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CONTINUING EDUCATION PROGRAM: FOCUS...

Imaging of the postoperative knee

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KEYWORDS
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Abstract On sagittal images after anterior cruciate ligament (ACL) reconstructions, the femoral tunnel aperture should be at the junction of the line drawn along the posterior femoral cortex and the line drawn along the roof of the intercondylar notch (Bluemensaat line). The tibial tunnel aperture should be in the anterior portion of the second third, i.e. anterior aspect of the middle of the tibial epiphysis. An inaccurate placement of the femoral tunnel affects the graft isometry. A tibial tunnel too anteriorly placed results in intercondylar notch roof impingement. After meniscus surgery, first-line MRI is often sufficient to diagnose new tears; however, sometimes it is necessary to perform CT arthrography or MR arthrography. Surgical cartilage repair is evaluated based on articular congruity and on the appearance of the subchondral bone.

Introduction

The increased use and improvement of knee surgery techniques has led to an increased number of indications for imaging. In routine practice, it has become increasingly frequent to come across MR images of knees that underwent previous surgery. Prior surgery is a crucial information because imaging protocol and interpretation need to be adapted.

Abbreviations: STGT, semitendinosus/gracilis tendons; BTB, bone-tendon-bone; ACL, anterior cruciate ligament; PCL, posterior cruciate ligament; PD, proton density; fs-PD-weighted, fat-suppressed proton density-weighted, equivalent in this text to fat-suppressed intermediate-weighted.

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This information is usually obtained during history taking. The surgery report is often not available. It is also important to obtain the images from previous examinations.

If, at time of assessment, it is not possible to know if the patient has had prior surgery, it is sometimes possible to visualize postoperative signs on MR images. Besides obvious signs of material migration or obvious morphologic changes, rounded or linear small fibrous areas in the infrapatellar fat are signs of trocar passage during arthroscopy. This type of sign is usually seen on both parts of the patellar tendon. Susceptibility artifacts generated by metallic particles, better visible on gradient echo sequences, are also signs of previous surgery. Knee surgery involves many areas and procedures.

The purpose of this review was to address surgical procedures of the anterior cruciate ligament, menisci and cartilage.

Anterior cruciate ligament reconstruction

Types of reconstruction

Today, ACL reconstruction uses tendon grafts (Table 1). Direct ligament sutures and grafting with synthetic materials are no longer performed. In most cases, an autograft from the patient himself is performed, rather than an allograft from a corpse donor. There are two types of tendon reconstruction: reconstruction with an autograft of the patellar tendon (bone-tendon-bone or BTB technique) and an autograft with semitendinosus/gracilis tendons (STGT technique). The BTB reconstruction uses the patellar tendon with its two bone fragments on each side (corresponding to the central third of the tendon), while the STGT technique uses the semitendinosus and gracilis tendons, with both tendons folded to form four strands.

On postoperative images, the BTB reconstruction is characterized by a defect on the central third of the patellar tendon, clearly visible during the first months after surgery and even later [1,2]. In the STGT reconstruction, tendons heal and no defects are, generally, visible later on [3].

Recently a new anatomic double-bundle reconstruction technique has been used (Fig. 1). This technique involves two femoral tunnels, or two tibial tunnels and two tendon grafts (STGT with each tendon folded to form two bundles of two strands each).

Table 1 Comparison between BTB and STGT reconstructions.

	BTB	STGT
Origin of the graft	Patellar tendon	Semitendinosus/gracilis tendons
Constitution of the graft	Central third of the tendon with bone fragments on each side	Several intertwined tendon strands
Abnormality at the site of harvesting	Defect at the central third of the tendon, sometimes persisting	Almost none (regeneration of the tendon)

BTB and STGT are intra-articular reconstructions. Standard radiography ensures correct tunnel placement (Fig. 2) (Table 2) [4—6]. On sagittal images of ACL reconstructions, the aperture of the femoral tunnel should be located right in front of the junction of the line drawn along the posterior femoral cortex and the line drawn along the roof of the intercondylar notch (Bluemensaat line). The tibial tunnel aperture should be in the anterior portion of the second third, i.e. anterior aspect of the middle tibial epiphysis. An inaccurate placement of the femoral tunnel affects the graft isometry (Figs. 3 and 4). If the tibial tunnel is too anteriorly placed, it may cause an impingement against the roof of the intercondylar notch. Extra-articular reconstruction technique is possible, but has been much less widely performed.

MRI Protocol

A standard knee MRI protocol including fat-suppressed proton density (PD)-weighted sequences is usually performed. Non fat-suppressed T2- or PD-weighted sequences are useful

Table 2 Accurate tunnel placement and consequences in case of inaccurate placement.

	Femoral tunnel	Tibial tunnel
Sagittal view	Aperture at the junction of the posterior femoral cortex and the line along the roof of the intercondylar notch	Aperture on anterior aspect of the middle of the tibial epiphysis Parallel and posterior to the line along the roof of the intercondylar notch, in extension
Frontal view	Aperture in the superolateral part of the intercondylar notch Superolateral orientation	Aperture in projection of the tibial spine Inferomedial orientation
Accurate placement	Isometric reconstruction	No intercondylar notch roof impingement, anterior stabilization
Too anterior	Reconstruction too tight in flexion	Intercondylar notch roof impingement (in extension)
Too posterior	Reconstruction too tight in extension Risk of tear in the posterior femoral cortex	Reconstruction too vertical with reduced anterior stabilization

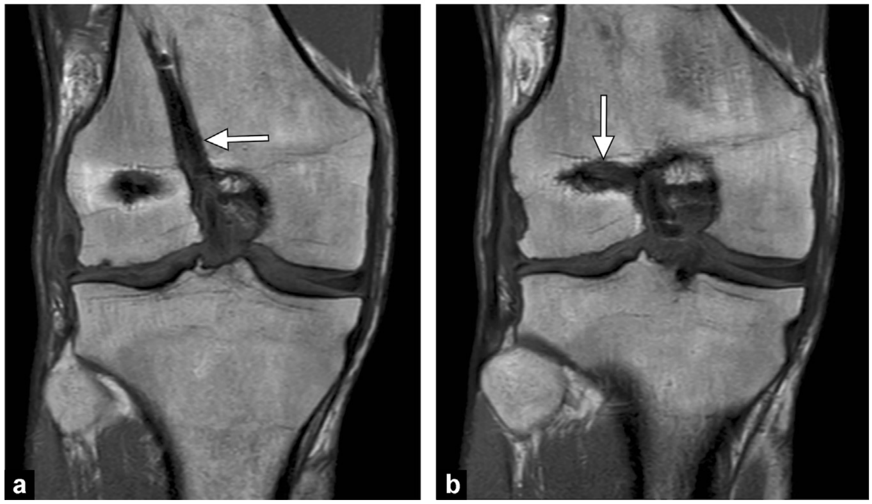

Figure 1. a and b: double-bundle reconstruction. T1-weighted coronal MR images. Note the presence of two femoral tunnels, oriented differently (arrows).

