CMEArticle

Clinics in diagnostic imaging (141)

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Fig. 1 (a & b) Contiguous sagittal fat-suppressed PD-W MR images taken through the intercondylar area. (c) Coronal fat-suppressed PD-W image through the intercondylar area.

CASE PRESENTATION

A 38-year-old man presented with knee pain and swelling. He had sustained a lateral blow to the right lower leg while playing football approximately five months prior to presentation. At that time, he had felt a snap in his right knee and complained of knee swelling soon after. He had difficulty walking and was unable to climb up the stairs due to pain. Initial examination revealed pain over the medial collateral ligament, but Lachman's test and anterior drawer test were negative. He was conservatively managed and referred to an orthopaedic specialist. Physical examination in the clinic showed that the knee was not swollen; however, the anterior drawer, pivot shift and Lachman's tests were all positive. He subsequently underwent rehabilitation, but did not get better. Magnetic resonance (MR) imaging of the knee was performed. What do these images (Figs. 1a–c) show? What is the diagnosis?

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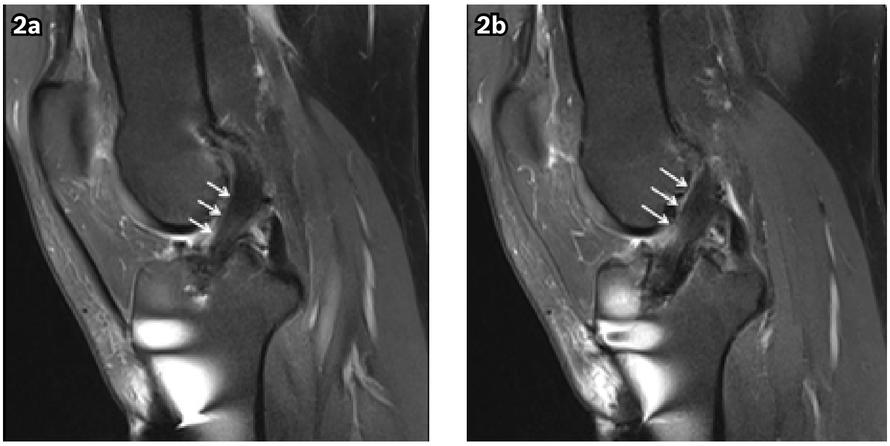

Fig. 2 Post-ACL graft reconstruction images. (a & b) Contiguous sagittal PD-W MR images show the normal position of the ACL graft (arrows). The reconstructed anterior cruciate ligament graft is intact.

IMAGE INTERPRETATION

MR images (Figs. 1a–c) show only the lower stump of the anterior cruciate ligament (ACL). The upper fibres are not visualised. A moderate-sized knee joint effusion is present. No bone contusion or oedema is seen. The articular surfaces are intact, as is the posterior cruciate ligament (PCL). There was a horizontal tear at the body of the lateral meniscus (not shown), as well as high signal at the anterior horn of the lateral meniscus, most likely corresponding to the fraying of the anterior horn seen intra-operatively. Both the medial and lateral collateral ligaments were normal (not shown).

DIAGNOSIS

Complete anterior cruciate ligament tear.

CLINICAL COURSE

The patient subsequently underwent surgery to repair his torn ACL. Intra-operatively, he was found to have a torn ACL, an intact PCL, frayed anterior horn of the lateral meniscus, a small tear at the body of the lateral meniscus and a small tear at the body of the medial meniscus. The torn ACL was repaired with a graft obtained from the semitendinosus muscle, and the menisci were debrided.

Six months post operation, the patient complained of a week's history of 'locking' and pain in his right knee. He mentioned that he had been walking when he first felt locking and pain over the medial aspect in his right knee. Since then, he had been experiencing a recurrence of on-and-off locking in his knee. He denied any symptoms of giving way/instability in his knee, and had no recent fall or trauma. Repeat MR imaging showed that the ACL graft was intact (Figs. 2a & b). There was also a new finding of a horizontal tear at the periphery of his medial meniscus. On follow-up examination, he was found to be clinically stable with no significant knee instability. Management plan for the patient included continuation of physiotherapy.

