ACL Repair and Reconstruction: Keeping up to date with the role of MRI.

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Learning objectives

1. Review normal MRI features of the different types of ACL repair and reconstruction.
2. Review the current literature on tunnel positioning.
3. Review the MRI features of ACL and related complications.
4. Review the MRI features that would indicate risk of graft failure, contralateral injury and early onset osteoarthritis.
Background

Anterior Cruciate ligament injury is one of the commonest ligamentous injuries requiring surgery. ACL reconstruction is the Gold Standard but new techniques are being developed and there is increasing renewed interest in primary repair on selected patients as well as reconstruction in the skeletally immature.

Although X-ray and CT are useful postsurgical baseline imaging tools, MRI represents a complete postoperative imaging tool because of its ability to non-invasively identify and differentiate normal postoperative features, assess tunnel placement and graft maturation and incorporation, recognise graft failure and complications of surgery, identify missed injuries and other indirect non-ACL problems like osteoarthritis, meniscal tears and loose bodies as well as identify risk factors which could indicate increase risk of graft failure and contraletal ACL rupture all of which would impact on outcome and therefore treatment.
1. SURGICAL TECHNIQUES AND GRAFT TYPES

A. Primary Repair

ACL reconstruction remains the gold standard but there is recent renewed interest in primary arthroscopic repair in selected patients where the tear is proximal and >75% of the distal tendon is intact and of good quality. Surgical techniques include:

- arthroscopic suturing
- transosseous pullout
- suture anchor +/- internal augmentation

In arthroscopic suturing the only finding may be linear and/or heterogeneous signal within the graft (Fig. 1 on page 12) which can persist for over a year.

In the transosseous pullout technique small drill holes are made through the lateral femur into the ACL footprint through which the ACL is sutured. The sutures are then fixated with an endobutton (Fig. 2 on page 12).

With the suture anchor technique, suture anchors fixate the proximal ACL bundles at the footprint (Fig. 3 on page 13) and in patients with increased risk of reinjury internal bracing is performed via a small tibial tunnel (Fig. 4 on page 14).

B. Reconstruction

Autografts:

Bone-Patellar Tendon-Bone (BPTB) Autografts consist of the mid patellar tendon with tibial and patellar bone plugs on either end. The donor site can be identified on MRI as a linear defect in the patellar tendon (Fig. 5 on page 15) for up to 2 years and the graft itself appears thick and homogenously hypointense (Fig. 6 on page 16).

Hamstring autografts are usually harvested from the semitendinosus and gracilis tendons and then folded into a single graft with a tibial bone plug on either end. These have a thinner appearance with linear striations on MRI (Fig. 7 on page 17). The donor sites
initially appear as empty sacs but usually regenerate and appear normal within 1 to 3 years.

**Allografts:**

These can be harvested from cadavers or relatives and harvest sites include BPTB, hamstring, achilles, quadriceps, anterior/posterior tibialis tendons and the peroneus longus tendon. They have longer 'ligamentisation' times and are therefore reserved for revision ACL reconstructions and multi-ligament injuries where there is no other autograft source.

**Single Bundle vs. Double Bundle Techniques:**

The native ACL has two bundles (AnteroMedial and PosteroLateral). Both act as restraints to anterior translation but the posterolateral bundle plays a larger role in rotational stability. Older single bundle techniques aimed to reconstruct the AM bundle but then double bundle techniques were developed to more closely reproduce normal knee kinematics. This was met with limited success and with increased complications owing largely to the drilling of extra tunnels. Newer single bundle techniques aim to place the graft isometrically between the AM and PL bundles.

**C. Reconstruction in the skeletally immature patient**

Surgical repair of the ACL in paediatric patients introduces the risk of injury to the open physis with subsequent growth arrest and therefore newer techniques have had to be developed. Although somewhat controversial, the patients predicted future growth potential rather than the chronological age determines the choice of technique.

Physeal Sparing options include:

- 'Combined intra and extra-articular technique' (Fig. 8 on page 19).
- 'Transepiphyseal technique' (Fig. 9 on page 20).
- 'All Epiphyseal Technique' (Fig. 10 on page 21).

The 'Transphyseal Technique' is used in those nearing skeletal maturity and involves similar tunnel placement to adults but only the graft crosses the physis and the hardware stays on the metaphyseal side (Fig. 11 on page 18).

**D. Other**
**Synthetic Grafts:** These were popularised and promptly abandoned in the 1980s owing to excessive complications but has shown a recent resurgence following newer synthetics and improved patient selection. Research is ongoing.