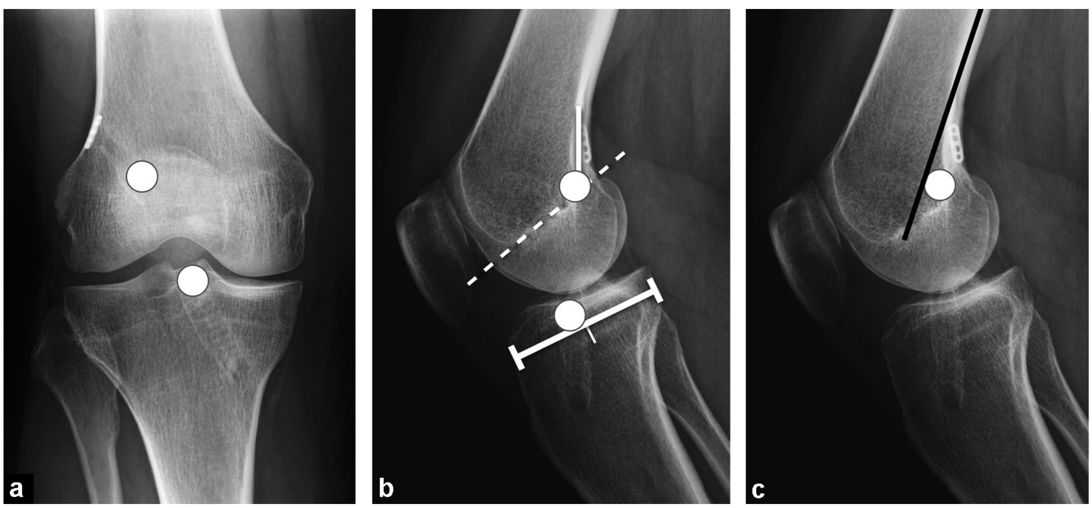

Figure 2. Normal placement of tunnels on standard radiographs. White rounds indicate the apertures of the tunnels: a: on frontal view, the femoral tunnel aperture should be located in the superolateral part of the intercondylar notch, and the tibial tunnel aperture projecting from the medial tibial spine; b: sagittal view: the femoral tunnel aperture should be at the junction of the line drawn along the posterior femoral cortex and the line drawn along the roof of the intercondylar notch, also called Bluemensaat line (white dotted line). The posterior border of the tibial tunnel aperture must correspond to the middle of the tibial epiphysis. The graft, the location of which can be inferred from the location of the two apertures, must be located behind the Bluemensaat line to avoid anterior impingement. Maximum extension is better to assess the graft; c: another useful marker is the femoral tunnel aperture located behind the line extending from the posterior femoral cortex (black line).

because they are less susceptible to metal artifacts and offer better morphologic analysis of the graft and the bony structures (especially the intercondylar notch) (Fig. 5). To visualize bone edema and soft tissues, STIR or Dixon sequences are useful because they show less pronounced artifacts than fat-sat sequences. Other parameters that reduce metallic artifacts are: increasing the bandwidth, using three-dimensional (3D) spin-echo sequences and reducing echo time. Moreover, 3D spin-echo sequences are useful for their reformatting and multiplanar capabilities.

Normal appearance of ACL reconstructions

During the first two months after surgery, grafts appear as low signal intensity on T1-weighted images and fluid-sensitive sequences (similar to the typical signal characteristics of tendons) [7]. Then, during the period between two months and 1.5 to 2 years, a process called ''ligamentization'' occurs. This process corresponds to vascularization, peripheral ''synovialization'' and collagen production. This ''ligamentization'' has a moderate high signal intensity on T1-weighted MR images and fluid-sensitive sequences. After 1.5 to 2 years, grafts, generally have a low signal intensity on T1-weighted and fluid-sensitive MR images again, with possible areas of intermediate signal. Beyond 4 years of surgery, intermediate signal is present in some portion of the graft in up to two thirds of cases [8]. These imaging features are presented in Table 3. In case of STGT, a linear high signal intensity on fluid-sensitive sequences is possible (fluid-like or not), corresponding

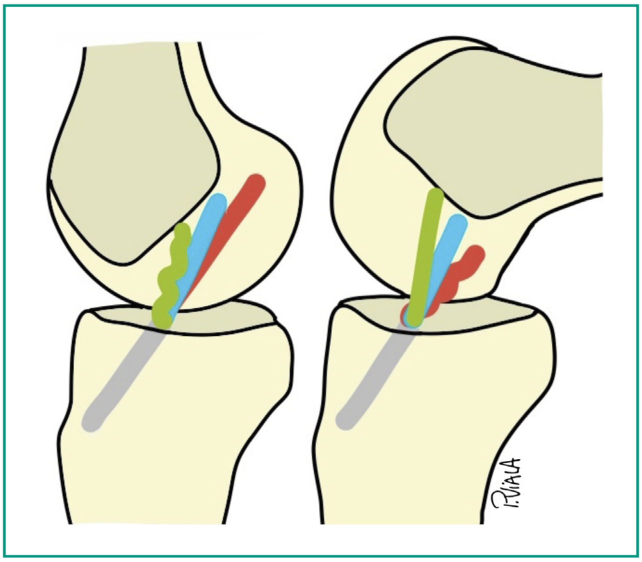

Figure 3. Effect of femoral tunnel placement on the tension in the graft. The accurate location is shown in blue (isometry). The articular aperture of the femoral tunnel of the green graft is too anteriorly located causing the graft to be too loose in extension and too tight in flexion. The articular aperture of the femoral tunnel of the red graft is too posteriorly located; consequently the graft is too tight in extension and too loose in flexion.

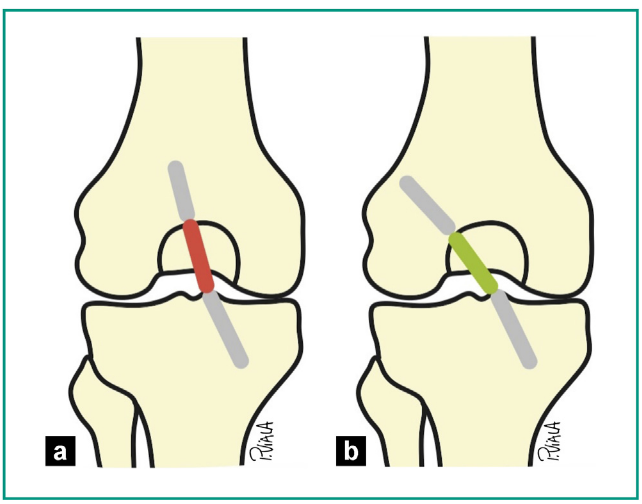

Figure 4. Graft too vertical in coronal plane: a: graft too vertical because the femoral tunnel aperture is placed too centrally. No rotational stability; b: normal placement of the graft. Rotational stability.

to a low quantity of liquid between the graft strands (Fig. 6).

Complications

Early complications

Early complications include inaccurate tunnel placement due to technical difficulties during surgery and spontaneous or trauma-induced material migration (screw, or bone graft with BTB technique) (Fig. 7) (Table 4).

Table 3 Normal MRI signal of the tendon graft, over time, after anterior cruciate ligament reconstruction.

	Graft signal
0 to 2 months	Low signal intensity on T1-weighted and fluid-sensitive sequences
2 months to 1½—2 years	''Ligamentization'' Possible high signal intensity on T1-weighted and edema-like high signal intensity on fluid-sensitive sequences
After 1½—2 years	Low signal intensity on T1-weighted and fluid-sensitive sequences Possible intermediate signal intensity on T1-weighted and fluid-sensitive sequences, non pathologic, especially after 4 years

Table 4 Main complications after anterior cruciate ligament reconstruction.

Types of complications	Causes
Early complications	Inaccurate placement due to technical difficulties during surgery Material migration (screws or bony graft)
Failed ACL reconstruction	
Primary cause	Tibial tunnel too posteriorly placed
Secondary cause	Loss of graft fixation Graft tear Graft laxity
Impingements	
Anterior against intercondylar notch	Tibial tunnel too anteriorly placed Intercondylar notch too small (sometimes osteophyte) Localized anterior arthrofibrosis
Posterior against posterior cruciate ligament	Tibial tunnel too posterior and too medial
Lateral against intercondylar notch	Narrow notch Tibial tunnel too lateral
Harvest site complications	
BTB	Patellar tendinopathy (frequent) Tendon rupture (rare) Avulsion fracture of the patella (rare) Hoffite
STGT	Neuralgia caused by injured infrapatellar branch of the saphenous nerve

Figure 5. A better morphologic definition of the reconstruction is obtained on non fat-suppressed sequences. Coronal fat-suppressed-PD- (a) and T2-weighted MR images (b).