DISCUSSION

The ACL is a dense fibrous collagen band that measures approximately 3.5 cm long. The ACL arises from the postero-medial surface of the lateral femoral condyle, runs in an anterior, inferior and medial direction through the intercondylar notch of the knee, and inserts just anterior and lateral to the tibial spine. It comprises two bundles, named according to their sites of insertion on the tibia. The anteromedial bundle is taut in flexion, while the posterolateral bundle becomes taut when the knee is in extension.[1] At its tibial attachment, the ACL is broad and fan-like, and hence stronger at its tibial insertion than at its femoral insertion. Due to the site of attachment on the tibia, the ACL is closely related to the anterior horn of the medial meniscus; therefore, associated injuries to the medial meniscus can occur when the ACL is torn.

The ACL is intra-articular but extrasynovial. Blood supply to the ACL is primarily from the arteries supplying the surrounding synovial membrane, which arise from the branches of the middle geniculate artery piercing the posterior capsule. Additional blood supply to the ACL comes from the medial and lateral genicular arteries.[2] The central core of the ACL is relatively avascular, and this partly accounts for the generally ineffective healing of ACL tears. The nerve supply to the ACL comes from the terminal branches of the tibial nerve. The main function of the ACL is to limit anterior translation of the tibia as well as tibial rotation on the femur. It also serves to limit varus and valgus angulation as well as hyperextension of the knee.[3]

Injuries to the ACL can occur with or without direct contact to the knee. They can occur in any position, from being flexed to fully extended (e.g. lateral blow to a partially-flexed knee, hyperextension or varus hyperextension from an anterior blow). With more severe hyperextension, the knee can dislocate and the popliteal neurovascular bundle or peroneal nerve may also be injured. Non-contact mechanisms account for 70%–80% of ACL tears. Injuries most commonly occur from actions involving deceleration, twisting or jumping, i.e. the pivot-shift mechanism, whereby the slightly flexed knee incurs a valgus load with internal rotation of the tibia or external rotation of the femur. This twisting injury often occurs with rapid simultaneous deceleration and directional movements in skiers and football, basketball or

Fig. 3 Normal ACL in a 21-year-old man. (a & b) Contiguous fat-suppressed sagittal PD-W MR images show a normal ACL, which appears as a taut, well-defined hypointense solid band (white arrows). Note the fan-like appearance of the distal ACL (posterolateral bundle) as it inserts onto the tibia (white open arrow). (c) Axial fat-suppressed MR image shows the ACL appearing as an elliptical hypointense band adjacent to the lateral wall of the intercondylar notch (black open arrows). (d) Fat-suppressed coronal MR image shows the ACL appearing as a hypointense structure close to the medial aspect of the lateral femoral condyle (*). Note the anteromedial bundle (white solid arrow) and posterolateral bundle (black solid arrow).

soccer players. Other coexisting injuries are common, such as medial and lateral meniscal tears as well as medial collateral ligament injuries or lateral patellar subluxation.

MR imaging is useful for detection, diagnosis and management of ACL injuries, although conventional computed tomography (CT) or CT arthrography may also be performed with a sensitivity and specificity of 90% and 96%, respectively, at first interpretation.[4] MR imaging can help identify 90%–98% of ACL tears, and aids in confirming the diagnosis when strong clinical suspicion is raised through careful history-taking and physical examination. On sagittal images, due to the extended position of the knee, the normal ACL appears as a taut, well-defined hypointense solid band or as a striated band diverging slightly distally (Figs. 3a & b). It lies at an angle of approximately 55 degrees between the femur and articular surface of the lateral tibial plateau,[5] although mild sagging inferiorly may sometimes be seen. The ACL can also be demonstrated on both coronal and axial images. On axial images, the proximal ACL is seen as an elliptical hypointense band adjacent to the lateral wall of the upper intercondylar notch (Fig. 3c). Distally, it fans out as it reaches the tibial insertion, and may be difficult to assess. On coronal images, the normal ACL is identified as a hypointense structure in close apposition to the medial aspect of the lateral femoral condyle (Fig. 3d) on the posterior images that extends to the tibial plateau on the anterior images.[6]

