Magnetic resonance imaging of anterior cruciate ligament (ACL) autografting

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Learning objectives
To demonstrate the application of MRI for the postoperative ACL autograft assessment. To illustrate major findings and diagnostic pitfalls of the imaging technique.

Background
The incidence of traumatic knee injuries constantly rises as more people become involved in sport activities. Anterior cruciate ligament injuries are relatively common in young athletes, especially in soccer, snow skiing and tennis. The unrepaired ACL rupture leads to knee instability and...

Imaging findings OR Procedure details
Our study sample included 27 patients with symptoms suspicious for postoperative complications or autograft injury. Patients from several surgical centers were referred to knee MRI (1.5T) for ACL graft control. MRI protocol The adequate examination protocol for the post-operative assessment...

Conclusion
Take-home points Arthroscopic reconstruction of ACL by patellar tendon autograft represents the "gold standard" of ACL ruptures treatment. MRI became a “one-stop-shop” method of ACL autograft assessment, providing indications for timely reoperation. Indications for MRI after...
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**Background**

The incidence of traumatic knee injuries constantly rises as more people become involved in sport activities. Anterior cruciate ligament injuries are relatively common in young athletes, especially in soccer, snow skiing and tennis. The unrepaired ACL rupture leads to knee instability and consequently to severe degenerative osteoarthritis. The modern surgical materials and arthroscopic techniques allow complete recovery of physical activity in more than 95-97% of patients with ACL rupture.

The success of ACL repair is determined by (1) **transplant selection**, (2) **transplant positioning**, and (3) **fixation technique**. Historically, allotransplants, autotransplants, and synthetic materials have been used. The selection of graft depends on patient's age, profession, sport activity, body mass index, concomitant injuries, and predisposition for re-rupture. Nowadays hamstring tendon or patellar tendon autografts are most frequently used. Arthroscopic reconstruction of ACL by patellar tendon autograft (**patella - patellar tendon - tibial tuberosity**) represents the “gold standard” of up-to-date ACL ruptures treatment.

"Bone - patellar tendon - bone" autograft for ACL reconstruction

**The transplant position is crucial for its integrity.** The correct tunneling of femoral and tibial bones determines isometric positioning of ACL autograft.
The fixation of graft bone plugs in femoral and tibial tunnels is usually achieved by interference screws with bioabsorbable ones being the optimum choice. Complete replacement of bioabsorbable interference screws by bone tissue typically occurs within 1-2 years.
The security of ACL autograft fixation is assessed arthroscopically during passive joint movements. The absence of bone plugs and transplant displacement during flexion and extension of the knee joint ascertains the isometry of the graft positioning.

Rehabilitation period commonly lasts from 7 to 9 months with subsequent return to pre-trauma level of physical activity. However, according to literature 10-25% of patients develop complications after arthroscopic ACL reconstruction, with the majority being of mild to moderate grade of severity. **The weakest point within 6 months after operation is the screw fixation site (especially in the tibia), later - autograft itself.**

Diagnostic imaging methods are widely used for post-operative assessment of patients with ACL grafts. **Conventional x-ray techniques and computed tomography** do not allow visualization of autograft and bioabsorbable screws. However, these methods are successfully used for the assessment of the tunnels dimensions and positioning.
3D reconstruction of MDCT images. Arrows indicate sites of ACL autograft harvesting in patella and
Previously used ferromagnetic surgical materials impeded application of MRI for the post-operative ACL graft assessment. Metal artifacts from fixation devices (staples) occasionally degrade visualization of bone tunnels and plugs, although visualization of the ligamentous part of the graft is not hampered in the majority of cases. Bioabsorbable screws and autografts do not produce artifacts on MR images. Moreover, MRI has been shown to be highly effective for the postoperative assessment of **graft harvesting sites, bone tunnels, surrounding bone marrow, soft tissues, and graft**.
Imaging findings OR Procedure details

Our study sample included 27 patients with symptoms suspicious for postoperative complications or autograft injury. Patients from several surgical centers were referred to knee MRI (1.5T) for ACL graft control.

MRI protocol

The adequate examination protocol for the post-operative assessment of the knee should include T1- and T2 (or proton density)-weighted sagittal and coronal images, including long TR sequences with fat-saturation or short tau inversion recovery (STIR) sequence. Visualization of ACL graft is ideally achieved in oblique plane along its course (positioned on coronal localizer - fig. 1) or by 3D gradient-echo sequences (however extremely susceptible to magnetic field inhomogeneities). T2-weighted images are preferable for the graft rupture assessment. Axial plane (This Mediafile cannot be embedded within a PDF Document) is not necessary in most cases, although it is useful for partial tears assessment. Slice thickness should not exceed 3-4 mm with no gap between slices.