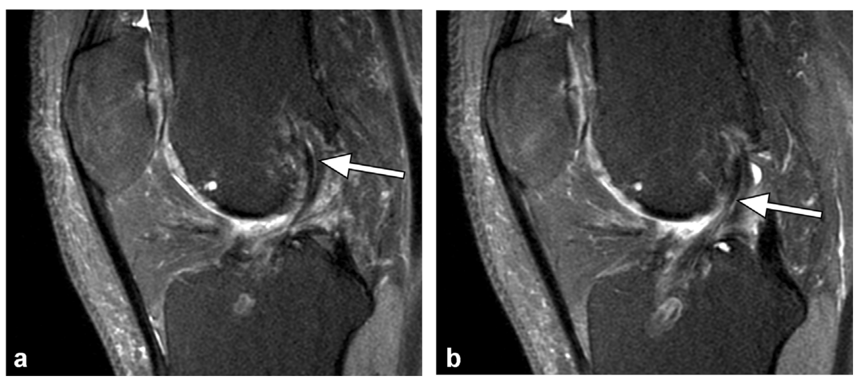

Figure 6. a and b: normal high signal intensity on fluid-sensitive sequences between the strands in an STGT reconstruction due to a small quantity of liquid (arrow). Sagittal fat-suppressed-PD-weighted MR image.

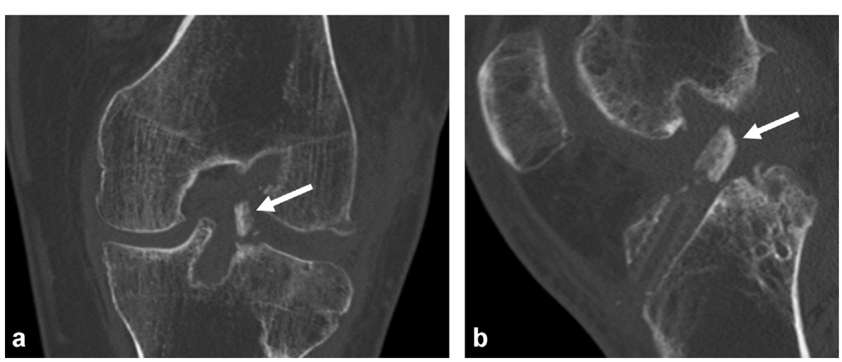

Figure 7. Intra-articular migration of tibial bone graft (arrows) right after a BTB reconstruction. Coronal (a) and sagittal (b) CT images.

Failed ACL reconstruction

Factors that contribute to ACL reconstruction failure are a too posteriorly placed tibial tunnel (Fig. 8), loss of graft fixation, graft tear (Fig. 9) and graft laxity.

Impingements

Factors that contribute to intercondylar notch impingement, the most frequent impingement, include a tibial tunnel placed too anteriorly and an intercondylar notch too small, with sometimes osteophytes (Figs. 10 and 11). To avoid this type of impingement, it is sometimes necessary to perform a notchoplasty during surgery. This impingement may also be caused by localized anterior arthrofibrosis (see below). Lateral impingement with the intercondylar notch is also possible, caused by a narrow notch and a tibial tunnel placed too laterally. Posterior cruciate ligament (PCL) impingement occurs when the tibial tunnel is too medial and vertical, causing contact between the reconstruction and the PCL during flexion and thereby a flessum (Fig. 10).

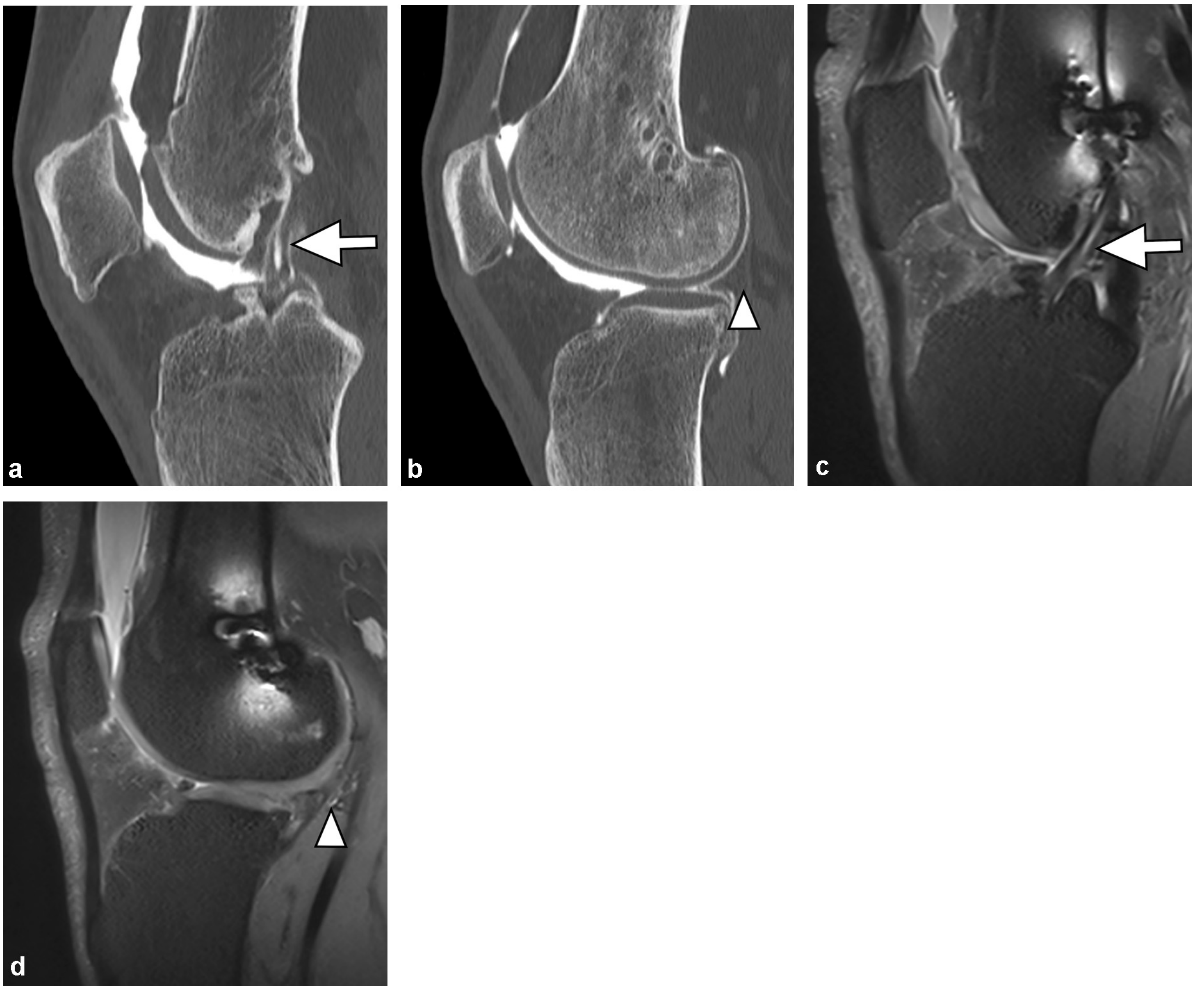

Figure 8. Too vertical graft. On CT arthrography the reconstruction appears too vertical (arrow in a), without spontaneous anterior drawer (arrowhead in b). On MR examination performed two weeks before (sagittal image on fat-suppressed PD-weighted sequence), the reconstruction appeared less vertical than on CT arthrography (arrow in c) and on MRI an anterior drawer was visible (arrowhead in d). This difference is probably related to the position inside the MRI coil.