In order to obtain images of good quality, a dedicated extremity coil should be used. The patient lies supine with his knee in a relaxed and externally rotated (5–10 degrees) position with the knee coil around his knee. This enables the ACL to lie orthogonal to the sagittal plane of imaging. An appropriate field of view should be used in order to maximise the resolution, with slice thickness not more than 0.4 mm so as to reduce partial volume artefacts. Sagittal, coronal and axial images of the knee are then obtained. T1-weighted images are obtained in at least one plane (usually coronal), with corresponding T2-weighted images for characterisation of lesion, detection of marrow abnormalities and evaluation of soft tissue masses. Proton density sequences are used for the evaluation of menisci. In addition, proton density sequences are also useful in defining the anatomy of the ACL. Due to its high signal-to-noise ratio, it is also sensitive to the detection of fluid. With fat suppression, the gray-scale range of soft tissue is narrowed, hence increasing the contrast. Other special sequences for imaging of the hyaline cartilage are often included in order to achieve a comprehensive study.

ACL tears may be classified into complete (Figs. 4 & 5) or partial tears. This can be further sub-classified into acute or chronic tears. On sagittal images, non-visualisation of the ACL is consistent with a complete tear of the ACL. An ACL tear may also be suspected when there is poor visualisation of the ACL, disruption of the substance of the ACL by abnormal focal or diffuse hyperintense signal, or abrupt angulation or a wavy appearance on sagittal MR images. Further confirmation of the

Fig. 4 Complete ACL tear (mid-portion) in a 45-year-old man. Contiguous fat-suppressed sagittal PD-W sequences show (a) a more horizontal orientation of the ACL (arrows); (b) complete disruption at the upper fibres of the ACL, consistent with a tear (arrowheads). The mid-portion of the ACL appears swollen, with heterogeneous hyperintense signal (black open arrows) and a more horizontal orientation (black arrows).

initial findings must then be performed with axial and coronal images. On axial images and coronal images, non-visualisation of the linear hypointense band representing the ACL and complete replacement by haemorrhage/fluid or displacement from the lateral wall of the intercondylar notch is in keeping with a complete tear. A partial tear (Fig. 6) is suspected when there is diffuse hyperintense signal in the otherwise intact ligament and the ACL appears partially replaced by haemorrhage on both axial and coronal images. Focal hyperintense signal in the fibres at the femoral origin of the ACL despite the presence of a few intact fibres next to the tibial plateau also raises the suspicion of an ACL tear.[6] Tears of the ACL occur most commonly at the middle substance of the ligament (90%) and less frequently at its femoral (7%) and tibial (3%) attachments.[7]

Once a tear has been diagnosed, it may be further classified into acute or chronic tears. One study reported that the presence of oedematous soft tissue, and not fluid in the intercondylar notch, was the characteristic feature of an acute ACL tear.[8] Oedematous regions are generally homogeneous and hypointense on proton density weighted images, and appear inhomogeneous and mildly hyperintense on T2-weighted images. In the same study,[8] chronic ACL tears were variable in appearance, appearing most commonly as variable-sized fragments without significant

Fig. 5 Complete ACL tear associated with a bucket handle tear of the medial meniscus in a 22-year-old man who presented with a twisting injury to the knee during football practice. He complained of locking and swelling in his knee and was unable to squat. On examination, he had pain at the medial aspect of his knee. (a) Fat-suppressed sagittal PD-W image of the left knee shows disruption of the ACL close to its femoral insertion (arrows), consistent with a complete tear. There is swelling of the torn ACL stump (open arrows). (b & c) The patient also had a bucket handle tear of the medial meniscus, where the torn fragment had flipped posteromedially to lie anterior to the PCL, resulting in a 'double PCL' sign. Notice the low signal band (solid black arrows) just anterior to the PCL (white arrows), which corresponds to a bucket handle tear of the medial meniscus.

oedema. The torn fragments most frequently scar to the lateral aspect of the PCL, which is relatively close to the femoral insertion of the ACL. At arthroscopy, scar tissue is most commonly seen within the intercondylar notch. Mature fibrous scar tissue has

Fig. 6 Partial ACL tear in a 24-year-old man with anterior knee pain after exercise. (a) Fat-suppressed sagittal PD-W MR image through the intercondylar notch shows heterogeneous hyperintense signal in the ACL, compatible with a partial tear (white arrows). (b & c) Contiguous fat-suppressed coronal PD-W MR image of the same patient shows increased signal in the intact lower fibres, compatible with a partial tear (black arrows).

