MR imaging of the reconstructed anterior cruciate ligament

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Authors: I. Y. Y. Tsou; Singapore/SG
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Purpose

To review

1. the normal appearance of the reconstructed anterior cruciate ligament (ACL) in the knee with magnetic resonance (MR) imaging.

2. the possible complications after ACL reconstruction.
Methods and Materials

One of the most important stabilizers of the knee joint is the anterior cruciate ligament (ACL). It is frequently damaged in sports injuries, resulting in an increased risk of knee instability, which can lead to limitation of athletic activities, chronic pain and premature osteoarthritis, particularly in the setting of meniscal deficiency.

Reconstructive surgery for the ACL is being performed more often, as it allows patients to return to their pre-injury level of activity, as well as to prevent complications related to instability. Re-injury to the reconstructed ligament may occur, and although the gross integrity of the reconstructed ligaments can be assessed clinically, the presenting symptoms may be non-specific.

Imaging may be needed to assess the integrity of the graft, and magnetic resonance (MR) imaging serves as a useful adjunct in evaluation of potential complications.

NORMAL ACL ANATOMY AND FUNCTION

Ligament reconstruction attempts to replicate the course of the native ligament as far as possible, to regain stability of the knee joint.

The ACL arises from the medial aspect of the lateral femoral condyle, and runs inferiorly, medially and anteriorly. The ligament also fans out at the distal aspect before its insertion in the midline of the tibia, which aids to prevent acute angulation and impingement at terminal extension of the knee. As such, its acts as the principal restraint to anterior tibial translation with respect to the femur.

Secondary functions of the ACL include as a major restraint to internal rotation, and minor restraint to external rotation and varus-valgus angulation.

The ACL is enclosed by the synovial membrane, which places it in an intra-articular but extra-synovial position. It is narrowest at the femoral origin and spreads out as it approaches the tibial insertion.

The ACL can be divided into 2 parts, the anteromedial band (AMB) and posteromedial band (PMB), with the anteromedial band being the smaller of the two. The length and orientation of the bands change as the knee position changes from flexion to extension.

In flexion, the AMB is taut and the PLB is relatively lax, while in extension, the PLB tightens, and the AMB is also tight, but not as tight as the PLB.
As a result of the relationship between the two bands, the ACL when taken as a whole is not an isometric ligament. With passive flexion from 0 to 90 degrees, the length of the AMB increased while the length of the PLB decreased. Because of this, true isometric placement of the ACL graft is an ideal which cannot be achieved. The attachment sites are then selected so as to minimize the change in tibiofemoral distance with knee flexion.

Like other ligaments, the ACL is considered to be viscoelastic. Compared to elastic materials, which demonstrate the same stress-strain (load vs elongation) graph during loading and unloading, the ACL has both time and history-dependent properties.

Time-dependence is shown both in creep, which is the progressive elongation over time, and stress-relaxation, where the amount of stress measured in a ligament decreases over time.

**NORMAL ACL RECONSTRUCTION GRAFT ASSESSMENT**

Initial imaging assessment of the reconstructed ACL is usually with plain radiographs, often obtained in the immediate post-operative period as a evaluation for position of the fixation devices and femoral and tibial tunnels. The outline of the femoral and tibial tunnels can also be visualized, with the ideal position of the femoral tunnel opening being posterosuperior the native ACL origin, and the tibial tunnel in the posterior one-third of the native ACL insertion.

MR imaging is better suited to evaluation of the graft due to its superior soft tissue contrast resolution, which is able to image the graft directly and its relationship with the fixation devices and bony tunnels. The multiplanar capability of MR imaging also allows visualization of any normal anatomy or pathology in three or more planes, increasing diagnostic confidence.

The appearance of the graft depends both on the type of graft used, as well as the time interval since the surgery. There is hypertrophy of the synovial tissue around the graft in the first 1 to 3 months, where the graft is converted into tissue similar to the native ACL.

At this stage, there is increased signal intensity within the ACL graft due to revascularization and increased mobility of water, however, the signal is not as high as fluid on T2-weighted sequences. The duration of the increased signal intensity within the graft is variable, ranging up to slightly more than 1 year.

The signal properties may also be affected by the mode of fixation, with an inflammatory response secondary to screws composed of bioabsorbable polymers causing a regional synovitis and variable signal hyperintensity in the graft, at time simulating infection.
If careful attention is not paid to MR sequences, the fixation devices may not be well demonstrated, due to magnetic susceptibility artifacts. However, persistent fluid around the interference screws or bone plugs may indicate loosening or the lack of incorporation, respectively.

The position of the femoral and tibial tunnels is crucial to normal function of the ACL. The opening of the femoral tunnel should lie at the junction of the posterior femoral cortex and Blummensaat's line, with the position as posterior as possible, without blow-out of the posterior wall. The orientation of the femoral tunnel should lie at the 10 to 11 o’clock position when viewed in the coronal plane for the right knee, and between the 1 to 2 o’clock position for the left knee.