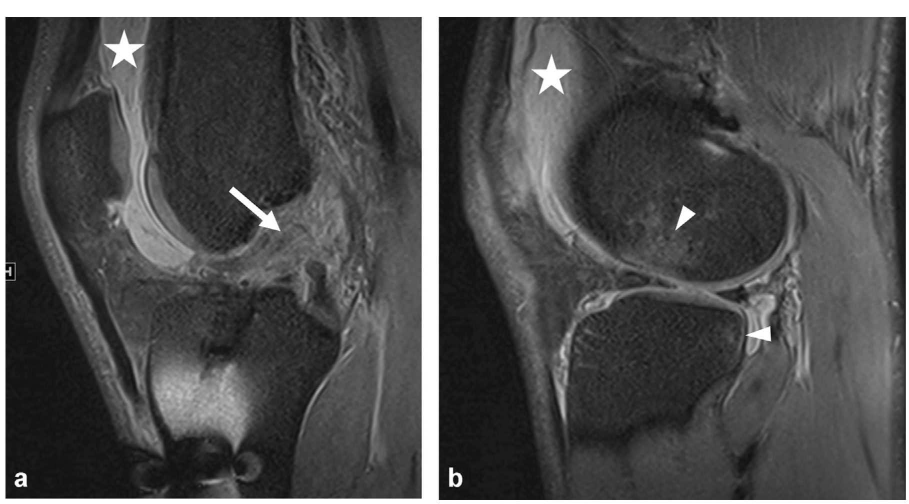

Figure 9. Recent trauma-induced graft tear. Sagittal fat-suppressed PD-weighted MR image. Hyperintense signal and heterogeneity of graft fibers (arrow). Articular effusion (star). Osseous defect at the anterior part of the lateral femoral condyle and the posterior part of the lateral tibial condyle (arrowheads) indicating recent sprain with anterior drawer mechanism.

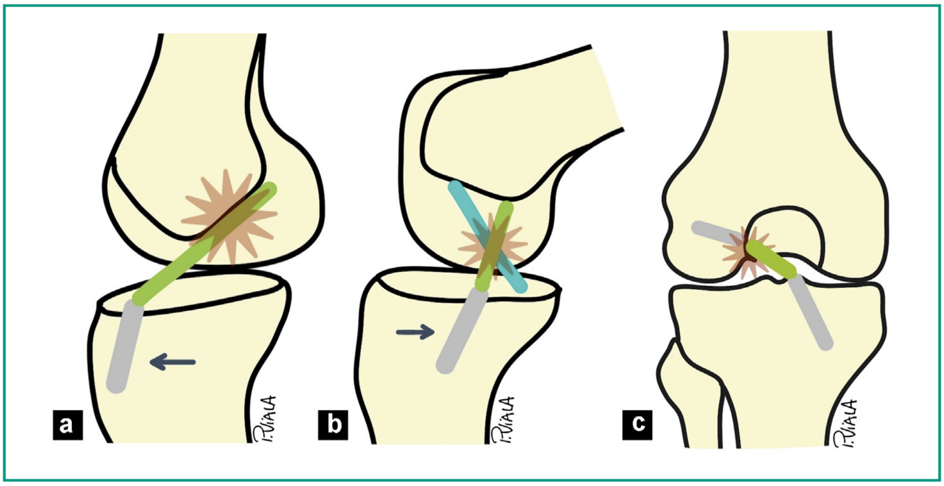

Figure 10. Different types of impingements: a: anterior notch roof impingement; b: posterior impingement with posterior cruciate ligament; c: lateral notch roof impingement.

Figure 11. Anterior impingement. Sagittal fat-suppressed PD-weighted MR image. Hyperintense signal and anterior concavity on distal part of the graft. Impingement is caused by a small osteophyte at the roof of the notch (arrowhead).

Finally, impingement between fixation material and tendons with the iliotibial band is also possible, especially at the lateral aspect of the femoral condyle (Fig. 12).

Tunnel cyst formation

Cyst formation is a rare complication and may occur relatively late. It occurs more frequently following an STGT reconstruction with fixation by a button. Cyst formation can progress without symptoms or cause pain and articular stiffness, without instability. Radiographs show a widened tunnel and MRI shows long cysts inside and around the grafts. Cysts may extend to the tibial tunnel distal aperture with, sometimes, pretibial subcutaneous swelling (Fig. 13).

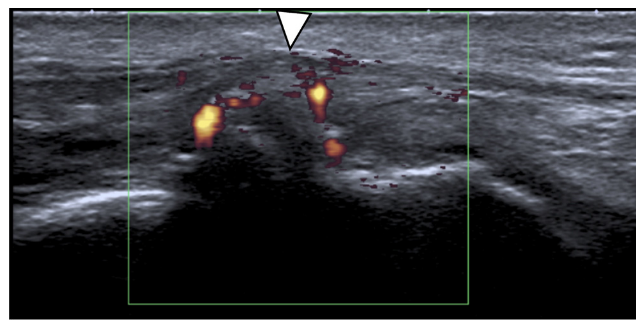

Figure 12. Ultrasound, coronal image with power Doppler. Lateral protrusion of femoral screw that causes impingement with the iliotibial band, with localized hyperemia (arrowhead).

Small amounts of fluid in the tunnels during the first 18 months following surgery are normal, especially in the tibial tunnel following STGT reconstruction. There is no bone tunnel widening.

Arthrofibrosis

There are two types of arthrofibrosis: diffuse and localized arthrofibrosis. Diffuse arthrofibrosis is a thickening of the joint capsule causing stiffness that can be treated with physical therapy and sometimes arthrolysis. Localized arthrofibrosis is usually anterior. This is fibrous tissue located anteriorly to the distal portion of the ACL graft that may develop from residual native ACL fibers (Fig. 14). Clinical signs are generally knee extension deficit, pain, snapping and effusion. MRI shows a mass of intermediate signal intensity on fluid-sensitive sequences and enhancement is possible (Fig. 15). Localized arthrofibrosis is treated by arthroscopy. In rare cases, arthrofibrosis may be observed at other locations (for instance suprapatellar, intercondylar, or infrapatellar arthrofibrosis).

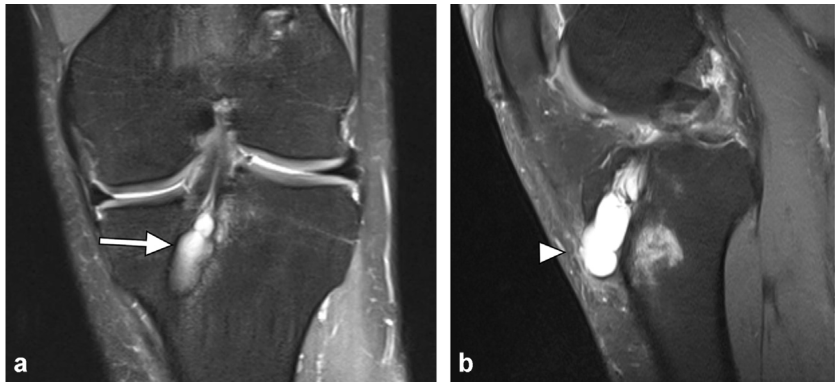

Figure 13. Cyst formation in the tibial tunnel (arrows) extending to the pretibial subcutaneous soft tissues (arrowhead). Coronal (a) and sagittal (b) fat-suppressed PD-weighted MR images.

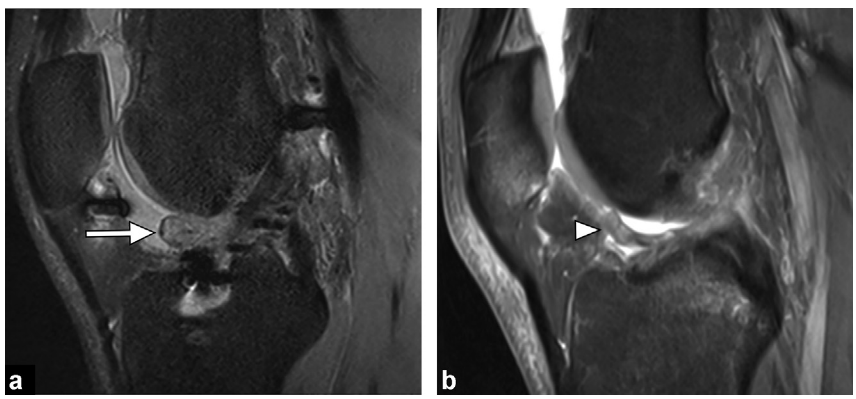

Figure 14. a: sagittal fat-suppressed PD-weighted MR image. Localized anterior arthrofibrosis (cyclops lesions) (arrow); b: MRI at 1-year post-trauma follow-up. Distal stump of ACL is turned anteriorly (arrowhead). This case confirms one of the pathophysiologic hypotheses for this type of arthrofibrosis that occurs on the distal stump of native ACL.