**Biological Options:** ACL reconstruction can be combined with biological adjuncts eg. Growth Factors, PRP, collagen composites and stem cells. Delivery is challenging and results have been mixed. Research is ongoing.

## 2. POSITION & ORIENTATION OF TUNNELS AND FIXATION DEVICES

The main goal of ACL reconstruction is to achieve graft isometry which is largely determined by tunnel positioning and orientation.

**A: Femoral tunnel**

In the *coronal plane* the tunnel should lie in the 10-11 o’clock (right) or 1-2 o’clock (left) positions (Fig. 12 on page 23).

In the *sagittal plane* the femoral tunnel should open on the lateral wall of the intercondylar notch at the point where the posterior femoral cortex intersects Blumensaats line (Fig. 13 on page 22).

More recently the quadrant method is thought to more closely replicate the native ACL insertion in the sagittal plane. A box with 16 equirectangular quadrants is drawn bordering Blumensaats line and the anterior, inferior and posterior margins of the femoral condyles. The optimal site of the tunnel entrance is at the antero-inferior corner of the supero-posterior quadrant (Fig. 14 on page 23).

**B: Tibial Tunnel**

On sagittal MRI the anterior margin of the tunnel should lie posterior to Blumensaats line. The Staubli and Rauschning surgical technique uses a point 43% along the Amis and Jakob line as the centre point of the tunnel (Fig. 15 on page 24).

On coronal MRI the tibial tunnel should be orientated 65 to 70 degrees to the horizontal and open at the intercondylar eminence.
A note on the skeletally immature: The goal of ACL isometry remains and therefore tunnel positioning is the same as for the adult. An exception is the 'transepiphyseal approach' where the femoral tunnel is more horizontal.

C. Intra-articular orientation of the Graft

In the coronal plane the graft should be less than 75 degrees to the horizontal.

In the sagittal plane the graft should lie parallel or steeper than Blumensaats line and within 50-60 degrees range from the horizontal.

D: Screw Divergence

This is the angle that is formed between the graft and the fixation device. It has been generally accepted that the closer to 0 degrees the better and that decreased pullout strength starts at 15 degrees with an absolute upper limit of 30 degrees. Interestingly, Laux et al. found that sagittal graft-tunnel divergence of 8.5 degrees had the best clinical outcomes albeit in a relatively small cohort of 31 patients.

3. MRI ASSESSMENT OF GRAFT: NORMAL VS. COMPLICATIONS

A. Normal Graft Changes:

Following primary repair the normal MRI findings include linear and/or heterogeneous signal within the ACL (Fig. 1 on page 12) which probably represents a combination of suture material, postoperative oedema and abnormal ligamentous architecture. This can persist for over a year. Unlike reconstruction grafts, the sutured ligament does not undergo ligamentisation and therefore any new signal should be considered suspicious for a tear.

For the first 4 to 8 months following reconstruction the graft demonstrates homogenous low T1 and PD signal. Following this the process of ligamentisation causes increased signal on all sequences. This slowly decreases and normalises with time and usually matures to normal between 2 to 4 years. (Fig. 16 on page 25).

Exceptions: Multi-bundle hamstring grafts can have increased linear interbundle T2 signal in the first 4 to 8 months (Fig. 7 on page 17). Ligamentisation can be more heterogeneous and prolonged in allografts compared to autografts.
B. Graft Failure: Laxity vs. Impingement

1a. Laxity due to Graft Tearing:

Daniels et al. found that retears following primary repair occurred in the mid substance or proximal third below the level of the repair.

There is increased risk of tear in the first 8 months following reconstruction and can occur anywhere along the graft, including the tunnel.

Primary and secondary signs (Fig. 17 on page 26) are as for native ACL tears. Using arthroscopic correlation, Horton et al. found that secondary signs have poor sensitivity for detecting graft tears.

1b. Laxity due to Graft Stretching or fixation failure:

Risks:

- A femoral tunnel that is too far anterior on the sagittal plane.
- Femoral/Tibial Tunnels that are too vertical in the coronal plane.
- Screw divergence > 30 degrees.
- Hamstring Grafts.

Signs: Posterior bowing, femoral tunnel AP widening.

2. Decreased Range of Motion (Impingement)

2a. Post ACL reconstruction impingement syndromes have been well described as follows:

- **Roof impingement**: Tibial tunnel is too anterior - graft is posteriorly bowed against the intercondylar roof.
- **Lateral sidewall impingement**: Tibial tunnel is too lateral - graft impinges against the lateral sidewall.
- **PCL impingement**: Tibial tunnel is too medial and/or vertical - graft impinges against the PCL.