Visualization of normal and complicated ACL reconstruction will be discussed further. The list of major complications follows:

• Donor site abnormalities
• Incorrect tunnel placement (predisposing to graft failure)
• Graft compression (including roof impingement)
• Graft failure
• Graft fixation failure
• Graft cystic degeneration
• Arthrofibrosis (diffuse/localized)
• Fracture of bone plug
• Patella fracture
• Infectious complications (most often synovitis)

Assessment of graft harvesting sites

Sagittal and axial images (fig. 3) are best suited for harvesting sites measurements. Patellar harvesting site should have trapezoid shape (on coronal plane). Its width should be measured at three different levels. The typical maximum dimensions of the patellar defect are 10 mm (width) and 23 mm (length). The distance between base of the patella and
proximal border of grafting site should constitute at least 1/3 of the patella length in order to avoid patella fragility and susceptibility to fracture. The typical maximum dimensions of the tibial tuberosity defect are 10 mm (width) and 25 mm (length).

Both patella and tibial tuberosity should be examined for possible oedema and inflammation (fig. 4). Patients involved in professions requiring kneeling are especially prone to inflammation at the tibial harvesting site. Patellar tendinitis may also cause postoperative pain, especially if paratendon was not spared during the operation.

**Assessment of bone tunnels**

*Femoral tunnel*

The femoral tunnel traverses through lateral femoral condyle at eleven or one o'clock (right or left knee, respectively) when viewed in coronal plane (fig. 5). The length of the femoral tunnel should exceed femoral bone plug length by 2 mm equaling 25 mm. The femoral tunnel width should not exceed 10-14 mm. Its intraarticular opening should be located at the junction of intercondylar roof and posterior femoral cortex. The location of the opening is extremely important for the isometry of ACL reconstruction. When viewed in sagittal plane the width of bone plate behind the femoral tunnel should equal at least 2 mm (fig. 6).

*Tibial tunnel*

The tibial tunnel traverses through medial tibial condyle parallel and posterior to the projected slope of intercondylar femoral roof (Blumensaat's line - fig. 7). Positioning of the tibial tunnel and bone plug anterior to the Blumensaat’s line results in the compression of graft by the tibial roof predisposing to rupture (roof impingement syndrome). While the tibial tunnel external opening may vary, its intraarticular opening site should always be found on the lateral surface of medial tubercle of intercondylar notch (fig. 8). The minimum length of the tibial tunnel is approximately 30 mm. The tibial tunnel width should not exceed 10-14 mm.

Autograft fixation by ferromagnetic screws leads to prominent magnetic field inhomogeneity artifacts impeding bone tunnels assessment. The bioabsorbable interference screws are typically hypointense on all sequences (without any artifacts) with hyperintense core on T2- and PD-WI (fig. 9). The screws should parallel the tunnels and be sandwiched between the tunnel wall and bone plug (not inside the tunnel). The protrusion of the screw into the joint cavity or outside of the bone diaphysis is considered a complication predisposing to ACL graft failure or compression of surrounding soft tissues (fig. 10 and fig. 11). In some cases MRI with maximum knee extension may be helpful for evaluation of ACL graft and its fixation (fig. 12).

Bone tissue around tunnels should be assessed for possible oedema (fig. 13). MRI signs of perifocal osteolysis indicate the high probability of screw dislocation and fixation failure.

**Assessment of ACL autograft**

ACL autograft is best visualized in oblique plane oriented along its axis (fig. 14). T2*-weighted 3D gradient echo sequences can also be applied for the graft assessment (fig. 15 - video), however their relatively low contrast-to-noise ratio may impede satisfactory visualization of oedematous...
The standard autograft length is 85-90 mm, width - 10 mm. MR characteristics of its tendinous part are typical for ligaments (hypointense on all sequences). However, it should be kept in mind that normal ligamentization of the graft from 1 to 6 months after operation exhibits intermediate SI on T1-WI and moderately high SI on T2-WI (fig. 16). Normal ligamentization of autograft should be differentiated from spraining and edema, which demonstrate higher SI on T2-WI. A normal graft returns to complete hypointensity after 1-1.5 years post-operatively.

Graft impingement typically occurs when tibial tunnel is placed anterior to Blumensaat's line. Impingement can be revealed on T2-WI as ligament hyperintensity typically involving its distal two-thirds (fig. 17). Other causes of impingement include screw protrusion and osteophytes.

Autograft rupture characteristics are similar to that of ACL rupture. Its major causes are roof impingement and repeated trauma. Graft fibers discontinuity (partial or complete) with prominent hyperintensity on T2- or PD-WI indicate ligamentous injury and rupture (fig. 18).

Other complications

Localized arthrofibrosis ("cyclops lesion") is not an uncommon complication of ACL reconstruction. It is characterized by proliferation of synovium (usually moderately hypointense on T1-WI and variable on T2-WI) anterior to the ACL graft (fig. 19).

Graft cystic degeneration (a.k.a. ganglion - fig. 20) is a late complication more frequently involving hamstring autografts.

Hamstring autograft

Hamstring tendon autograft is often preferred due to lower frequency of donor site abnormalities and anterior knee pain. It consists of two linear structures (bundles of quadrupled hamstring) hypointense on all pulse sequences (fig. 21). Hamstring graft fixation is typically achieved by endobuttons (fig. 22).