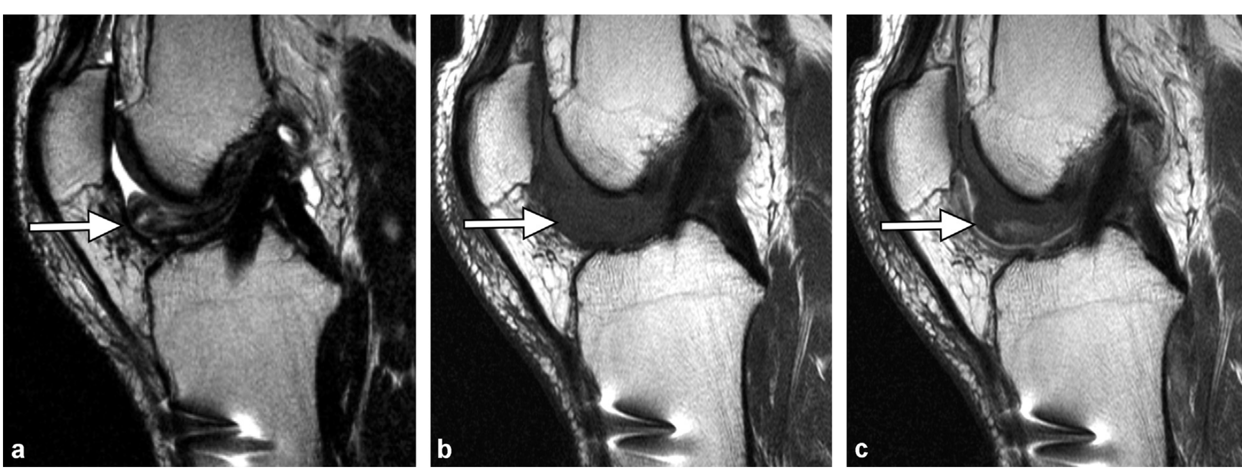

Figure 15. Localized anterior arthrofibrosis (cyclops lesions). Sagittal T2- (a), T1- weighted MR images before (b) and after intravenous administration of gadolinium-chelate (c).

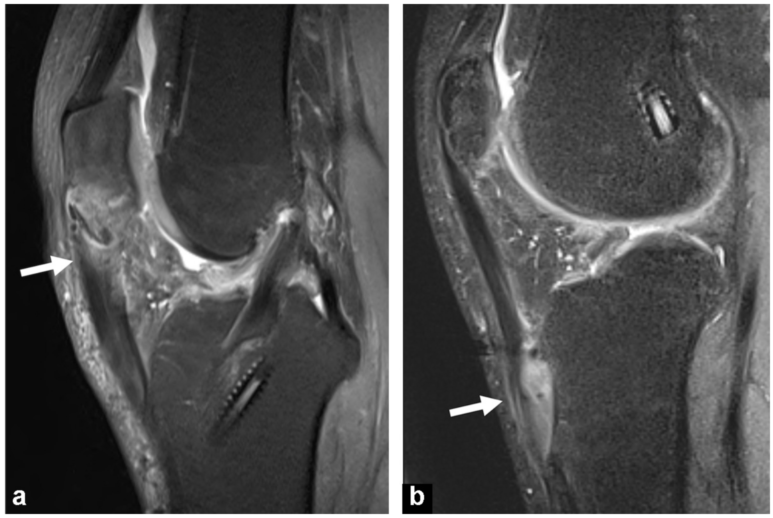

Figure 16. a and b: patellar tendinopathy after BTB reconstruction in 2 different patients. Sagittal on fat-suppressed PD-weighted MR images.

Complications at the tendon graft harvest site

After BTB reconstruction, patellar tendinopathy may be observed (Fig. 16), but very rarely tendon rupture or avulsion fracture of the patella. When harvesting the STGT graft, the infrapatellar branch of the saphenous nerve is frequently damaged (up to two thirds of the cases). In rare cases (about 10%), the saphenous nerve is injured [9].

Postoperative meniscus imaging

When examining menisci with MRI, it is crucial to know if there has been previous surgery because tears will be diagnosed differently. This information is usually obtained through case history (direct or by questionnaire). There are two main types of meniscus surgery: meniscectomy and meniscus repair.

Techniques

Meniscectomy

Meniscectomy consists in surgically removing part of the meniscus (partial meniscectomy). Total meniscectomy is now rarely performed because it is known to be a major risk factor of osteoarthritis. Partial meniscectomy aims to restore meniscus stability (by removing meniscal fragments) while preserving as much meniscus as possible to reduce the risk of osteoarthritis.

Meniscectomy may be performed on all types of meniscal tears, provided they are symptomatic and unstable. Horizontal, stable and degenerative meniscal tears generally do not warrant meniscectomy.

After partial meniscectomy, imaging shows morphologic changes: smaller meniscus (loss of substance), sometimes irregular borders, truncated meniscal free edge, sometimes stable micro-tears (for example small horizontal tears the free edge), and ''degenerative'' areas contacting the meniscal surface (Figs. 17 and 18). No meniscal fragment should remain.

After meniscectomy, there is an increased risk of new meniscal tears, especially radial tears [10]. Subchondral bone modifications are frequently observed, because of mechanical adaptation: subchondral bone edema signal may be a sign of simple mechanical adaptation, or a stress reaction with, at the advanced stage, a stress fracture in the subchondral bone, and even osteonecrosis if the fractured fragment has become devascularized (Fig. 19).

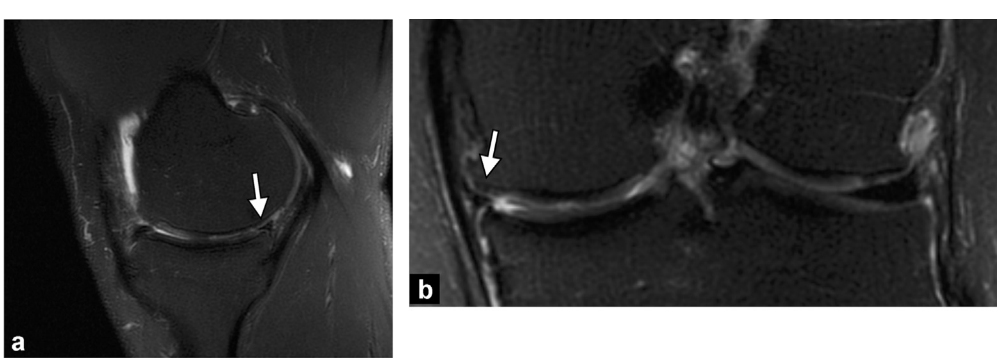

Figure 17. Normal appearance after partial meniscectomy. Loss of substance and amputation of posterior horn and substance of the medial meniscus (arrow). Sagittal (a) and coronal (b) fat-suppressed PD-weighted MR images.

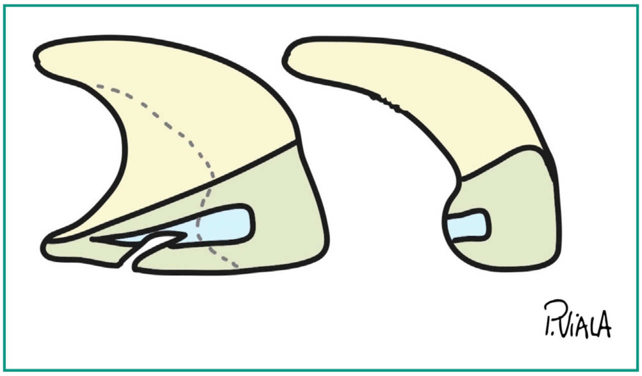

Figure 18. Meniscus before and after partial meniscectomy. The blue area represents a degenerative area adjacent to a tear (before meniscectomy, left). After meniscectomy, the remnants of degenerative area remain and could be the cause of the adjacent high signal intensity on fluid-sensitive sequences at the free edge, without any new tear.