The opening of the tibial tunnel should lie in the posterior third of the native ACL footprint on the proximal tibial surface, at the tibial eminence. This corresponds to the junction of the posterior edge of the anterior horn of the lateral meniscus with the ACL stump, which is approximately 7 mm anterior to the posterior cruciate ligament. The diameter of the tunnels ranges from 7 to 10 mm, depending on the size of the graft used.
Fig. 1: AP radiograph showing femoral endobutton and radiolucent tibial interference screw utilised in ACL reconstruction.

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Fig. 2: Lateral radiograph showing orientation and width of femoral and tibial tunnels created during ACL reconstruction.

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Fig. 3: Coronal proton-density MR image with red dashed line showing oblique sagittal plane to obtain full-length view of reconstructed ACL graft.

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Fig. 4: Oblique sagittal proton-density image showing complete length of ACL graft in 1 image, extending between the femoral and tibial tunnels.

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**Fig. 5:** Sagittal T2 frequency-selective fat-suppressed image showing areas of failure of fat-suppression around femoral and tibial interference screws (red arrows).

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Results

INDICATIONS FOR MR IMAGING AFTER ACL RECONSTRUCTION

The indications for MR imaging after ACL reconstruction would include:

1. persistent instability after surgery: to evaluate tunnel placement and integrity of the graft.

2. re-injury: to assess graft integrity and other meniscal and chondral injuries.

3. limitation in range of motion with extension loss: to assess impingement or arthrofibrosis.

4. revision of failed ACL reconstruction: to evaluate tunnel size, tunnel placement, meniscal and chondral injuries.

COMPLICATIONS AFTER ACL RECONSTRUCTION

GRAFT FAILURE

Rupture of the graft has occurred when there are no intact fibres demonstrable, it usually presents clinically with knee instability. The graft may be partially or completely torn, and it may not always be possible to distinguish the two, given the variability in signal intensity within the graft at different ages. However, a complete tear is considered to have occurred when there is complete discontinuity of low signal intensity fibres, while the presence of some intact fibres adjacent to areas of fluid signal intensity indicates a partial tear.

Unlike the native ACL, a horizontal graft orientation does not necessarily indicate a tear, as the orientation is dependent also on the position of the femoral and tibial tunnels. In some instances, the fixation screw can become loose or dislodged, and although the graft itself is intact, one end is not fixed and functionally the graft has failed.

Laxity or bowing of the graft may also be due to a prior partial tear which elongates without rupture, and similarly, the graft is functionally incompetent. Centralization of the graft in the coronal plane (femoral origin at 12:00) or vertical orientation in the sagittal plane leads to a vertical strut that allows for the pivot shift to occur in the absence of significant tibial translation.
The most common cause for ACLR failure is poor tunnel placement, with overlooked associate instabilities (posterolateral, medial) acting as a strong secondary cause of functional graft failure. Carefully scrutiny of the posterolateral corner structures is vital in the full assessment of the reconstructed ligament.

**FIXATION FAILURE**

The fixation screw can become loose or dislodged, and although the graft itself is intact, one end is not fixed and functionally the graft has failed. The fixation screw or pin can also protrude and impinge on adjacent structures, and it can also break or fracture. This would result in lack of fixation at one end of the graft, resulting in abnormal movement of the graft and laxity.

**GRAFT IMPINGMENT**

Impingement is related to abnormal position of the graft, and presents with pain and lack of terminal extension. This is most often due to abnormal tunnel placement, but can also occur due to failure to fully debride the native ACL remnant. This is known as the "cyclops lesion", with a focus of intermediate signal intensity scar against the anterior synovial reflection. It has a defined margin, and due to its location, causes terminal block to knee extension when compressed between the femur and tibia. It has intermediate to low signal intensity on both proton density and T2-weighted sequences.

When the opening of the tibial tunnel is partly or completely anterior to the inferior projection of Blumensaat's line (roof of the intercondylar notch) on the sagittal MR images, there is high likelihood that the graft will impinge on the inferior end of the intercondylar notch in full extension of the knee. The positions of both the femoral and tibial tunnel openings are important to reduce the risk of impingement, but an anterior femoral tunnel position predisposes to a more vertical orientation, allowing abnormal rotation in the knee.

The cyclops lesion needs to be differentiated from the normal degree of scarring at the arthroscopic portals, which are typically located in the far lateral and medial infrapatellar regions, and are small linear or stellate areas of fibrosis, without an associated mass.

Widening of the opening of the tibial tunnel can occur due to the 'windshield-wiper' effect, which is related to graft-tunnel interface micromotion, graft fixation and improper graft placement. This allows excess motion of the graft within the tunnel, which can also lead to impingement. This is seen as increased fluid tracking into the tibial tunnel, around the graft. Significant tunnel widening planned for revision may require a staged procedure, with bone grafting of the tunnel before delayed ligament reconstruction.

Impingement on the side of the superior aspect of the graft can also occur due to the medial aspect of the lateral femoral condyle, which can be seen on coronal or axial MR
images as indentation or kinking of the graft. Notchplasty attempts to reduce this by removing bone or bony outgrowth from the intercondylar roof, if the notch is too narrow or if the tunnel position predisposes to impingement.