A less common cause of impingement is a tunnel osteophyte (Fig. 18 on page 27).
2b. Arthrofibrosis

Arthrofibrosis is fibrocartilaginous tissue that forms in relation to the graft. It is common and often asymptomatic but when it cause loss of terminal knee extension (ie. cyclops syndrome) they require debridement.

The more common focal variant forms anteriorly to the graft in the intercondylar notch and is termed a cyclops lesion at arthroscopy (Fig. 19 on page 29). It may or may not have a central ossification.

A far less common diffuse form may encase the entire ACL graft (Fig. 20 on page 28).

2c. Ganglion Cysts

These may be inter-bundle or adjacent to the graft and may be isolated or related to mucoid degeneration of the graft. Mucoid degeneration does not effect graft integrity but large cysts may cause impingement depending on their location.

2d. Loose Intra-articular Bodies

Loose bodies may be from the initial injury or from surgery and may consist of cartilage, cortical bone and/or cancellous bone. This can be confused with multiple small accumulated surgical bone shavings which often accumulate posteriorly and are of doubtful clinical significance.

4. MRI assessment of hardware/fixation device failure

This is most crucial in the first 12 weeks postoperatively when graft-tunnel incorporation takes place.

Hardware complications include hardware migration (which may be isolated or occur as a result of fixation device or bone plug fracture) or fixation device divergence.

Both of these complications can lead to failure of incorporation, graft failure or other forms of impingement depending on the location, severity and timing.

5. Miscellaneous complications
Missed injuries: Injuries associated with ACL rupture that can cause instability include medial collateral, lateral collateral, posterolateral corner and posterior cruciate ligament tears.

Little is understood about Tunnel widening but it can occur in the first 6 to 24 months postoperatively and usually involves the tibial tunnel. The walls should be parallel and the width in all planes should be <10mm. It is not related to graft failure but may complicate revision surgery. Revision surgery on a tunnel with a diameter >15mm requires a 2 stage procedure with bone grafting, the choice of surgical technique for revision surgery on a 10mm - 15mm tunnel depends on the shape of the tunnel and graft choice whereas <10mm revisions are less complicated single stage procedures.

A small amount of tunnel fluid is a normal finding that can persist for 18 months postoperatively.

Tunnel cysts are a rare cause of tunnel expansion.

Infection is a rare complication. The diagnosis is usually made clinically but MRI features include effusion, synovitis and articular erosions.

Harvest site complications: Most complications are clinical but complications that can be detected on MRI include patellar fracture and patellar tendinosis in the form of persistent signal in the tendon after 18 months postoperatively.

The ultimate goal of ACL reconstruction surgery is to reduce further cartilage damage, meniscal injury and early onset osteoarthritis. Despite successful surgery some studies have shown that the risk of early osteoarthritis remains and the risk factors include concomitant meniscal injury, greater than 6 months between injury and reconstruction and age > 25 at the time of surgery. (Fig. 21 on page 30)

6. A note on Complications in the paediatric group

In addition to being susceptible to all the usual complications, paediatric patients are also susceptible to growth disturbances if surgery breaches the physis. The disturbance is generalised if the entire physis is involved (ie. limb shortening or lengthening) or with an angular limb deformity in the case of a focal growth disturbance. This is usually diagnosed on serial radiography but on MRI one can identify a physeal bridge which appears as a focal absence of the physis on T1 and loss of the normal T2 physeal signal intensity.
7. Risk factors for ipsilateral graft failure and contralateral ACL tear

About 6 to 12% of patients develop ipsilateral graft rupture or contralateral ACL rupture and number of studies have identified risk factors for subsequent ACL tears in either knee following ACL reconstruction. The main risk factors include younger age (<30) and higher activity levels (Tegner scale >6) and are also more common in allografts and double bundle techniques.

Anatomical risk factors have also been identified for primary ACL injury and since these are developmental, usually bilateral findings they have been linked to contralateral ACL injury. Further research is necessary to prove a link between anatomical risk factors and graft tear.

- Beta-angle >38.5 degrees (Fig. 22 on page 30).
- Narrow intercondylar notch index <0.252 (Fig. 23 on page 31).
- Elevated lateral tibial slope > 7.5 degrees (Fig. 24 on page 32).

Other anatomical measurements including notch height and morphology, medial tibial slope, posterior tibial slope and the alpha-angle have not yet been shown to be significant risk factors. Research is ongoing.
Fig. 1: Sagittal STIR sequence showing linear hyperintense signal in the ACL graft 14 months after surgery, a normal postoperative finding.