Meniscal repair

Meniscal repair has the advantage of avoiding loss of meniscus, but its indications are more limited than meniscectomy and it involves more postoperative restrictions. The main indications are recent peripheral tears and detachment of the meniscus from its capsular attachment in patients under the age of 40. After meniscal repair, linear high signal intensity is seen at the site of repair on short or intermediate echo time sequences (PD and T1-weighted MR sequences).

Meniscal transplantation

Meniscal transplantations are allografts, usually performed after meniscectomy in patients under the age of 40, who are still suffering from pain. This surgery is evaluated based on relief of pain [11]. Its effect on cartilage preservation is currently being evaluated.

Diagnostic criteria for recurrent tears in postoperative meniscus (meniscectomy or meniscal repair)

MRI does not diagnose recurrent tears on postoperative menisci as well as on native menisci (Table 5). Basically, the lower performance of conventional MRI is directly related to the amount of resected meniscus.

The signal intensity of repair tissue may be moderately high on short or intermediate echo time images (T1-, PD- and fat-suppressed-PD-weighted). After meniscal surgery, the accuracy of MRI to diagnose a new tear is about 80% [12]. When available, preoperative images and surgery report are very useful, especially because the parts of non-repaired meniscus may be assessed with the same diagnostic criteria as those applicable to native menisci.

In clinical practice the strategy is the following: first, a conventional MRI to classify the meniscus into one of the three following groups based on appearance: normal appearance, new tear, or doubtful. A displaced meniscal fragment is always a sign of a new tear. Parameniscal cysts result from communication between the joint and the basis of the meniscus, usually a horizontal tear, not necessarily unstable. The cyst may cause symptoms by itself. These cysts often do not enhance on CT arthrography and on T1-weighted sequence of MR arthrography, and conventional MRI is thus more sensitive.

If less than 25% of the meniscus has been previously resected, the diagnostic criteria for tears on native meniscus may be used, i.e. a high signal intensity on fluid-sensitive sequences (fluid-like or not) contacting a meniscal surface, visible on at least two 3-mm slices. The high signal contacting the surface must be in the same area of the meniscus on the two images, but one image can be in the coronal plane and one, in the sagittal plane [13,14].

If more than 25% of the meniscus has been previously resected or in case of meniscal repair, a new tear is identified by fluid-like high signal intensity on fluid-sensitive sequences contacting the meniscal surface and seen on at least two 3-mm slices [13]. The presence of a meniscal tear is doubtful

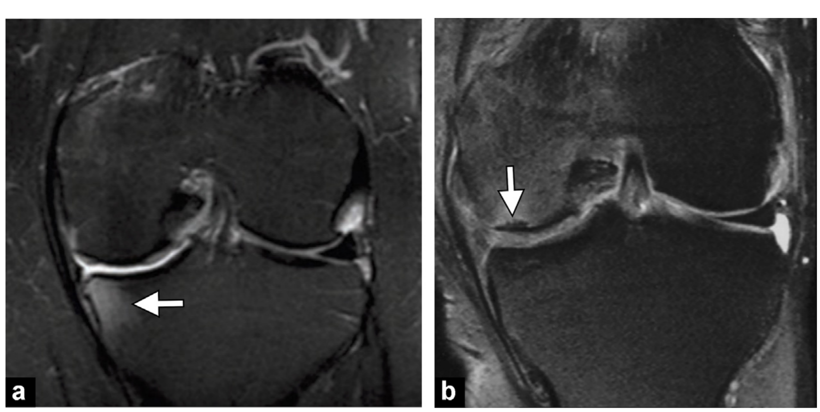

Figure 19. Modification of subchondral bone after meniscectomy: a: coronal fat-suppressed PD-weighted MR image. Bone edema-like high signal intensity (arrow) 1 month after medial meniscectomy indicating mechanical adaptation; b: coronal fat-suppressed PD-weighted sequence in another MR image. Mechanical osteonecrosis following partial medial meniscectomy (arrow).

Table 5 Diagnostic criteria for postoperative recurrent meniscal tears.

	Tear	Doubtful	Normal
All techniques	Displaced meniscal fragment	—	Possible border irregularities
CT arthrography or MR arthrography	Intrameniscal opacification (especially if deep)	—	No intramensical opacification Possible irregularities
Conventional MRI			
Less than 25% resected meniscus	Fluid-like or not high signal intensity on fluid-sensitive sequences contacting the meniscal surface on two 3-mm slice	Fluid-like or not high signal intensity on fluid-sensitive sequences contacting the meniscal surface on one 3-mm slice	Possible border irregularities
More than 25% resected meniscus Meniscal repair	Fluid—like high signal intensity on fluid-sensitive sequences contacting the meniscal surface seen on at least two 3-mm images	Fluid—like high signal intensity on fluid-sensitive sequences contacting the meniscal surface seen on only one 3-mm image	Possible border irregularities

if there is edema-like or fluid-like high signal intensity on fluid-sensitive sequences contacting the meniscal surface but seen only on one 3-mm slice. It should be noted that these diagnostic criteria need to be adapted if slices thinner than 3 mm are used, especially for 3D sequences.

If conventional MRI does not provide a definite diagnosis, and without obvious explanation for the pain (cartilage or subchondral bone), the best way to proceed is with intra-articular opacification, CT arthrography or MR arthrography.

On CT arthrography, signs of new tears following partial meniscectomy are: partial peripheral meniscal separation, longitudinal tears contacting both meniscal surfaces, horizontal tear to the base of the meniscus, and displaced meniscal fragment. Small irregularities, small tears (less than a third of the meniscus thickness or length) are not diagnostic criteria of new tears [15].

It should be noted than if MR arthrography is performed, radiologists should compare fat-suppressed T1-weighted sequences before and after intra-articular injection of gadolinium, as the quantity of the gadolinium that penetrates into the meniscal tear is often very small [16]. In some cases, conventional MRI is better than MR arthrography: some tears detected during arthroscopy are not visible on MR arthrography but well on conventional MRI [16].

Some experts have recommended indirect MR arthrography that involves an intravenous injection of contrast material followed by physical exercise, to create articular effusion of contrast material without performing joint puncture [12]. Performance seems similar to that of direct MR arthrography. The procedure should, however, be avoided during the first year following meniscal repair, because the repair zone may enhance.

Postoperative cartilage imaging

Cartilage may be surgically repaired in the following cases: osteochondral fractures, trauma-induced cartilage defects and osteochondritis. Four types of surgical techniques are available: fixation of osteochondral fracture, subchondral bone marrow stimulation (for instance microfractures), osteochondral graft transplantation (for instance mosaicplasty) and chondrocyte implantation.

Indications

These techniques are indicated in the case of deep defects affecting one side of the articular interline. Contraindications are morbid obesity, uncorrected misalignment, laxity and cartilage defects on both sides of the joint (osteoarthritis).

Debridement surgery is performed in case of symptomatic cartilage loose bodies. Osteochondral grafts and chondrocyte grafts are indicated for large lesions. However, there is no consensus about indications for each procedure. One should always consider treating the underlying cause, for instance misalignment and laxity (ligament reconstruction).