Fig. 7 A 23-year-old man presented with knee pain and swelling after sustaining a twisting injury to the left knee while playing football. This did not improve with bed rest, analgesia and physiotherapy, and the patient subsequently complained of knee instability with positive Lachman's test on examination. (a & b) Contiguous fat-suppressed sagittal PD-W MR images show disruption of the ACL fibres with horizontal configuration (white solid arrows), in keeping with a tear. A moderate knee joint effusion is also present. (c) Fat-suppressed sagittal PD-W image shows 'kissing contusions', i.e. bone bruising (solid white arrows) at the lateral femoral condyle and posterior lateral tibial plateau as a result of the twisting injury. There is also anterior tibial translation (distance between the vertical tangent lines through the posterior margins of the lateral femoral condyle and tibia) with uncovering of the posterior horn of the lateral meniscus. A linear fluid collection (black arrows) is seen in the infrapatellar fat pad, compatible with shear injury.

the same imaging characteristics as a ligament, and hence, some chronic ACL tears may be misdiagnosed as intact ligament. In these cases, correlation with history and clinical examination may be helpful.

There is limited sensitivity in indirect signs of an ACL tear, but the absence of these signs does not exclude ACL disruption.[9] A useful sign to look out for is the change in orientation of the ACL (Figs. 7a & b). As mentioned earlier, the normal taut ACL lies at an angle of 55 degrees between the femur and the articular surface of the lateral tibial plateau. At this point, the ACL is parallel to the posterior surface of the femoral notch. A more horizontal lie of the ACL is suspicious for an ACL tear; in one study, the authors found that it had high sensitivity and specificity for an ACL tear.[5,10] Other signs to look out for are bone bruising and osteochondral fractures, which can indicate > 90% chance of an ACL injury. Kissing anterior femoral and tibial bone bruises (Fig. 7c), indicating a hyperextension injury, are found to be associated with ACL tears in about 50% of patients. Another sign is anterior translocation of the tibia (> 5 mm between the vertical tangent lines through the posterior margins of the lateral femoral condyle and tibia) (Fig. 7c). This sign is associated with uncovering of the posterior horn of the lateral meniscus (uncovered lateral meniscus sign) and is analogous with the anterior drawer sign elicited on clinical examination. Both chronic and acute ACL tears may demonstrate the anterior tibial translocation sign.[10]

The presence of a linear collection of fluid within the substance of the infrapatellar fat pad,[11] which occurs with a shear injury to the knee (Fig. 7c), is another sign that indirectly suggests an ACL injury. Other subtle signs include fractures of the tibial spine and buckling of the PCL. On plain radiographs, these subtle signs include the presence of a Segond fracture (lateral capsular avulsion fracture) and lateral notch fracture (located in the lateral femoral condyle). This is more commonly seen in chronic ACL tears due to anterior subluxation of the lateral tibial plateau. The lateral notch fracture is caused by an impacted fracture and