**Fig. 2:** Transosseous pullout technique: Arrows in C show a small femoral drill hole through which the proximal ACL was sutured. Arrows in A, B and D show sutures are the ACL footprint.

Fig. 3: White arrows shows suture anchor at proximal ACL footprint.

**Fig. 4:** Black arrows show a thin tibial drill hole and white arrows show bracing material (Fibertape in this case) which indicates internal bracing/augmentation of a primary repair.

**Fig. 5:** Red arrow shows linear signal in the mid patellar tendon which served as the autograft for an ACL reconstruction.

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**Fig. 6:** Red arrow showing normal thick, homogenous appearance of a BPTB graf.

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Fig. 7: Red arrows show thinner graft with inter-bundle linear striations which is a normal appearance for a folded hamstring graft.

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Fig. 11: The ‘Transphyseal Technique’ is used in those nearing skeletal maturity and involves similar tunnel placement to adults but only the hamstring autograft crosses the physis and the hardware stays on the metaphyseal side.

Fig. 8: 'Combined intra and extra-articular technique' where the proximal iliotibial band is detached, looped around the back of the knee, directed under the transverse meniscomeniscal ligament and fixated to the proximal medial metaphysis.

Fig. 9: 'Transepiphyseal technique' where the femoral and tibial tunnels are both completely epiphyseal.

Fig. 10: 'All Epiphyseal Technique' utilises a single fixation at the femoral epiphyseal tunnel with a graft that is looped through 2 tibial epiphyseal tunnels.

**Fig. 13:** Triangulated images showing correct position of Femoral Tunnel. Axial image A shows the opening on the lateral wall of the intercondylar notch and sagittal image B shows the opening at the intersection of Blumensaats line and the posterior femoral cortex.

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**Fig. 12:** Annotated diagram showing the correct coronal orientation of the femoral tunnel. The tunnel should be orientated between the 10 and 11 o’clock positions in the right knee and in the 1 to 2 o’clock orientation in the left knee.

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Fig. 14: If a grid is drawn with its borders tangential to Blumensaat's lines (A) and the femoral condylar margins (B, C, D) then the anteroinferior corner of the superoposterior box (yellow circle) shows the correct placement of the femoral tunnel on the lateral intercondylar wall.

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**Fig. 15:** Illustration showing correct sagittal position of tibial tunnel. The red arrows show the anterior margin of the tibial tunnel lying behind Blumensaats line. The blue arrow shows the mid point of the tibial tunnel at the 43% mark along the Amis and Jakob line.

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Fig. 16: Annotated images from the same patient showing normal post ACL graft reconstruction changes. Ligamentisation (synovial proliferation and neovascularisation) begins at 4 months and slowly decreases with time to normalise within 2 to 4 years.

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Fig. 17: Annotated images showing features of ACL graft rupture. A shows normal ACL graft. Following a second injury 7 years later image B shows thin, discontinuous, more horizontal fibres (primary signs), C shows anterior tibial translation >7mm and C shows posterolateral tibial plateau contusion (secondary signs).

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**Fig. 18:** Red arrows show formation an osteophyte at the entrance of the femoral tunnel projecting over the ACL graft. This had not been present on a previous MRI.

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Fig. 20: Diffuse arthrofibrosis: Red arrows show fibrous tissue encasing the ACL graft.

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Fig. 19: Focal arthrofibrosis (cyclops lesion): Red arrows show focal ovoid fibrous tissue forming anteriorly to the ACL graft in the intercondylar notch.

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**Fig. 21:** MRI knee of a 30 year old former contact sport athlete who had a delayed presentation (>12 months) of an ACL rupture. Despite successful ACL reconstruction and rehabilitation he presents with recurrent meniscal tears and early onset osteoarthritis. Red arrow shows attenuated medial meniscus as a result of partial meniscectomy and orange arrow shows chondral thinning in the medial tibiofemoral compartment.

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**Fig. 22:** The Beta angle is formed by Blumensaats line and the long axis of the femur. An angle greater than 38.5 degrees is associated with increased risk of ACL rupture.

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Fig. 23: Annotated images demonstrating how to calculate notch width index.

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**Fig. 24:** Angle A represents lateral tibial slope and is calculated by using the tibial long axis (B), a line perpendicular to the tibial long axis (C) and a tangent to the lateral tibial plateau (D).

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Conclusion

MRI is a complete tool for the imaging of ACL reconstruction and repair because of its ability to noninvasively assess the graft and surgical tunnels as well as differentiate normal graft maturation from complications of surgery. Further value lies on its ability to identify missed injuries and other risk factors for future complications including early onset osteoarthritis and contralateral ACL rupture.
References