Techniques and postoperative imaging

Fixation with screws

Osteochondral fractures are surgically treated by fragment fixation with metallic or resorbable screws. The heads of the screws are embedded in the cartilage (Fig. 20). This surgery is evaluated based on osseointegration of the fragment into the subjacent cancellous bone and on recovery of articular

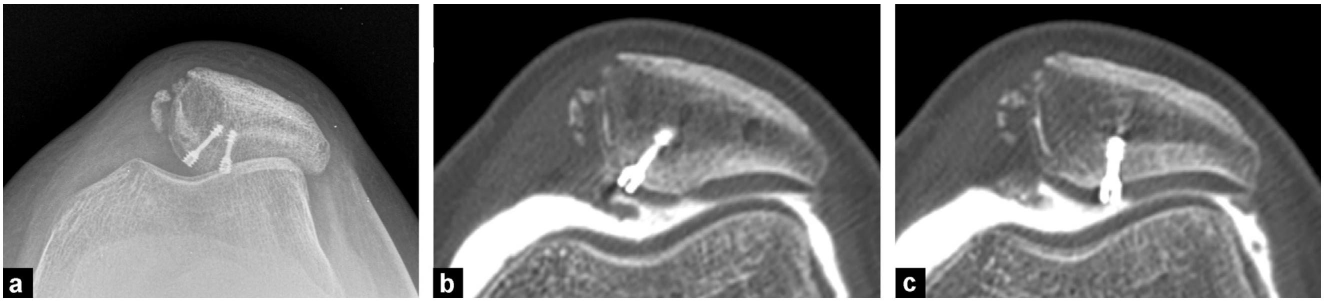

Figure 20. Osteointegration and recovery of articular congruity after osteosynthesis of an osteochondral fragment with 2 metallic screws following lateral patellar dislocation. X-rays, transverse view (a), and CT arthrography, axial images (b and c).

congruity. Resorbable screws are sometimes used to stabilize osteochondritis and cartilage loose bodies.

Microfractures and other stimulation techniques

Microfracture is the most widely used stimulation technique to repair cartilage. First it creates a clot and causes migration of bone marrow cells, including multipotential cells, which form fibrocartilaginous tissue. This fibrocartilage has mechanical properties not as good as native hyaline cartilage. The technique is indicated for lesions smaller than 2 or 3 cm^2. After surgery, modifications of the subchondral bone are observed with edema-like signal. This subchondral edema-like signal decreases and disappears after 1 year (Fig. 21). More or less sclerotic changes in the subchondral bone are observed with a subchondral plate often irregular on T1-weighted MR images (Fig. 22). Cartilage defect filling is usually complete, and even if the fibrocartilage generated is slightly heterogeneous on MRI and its surface slightly irregular, in the end there are almost no signs visible anymore. In 25 to 50% of the cases, there is overgrowth of the subchondral bone without necessarily any clinical sign [17—19].

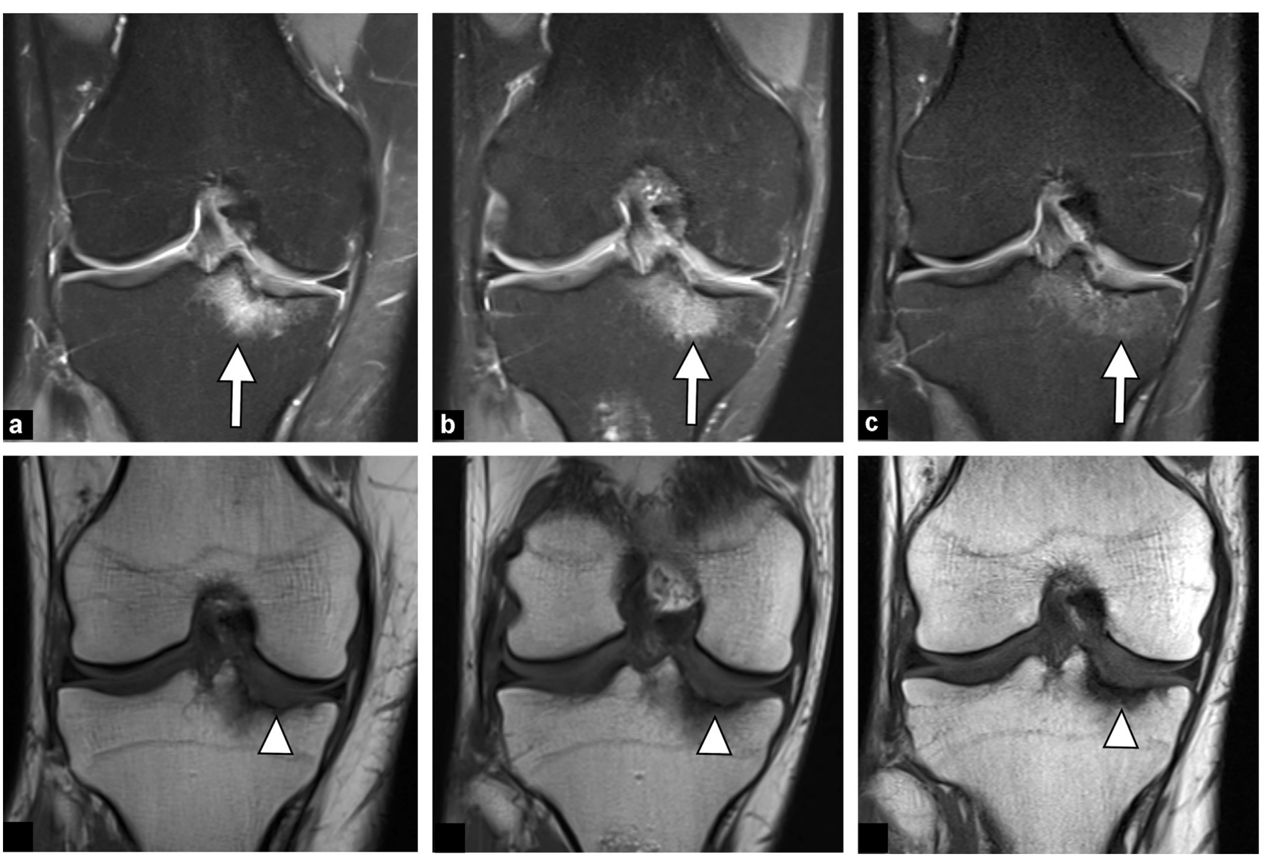

Figure 21. Evolution after microfractures on the tibial aspect of the medial femorotibial segment. Coronal fat-suppressed PD-weighted MR images (a—c) and T1-weighted (d—f) after 1 month, 4 months and 2 years, respectively. Decrease of the subchondral edema-like signal (arrows) and persistent irregularity of the subchondral bone plate on T1-weighted images (arrowheads).

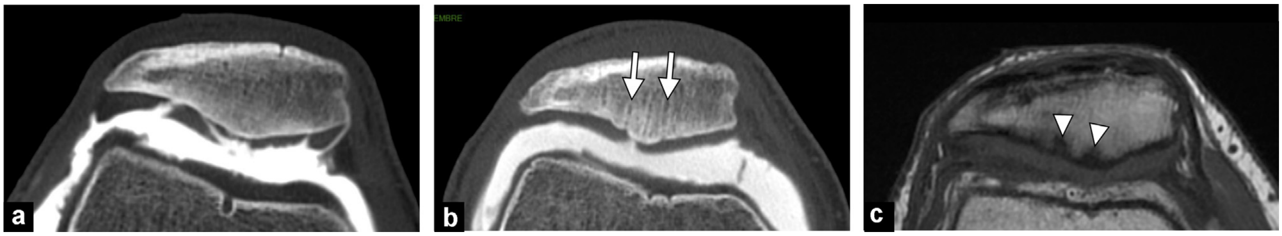

Figure 22. Deep microfractures and evolution: a: axial view, CT arthrography. Many cartilaginous ulcerations; b and c: axial images, CT arthrography and T1-weighted MR images after 1 year. Path of lesions is visible on CT arthrography (arrows) as well as irregularities of the subchondral bone plate on T1-weighted image (arrowheads).

Long-term results are evaluated based mainly on articular congruity.