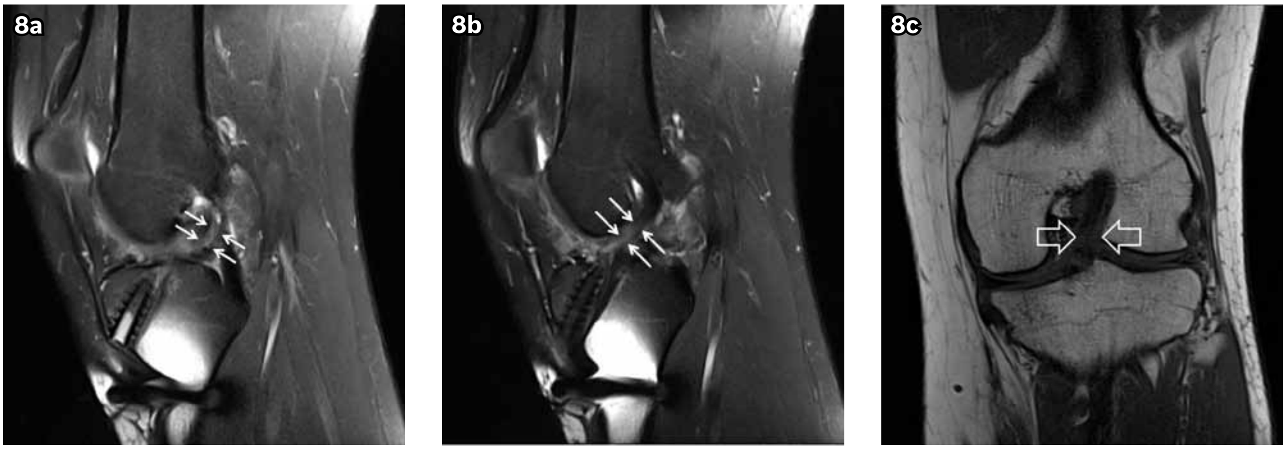

Fig. 8 (a & b) Follow-up fat-suppressed sagittal PD-W MR images of the patient in Fig. 5 taken 18 months post-ACL reconstruction. The mid-portion of the reconstructed ACL graft is slightly angulated with hyperintense signal, in keeping with a partial tear (white arrows). (c) Corresponding coronal T1-W MR image shows a discontinuity of the normal hypointense signal in the mid-portion of the ACL graft, in keeping with a tear (open white arrows).

Fig. 9 'Cyclops' lesion in a 24-year-old man with previous ACL reconstruction. Fat-suppressed PD-W image shows a 'cyclops' lesion in the anterior compartment of the knee (arrows).

results in the 'lateral femoral notch' sign. This fracture occurs when the tibia is displaced anteriorly and the lateral femoral sulcus pushes against the posterior rim tibial plateau. Although ACL injuries may occur in isolation, there are often other associated injuries that are readily detected on MR imaging, such as meniscal injuries (Figs. 5b & c) and other ligamentous injuries.

The goals of treatment of ACL tears are to stabilise the knee, return it to normal or almost normal functioning and to reduce the likelihood of further damage to the knee. Treatment options are either surgical (ACL reconstruction) or non-surgical (physiotherapy), depending on the patient's lifestyle. The most commonly used methods for ACL graft reconstruction are bone-patellar tendon-bone and hamstring autografts. Hamstring autografts are often made from the semitendinosus tendon, the gracilis tendon or both. The positioning of the femoral and tibial tunnels is of utmost importance for the function of the ACL graft. On coronal images, the femoral tunnel should open superiorly above the lateral femoral condyle at the 10–11 o'clock position in the right knee and the 1–2 o'clock position in the left knee. On sagittal images, the tibial tunnel should be oriented parallel to the projected slope of the intercondylar roof (Blumensaat's line), with the opening of the proximal tibial tunnel posterior to the intersection of the Blumensaat's line and tibia. The tibial tunnel should open at the intercondylar eminence on coronal images.[12]

MR imaging plays an important role in detecting post-ACL graft complications. Common complications include partial and complete graft tears, arthrofibrosis and less commonly, tunnel cysts, iliotibial band friction syndrome, infection and hardware loosening. Partial graft tears appear as focal areas of high signal within a portion of the graft with intact fibres still present on T2-weighted images (Fig. 8). Similar to a torn ACL, the absence of intact graft fibres and a fluid-filled defect on T2-weighted images, or horizontal graft orientation or laxity and resorption of graft fibres is suspicious for a complete ACL graft tear. Other features confirming a tear include the presence of a large knee joint effusion and bone bruising in a pivot-shift pattern.[13]

Arthrofibrosis is the presence of scar tissue in at least one compartment of the knee joint, leading to reduced range of motion. Localised anterior arthrofibrosis, or 'cyclops' lesion, is a nodular fibrous lesion (Fig. 9) that is located in the anterior intercondylar notch. It has been reported to occur in 1%–10% of patients with ACL reconstruction.[14-16] Cyclops lesions are typically small, measuring between 10–15 mm, usually in the anterior intercondylar notch. However, it may become caught between the femur and tibia during knee extension, resulting in a reduction in range of motion. MR imaging findings show an anterior intercondylar nodule with mixed signal intensity on T1-weighted, T2-weighted and proton-density-weighted fast spin-echo images. The lesion extends in a linear fashion along the intercondylar roof.