Conclusion

Take-home points

- Arthroscopic reconstruction of ACL by patellar tendon autograft represents the "gold standard" of ACL ruptures treatment.
- MRI became a “one-stop-shop” method of ACL autograft assessment, providing indications for timely reoperation.
- Indications for MRI after ACL reconstruction: knee pain or instability, postoperative infection, clinical suspicion for graft failure, new injury.
- Isometry of ACL reconstruction is determined by the correct tunnels placement.
- Roof impingement typically occurs when tibial tunnel is positioned anterior to Blumensaat's line, leading to autograft failure.
- Differentiation of ACL autograft normal ligamentization, impingement, partial and complete tears is a challenging task for musculoskeletal radiologists, requiring thorough knowledge of the ACL reconstruction technique.
Recognition of MRI features of normal and complicated reconstruction of ACL is ideally pursued by the close cooperation of radiologists with orthopedic surgeons.

References


Personal Information

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MeSH

1 Anterior Cruciate Ligament [ A02.513.514.100 ]
   A strong ligament of the knee that originates from the posteromedial portion of the lateral condyle of the femur, passes anteriorly and inferiorly between the condyles, and attaches to the depression in front of the intercondylar eminence of the tibia.

2 Bone-Patellar Tendon-Bone Graft [ E04.555.130.100 ]
   Fixation of the ANTERIOR CRUCIATE LIGAMENT, during surgical reconstruction, by the use of a bone- patellar tendon autograft.

3 Bone-Patellar Tendon-Bone Graft [ E04.936.450.050.100 ]
   Fixation of the ANTERIOR CRUCIATE LIGAMENT, during surgical reconstruction, by the use of a bone- patellar tendon autograft.

4 Magnetic Resonance Imaging [ E01.370.350.500 ]
   Non-invasive method of demonstrating internal anatomy based on the principle that atomic nuclei in a strong magnetic field absorb pulses of radiofrequency energy and emit them as radiowaves which can be reconstructed into computerized images. The concept includes proton spin tomographic techniques.

Keywords

1 MRI
   [Entered as: MRI]

2 acl
   [Entered as: acl]

3 orthopedy
   [Entered as: orthopedy]

Linked Mediafiles

Link 1
Positioning of oblique slices for ACL graft assessment.

Axial MR images showing patellar and tibial defects after ACL autograft harvesting.
Sagittal PD-WI with fat saturation demonstrating prominent oedema at harvesting sites (red arrows) and patellar tendinitis (asterisk).
Coronal T1-WI. Femoral tunnel traverses through lateral condyle at one o'clock (left knee).

Scheme demonstrating femoral tunnel positioning in sagittal plane. The thickness of the cortex posterior to the tunnel should equal 2 mm at the minimum (when the
tunnel radius equals 5 mm).

Sagittal T1-WI. Positioning of the tibial tunnel posterior to Blumensaat's line is necessary to avoid graft impingement by femoral intercondylar roof.
Coronal T1-WI. The tibial tunnel opening is located on the lateral surface of medial tubercle of intercondylar notch.
Sagittal T1-WI demonstrating bioabsorbable interference screw along the tibial tunnel wall.

Link 9
Sagittal PD-WI with fat saturation demonstrating the screw protrusion into the joint cavity.

Link 10
Sagittal PDWI demonstrating anterior extrusion of the screw.
Oblique sagittal T2-WI during maximum knee extension demonstrates bioabsorbable screw (red arrow) protruding into the joint cavity. ACL graft appears intact but loose (yellow arrow). The patient complained of knee instability upon complete knee extension incapacitating him from professional sport activity.
Sagittal PD-WI with fat saturation demonstrating moderate perifocal oedema (red arrow). Yellow arrow indicates magnetic susceptibility artifact caused by metal staples.
Oblique T2WI demonstrating all three parts of ACL autograft. Arrow indicates normal ligamentous tissue of the graft.
Sagittal PD-WI with fat saturation

demonstrating ACL autograft moderate hyperintensity associated with the normal ligamentization.

Link 15
Sagittal PD-WI with fat saturation demonstrating impinged ACL autograft (prominent hyperintensity of distal two-thirds). Note location of the tunnel anterior to the Blumensaat’s line.

Link 16
Oblique sagittal PD- and T1-WI demonstrating ACL graft partial tear due to roof impingement.

Link 17
Sagittal PD-WI with fat saturation demonstrating area of mixed signal intensity ("cyclops lesion") anterior to the tibial insertion of ACL autograft.
Axial T2-WI demonstrating graft cystic degeneration (red arrow).
Hamstring tendon autograft (T2WI, oblique plane). Linear increased signal intensity (red arrow) represents normal gap between tendon bands.

Sagittal and coronal PD-WI with fat saturation demonstrating hamstring graft fixation in femoral bone by endobutton (red arrow). Note prominent magnetic field inhomogeneities due to ferromagnetic staples.