**FIBROSIS**

Post-operative fibrosis occurs due to an increased inflammatory, cytokine-mediated cellular response around the ACL graft, with resulting fibrous tissue depositing in a diffuse fashion within the knee joint. Diffuse arthrofibrosis extends from the ACL graft anteriorly to the infrapatellar fat pad, and posteriorly to the posterior capsule. In extensive cases, the fibrosis can spread further to the suprapatellar pouch as well as the parapatellar recesses laterally and medially.

Arthrofibrosis is seen as areas of diffuse low signal intensity on proton density and T2-weighted sequences, without a definite margin.

**GANGLION FORMATION**

An intra-substance ganglion with the ACL graft forms as a result of either cystic degeneration or a partial tear of the graft, both of which allow fluid to accumulate within the graft itself.

The ganglion is seen as of fluid signal intensity with intact graft fibres around it. They are not primarily associated with graft failure, but can cause pain and limitation of range of motion, if large. The use of endobutton fixation and hamstring autografts have been reported to predispose to ganglion formation.

**INFECTION**

The classic symptoms of septic arthritis such as erythema, warmth, severe restriction of motion and pain may not be a consistent feature in post-ACL reconstruction infection. The infection rate as reported range from 0.14% to 0.48%. The most common causative organism is Staphylococcus aureus. Cartilage damage is of concern in these patients.
Fig. 6: Sagittal proton-density image in a 18 year-old male track-and-field athlete. Had hamstring graft ACL reconstruction 10 months ago, and felt instability for past 1 month. Red arrow indicates complete tear of the ACL graft with no intact fibres.

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**Fig. 7:** Sequential sagittal proton-density images with long-standing instability post-ACL reconstruction. No remnant graft fibres are visualised, most likely due to resorption after complete tear.

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Fig. 8: Sagittal proton-density MR image of the left knee in a 34 year-old female who had ACL reconstruction 3 months ago. She sustained recent hyperextension injury, and red arrow indicates a partial re-tear of the inferior aspect of the left ACL graft. Some fibres are still seen in continuity.

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Fig. 9: Sagittal proton-density image showing posterior position of tibial tunnel (red arrow indicates expected position), and coronal proton-density image shows abnormal vertical orientation of ACL graft (solid yellow line) instead of expected oblique orientation (dashed yellow line).

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**Fig. 10:** Coronal proton-density image shows inferior position of femoral tunnel opening (yellow arrow indicated expected position), and sagittal proton-density images shows abnormal horizontal orientation of ACL graft (red line indicated expect position, in line with tibial tunnel).

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Fig. 11: AP and lateral radiographs showing femoral endobutton and tibial fixation screw for ACL reconstruction. Vertically-orientated interference screw (orange arrow) lies at posterior femoral cortex.

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Fig. 12: Sagittal and coronal MR images of same patient as Figure 11 shows interference screw (red arrows) to lie outside of femoral cortex, after being deployed incorrectly.

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**Fig. 13:** Axial proton-density MR images of the same patient shows fracture of the femoral cross-pin at 2 points in Aug 2009 (orange arrows), which shows further displacement in Feb 2011 (pink arrows).

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![Axial proton-density MR image showing fracture of the femoral cross-pin.](image)

**Fig. 14:** Axial proton-density image shows protrusion of the femoral cross-pin out of the medial femoral cortex (pink arrow), with resulting bursal fluid and synovitis (yellow arrows).

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**Fig. 15**: Sagittal proton-density image after ACL reconstruction shows irregular area of scarring (yellow circle) forming a cyclops lesion, which prevents terminal extension of the knee.

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Fig. 16: Sagittal proton-density image of a 20 year-old male, 4 months post-ACL reconstruction. Had episode of repeat trauma with twisting injury to the knee. MR images demonstrate a partial tear at the mid-portion of the graft and probable impingement at the posterior aspect of the graft by posterior margin of tibial tunnel opening (yellow arrow).

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Fig. 17: Sagittal proton-density image shows abnormal widening of the tibial tunnel (red arrow) due to excessive motion of the graft within the tibial tunnel (windshield-wiper effect).

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Fig. 18: Sagittal proton-density image showing ganglion formation in the anterior aspect of the tibial tunnel (yellow arrow), causing widening of the tibial tunnel.

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Fig. 19: Sagittal T1 post-contrast and proton-density images 6 months after ACL reconstruction demonstrate abnormal enhancement from infection in the distal femur, and breach of the posterior cortex (green arrow), and soft tissue abscess formation (red arrows).

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Conclusion

ACL reconstruction is an established procedure in orthopaedic surgery, and is being more frequently performed in view of increasing demands from both the professional and non-professional athlete.

In the small proportion of patients who have persistent symptoms of instability, pain, loss of range of motion, and those who have a repeat injury, MR imaging allows differentiation of an intact graft from a ruptured graft.

Knowledge of the normal appearance of the ACL graft, as well as potential complications of ACL reconstructive surgery, such as impingement, fibrosis and ganglion formation, is essential for accurate interpretation.
References