Osteochondral autograft

In this procedure, osteochondral plugs are obtained from a non-weight bearing area (generally the lateral and medial part of the femoral trochlea) and are implanted in the cartilage defect. The cartilage obtained consists of about 80% hyaline cartilage (plugs) and 20% fibrocartilage (between the plugs). Load handling must be prohibited for several weeks (usually 4 to 8 weeks). During the first 6 months, edema-like high signal intensity on fluid-sensitive sequences by the graft and the underlying cancellous bone is observed, as well as enhancement at the interface between the plugs and the underlying cancellous bone (Fig. 23). Between 6 months and 1 year, the signal returns almost to normal, with possible persistent defects at the subchondral plate and cartilaginous surface. In rare cases, the bone edema-like high signal intensity on fluid-sensitive sequences lasts two years. Cartilage may be slightly heterogeneous because of fibrocartilage that fills the space between the plugs. Early postoperative complications are due to incorrect placement with articular incongruity (protrusion, subsidence or rotation of the plugs). Secondary complications are unstable plugs with failed osseointegration. Cyst formations between the plugs and the adjacent

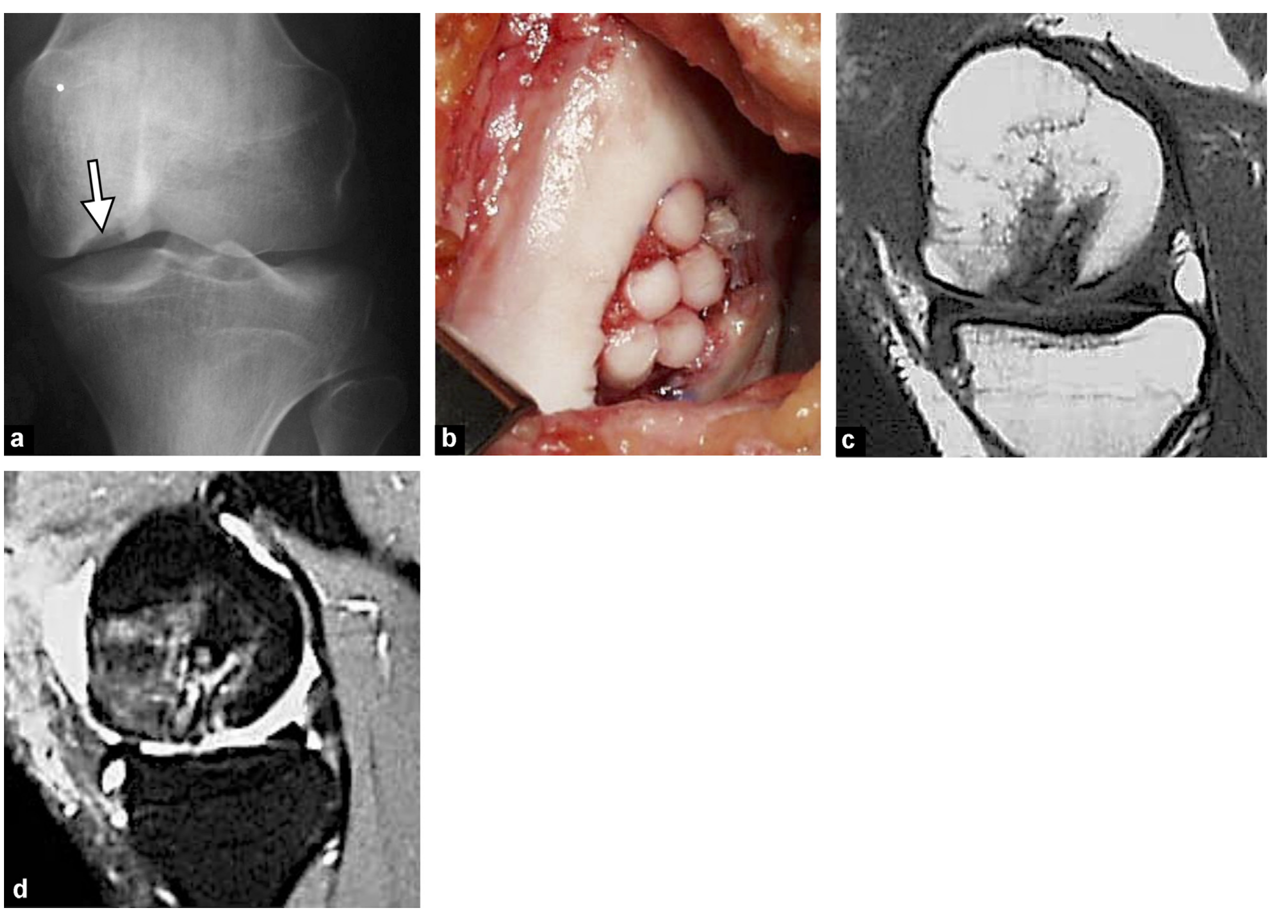

Figure 23. Osteochondral graft ''mosaicplasty'' type: a: osteochondritis on initial radiograph (arrow); b: intraoperative view of osteochondral plugs; c: T1-weighted MR image in the sagittal plane; d: fat-suppressed PD-weighted sequences in the sagittal plane 6 months after surgery. Persistent edema-like signal in the plugs and adjacent bone marrow.

bone are signs of failed osseointegration. On the graft donor site, the initial edema-like signal intensity on fluid-sensitive sequences disappears after 6 to 9 months. Complications, mainly pain at the graft donor site is possible [17—19].

Autologous chondrocyte implantation

Autologous chondrocyte graft is not widely performed in France, because it involves complex logistics, regulatory constraints and has not been clearly shown to be superior to the other techniques. The first-stage of the procedure consists in harvesting cartilage from a non-weight-bearing area, then to culture it in vitro, and finally, a few weeks later, reimplant the cultured chondrocytes in the cartilage defect. The cultured chondrocytes are reimplanted under an autologous periosteal patch or in a biological matrix [20]. The main complications are hypertrophy of the periosteal membrane, delamination of the periosteal membrane or delamination of the graft. The initial subchondral edema-like signal intensity disappears completely or almost completely after one year. At first, the graft shows a fluid-like signal intensity on fluid-sensitive sequences that decreases and becomes, after 6 months to 1 year, similar to the signal of native cartilage, even if it often remains moderately heterogeneous.

Conclusion

For ACL reconstructions, it is important to remember: correct locations of the tunnels, usual changes of signal of the graft over time, and complications such as anterior impingement, cyst formation in the tunnels, and localized anterior arthrofibrosis (cyclops lesions). For menisci, it is important to remember the imaging strategy (we recommend to always start with conventional MRI, then to add, if needed, CT arthrography or MR arthrography), the normal postoperative appearance and the imaging diagnostic criteria for recurrent postoperative meniscal tears. Finally for cartilage, one should remember that basically all techniques show edema-like signal intensity on fluid-sensitive sequences at the site of repair that returns to normal again after one year, and that surgery is evaluated based on articular congruity as well as on the appearance of subchondral bone.

Take-home messages

ACL reconstruction:

- on sagittal images of ACL reconstructions, the aperture of the femoral tunnel should be located at the junction of the line drawn along the posterior femoral cortex and the line drawn along the roof of the intercondylar notch (Bluemensaat line).
- the tibial tunnel aperture should be in the anterior portion of the second third, i.e. anterior aspect of the middle of the tibial epiphysis;
- an inaccurate placement of the femoral tunnel affects the graft isometry;
- if the tibial tunnel is placed too anteriorly, there is intercondylar notch roof impingement.

Meniscal surgery:

- two main types of meniscal surgery: partial meniscectomy and meniscal repair;
- after meniscal surgery, first-line MRI is often sufficient to diagnose recurrent tears; however sometimes in case of doubt, it is necessary to perform CT arthrography or MR arthrography.

Cartilage:

- four main types of surgery techniques: fixation of osteochondral fracture, subchondral bone marrow-stimulation (for example microfractures), osteochondral graft transplantation (for example mosaicplasty) and chondrocyte implantation;
- globally, all techniques induce bone edema-like signal intensity on fluid-sensitive sequences at the site of repair that returns to normal usually after one year;
- cartilage repair is evaluated based on articular congruity and on the appearance of the subchondral bone.

Disclosure of interest

The authors declare that they have no competing interest.

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