible internal fixation as well as extensor mechanism reconstruction.

**Osgood-Schlatter Disease**

The exact etiology of this entity is controversial in radiology literature. Recent hypotheses have invoked the concept of an insult to the distal insertion of the patellar tendon at the anterior aspect of the tibial tubercle as the pathophysiologic mechanism of injury, focusing more on the soft-tissue aspect of the disease rather than the osseous component. Ultimately, Osgood-Schlatter disease is suspected to be a chronic avulsion injury related to repetitive microtrauma and traction on the tibial tubercle by the patellar tendon. This entity nearly always occurs in adolescent male athletes performing activities that require jumping and kicking. Although this disease is frequently bilateral in up to 50% of cases, it is not associated with damage to other stabilizing structures of the knee. Conventional radiographs may be entirely normal or reveal fragmentation anterior to the tibial tubercle, soft-tissue swelling, and obliteration of the inferior angle of the infrapatellar fat pad. While this disease is nearly always apparent clinically, additional findings at MRI can help confirm the diagnosis and include patellar tendon enlargement with increased signal intensity at its distal insertion on both T1- and T2-weighted images, a distended deep infrapatellar bursa, marrow edema within the proximal tibia adjacent to the tuberosity, and thickened cartilage anterior to the tibial tubercle (Fig. 11, 12). The wide variation in clinical management, ranging from immobilization to local steroid injection or rarely surgical management, reflects the continuing controversy about the exact etiology of this entity.

**Images for this section:**
Fig. 1: ACL avulsion fracture. MR images show a partially displaced or type II tibial eminence fracture with anterior osseous elevation and adjacent marrow edema (arrows). A fracture in lateral tibial condyle is also demonstrated (arrowheads). (a) Sagittal T1-W FSE image. (b) Sagittal T2-W image at the same level to (a). (c) Sagittal FS PD-W FSE image at the same level to (b). (d) Coronal T1-W FSE image FSE. (e) Coronal FS PD-W FSE image at the same level to (d). (f) Axial T1-W FSE image.
Fig. 2: PCL avulsion fracture. MR images show an avulsed bone fragment arising from the posterior tibial plateau with an intact PCL and adjacent marrow edema (arrows). (a) Sagittal T1-W FSE image. (b) Sagittal FS PD-W FSE image at the same level to (a). (c) Sagittal 3D FS SPGR image at the same level to (b). (d) Coronal T1-W FSE image FSE. (e) Coronal FS PD-W FSE image at the same level to (d). (f) Axial STIR image.
Fig. 3: Conjoined ACL and PCL avulsion fracture. MRI clearly demonstrates the fracture line that extends from anterior to posterior tibial plateau and the insertion point of ACL and PCL (arrows). (a) Sagittal T1-W FSE image. (b) Sagittal T2-W FSE image at the same level to (a). (c) Sagittal 3D FS SPGR image at the same level to (b). (d), (e), (f) Adjacent sagittal images to (a), (b) and (c) images respectively.
Fig. 4: Continued (g), (h), (i) Adjacent coronal FS PD-W FSE images. (j), (k), (l) Coronal T1-W FSE images at the same level to (g), (h) and (i) images respectively. A partial (grade II) MCL tear is also demonstrated (arrowheads).
**Fig. 5:** Segond fracture. (a) Coronal T1-W FSE image and (b) coronal FS PD-W FSE image at the same level to (a) show the nondisplaced avulsion fracture of the lateral tibial plateau (arrows) with marrow edema along the lateral tibial rim. (c) Anteroposterior radiograph of the left knee shows an elliptic bone fragment (arrow) arising from the lateral tibial plateau (the lateral capsular sign). (d) Sagittal T1-W FSE image depicts the nondisplaced avulsion fracture of the lateral tibial plateau (arrow). (e) Sagittal T1-W FSE image adjacent to (d) shows the associated ACL tear.
Fig. 6: LCL avulsion fracture. Avulsion of LCL from the styloid process of the fibular head. The ligament demonstrates a wavy contour and loss of ligamentous continuity. There is edema within the adjacent bone marrow (arrows). (a) Coronal T1-W FSE image. (b) Coronal FS PD-W FSE image at the same level to (a). (c) Sagittal T1-W FSE image. (d) Sagittal FS PD-W FSE image at the same level to (c).
Fig. 7: Pellegrini-Stieda low-signal intensity ossification of the proximal portion of the superficial MCL (arrows). (a) Coronal T1-W FSE image. (b) Coronal FS PD-W FSE image at the same level to (a). (c) Sagittal T1-W FSE image. (d) Sagittal FS PD-W FSE image at the same level to (c).
Fig. 8: Grade III MCL tear with avulsed bone fragments from the femoral epicondyle. The associated extracapsular hemorrhage is hyperintense (arrows). An acute ACL tear is also present (arrowheads). (a) Coronal T1-W FSE image. (b) Adjacent coronal T1-W FSE image to (a). (c) Sagittal T1-W FSE image. (d), (e) Coronal FS PD-W FSE images at the same level to (a) and (b) images respectively. (f) Axial STIR image.
Fig. 9: Sinding-Larsen-Johansson syndrome. Elongation of the inferior pole of the patella with reactive bone marrow edema (arrows). (a) Sagittal T1-W FSE image. (b) Sagittal PD-W FSE image at the same level to (a). (c) Axial PD-W FSE image. (d) Axial PD-W FSE image adjacent to (c).
Fig. 10: Patellar sleeve fracture (arrows). The transverse patellar fracture involves the inferior pole with fracture extension to the articular cartilage (arrowheads). Associated proximal patellar tendinosis with anterior to posterior tendon thickening is also noticed. (a) Sagittal T1-W FSE image. (b) Sagittal PD-W FSE image at the same level to (a). (c) Sagittal 3D FS SPGR image at the same level to (b). (d) Coronal T1-W FSE image. (e) Coronal FS PD-W FSE image at the same level to (d). (f) Axial T1-W FSE image.
**Fig. 11:** Chronic phase of Osgood-Schlatter disease with a marrow fat-containing fragment and minimal adjacent reactive soft tissue changes. Mild distal patellar tendon thickening can also be seen (arrows). (a) Sagittal T1-W FSE image. (b) Sagittal PD-W FSE image at the same level to (a). (c) Sagittal 3D DESS image at the same level to (b). (d) Axial STIR image.
Fig. 12: Osgood-Schlatter disease. Tibial osteochondrosis (apophysitis) is seen at the patellar tendon insertion on the tibial tubercle. Tibial tubercle fragmentation, deep infrapatellar bursitis and soft-tissue edema are present (arrows). (a) Sagittal T1-W FSE image. (b) Sagittal T1-W FSE image adjacent to (a). (c) Axial T1-W FSE image. (d), (e) Sagittal PD-W FSE images at the same level to (a) and (b) images respectively. (f) Axial PD-W FSE image at the same level to (c).
Conclusion

Although conventional radiography is typically the first imaging modality performed, MRI is the ideal noninvasive method to assess the extent and severity of avulsion fractures of the knee, which impacts therapy and influences prognosis.

Personal Information

References

the posterolateral ligaments and posterior cruciate ligament. AJR Am J Roentgenol 2003; 180:381-387.