CONCLUSION

ACL injuries are relatively common, occurring mostly where there is a twisting knee injury. These injuries are frequently suspected with careful history-taking and examination. MR imaging is useful for identifying and confirming these injuries as well as other associated injuries such as bone bruising, osteochondral fractures and meniscal tears.

ABSTRACT A 38-year-old man presented with right knee pain and swelling following a football injury. Magnetic resonance (MR) imaging showed a complete anterior cruciate ligament (ACL) tear and lateral meniscal tears. The torn ACL was repaired with a graft obtained from the semitendinosus muscle, and the menisci were debrided. The mechanisms of injury to the ACL are varied and may be due to direct or indirect contact with the knee as well as with twisting injuries. Knowledge of the ACL's normal anatomy, together with MR imaging technique and understanding of the appearance of the lesion on MR examination, is crucial to aid in the identification of an ACL tear. Diagnosis of an ACL tear should be based on direct MR imaging signs, although indirect signs may be helpful, particularly in chronic tears. Other associated injuries to be aware of include meniscal and other ligamentous injuries. Normal ACL graft and post-ACL graft reconstruction complications are also briefly discussed.

Keywords: ACL graft, ACL injury, anterior cruciate ligament, anterior cruciate ligament tear
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SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME

(Code SMJ 201209B)

True False

Question 1. Concerning the anatomy of the anterior cruciate ligament (ACL):
(a) The ACL is a dense fibrous collagen band. ☐ ☐
(b) The ACL arises from the posteromedial surface of the lateral femoral condyle. ☐ ☐
(c) The ACL comprises the anterolateral bundle and posteromedial bundle. ☐ ☐
(d) The ACL is stronger at its tibial insertion than femoral insertion. ☐ ☐

Question 2. Normal MR imaging appearances of the ACL:
(a) On sagittal images, the normal ACL appears as a taut, well-defined hypointense solid band or as a striated band diverging slightly distally. ☐ ☐
(b) It lies at an angle of approximately 35 degrees between the femur and articular surface of the lateral tibial plateau. ☐ ☐
(c) The ACL cannot be seen on axial images. ☐ ☐
(d) On coronal images, the normal ACL is identified as a hypointense structure in close apposition to the medial aspect of the lateral femoral condyle. ☐ ☐

Question 3. Concerning tears of the ACL:
(a) An ACL tear should be suspected when there is poor or non-visualisation of the ACL, disruption of the substance of the ACL by abnormal focal or diffuse hyperintense signal or abrupt angulation or a wavy appearance on sagittal magnetic resonance (MR) images. ☐ ☐
(b) Non-visualisation of the linear hypointense band representing the ACL and complete replacement by haemorrhage or fluid or displacement from the lateral wall of the intercondylar notch is in keeping with a complete tear. ☐ ☐
(c) Tears of the ACL occur most commonly at the femoral attachment. ☐ ☐
(d) ACL tears may be classified into acute or chronic tears. ☐ ☐

Question 4. With regard to indirect signs of and associated injuries with ACL tears:
(a) Bone bruising and osteochondral fractures indicate a > 90% chance of an ACL injury. ☐ ☐
(b) A more horizontal lie of the ACL is suspicious for an ACL tear. ☐ ☐
(c) Anterior translocation of the tibia is analogous with the anterior drawer sign elicited on clinical examination. ☐ ☐
(d) A linear collection of fluid within the substance of the infrapatellar fat pad occurs with a shear injury to the knee. ☐ ☐

Question 5. Concerning treatment of ACL tears and its complications:
(a) Goals of treatment are to stabilse the knee and return the knee to normal or almost normal function with reduction in likelihood of further damage to the knee. ☐ ☐
(b) The most commonly used methods for ACL graft reconstruction are bone-patellar tendon-bone and hamstring autografts. ☐ ☐
(c) Common complications include partial and complete graft tear and arthrofibrosis. ☐ ☐
(d) A 'cyclops' lesion is a nodular fibrous lesion that is located in the posterior intercondylar notch. ☐ ☐

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