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REVIEW ARTICLE

Imaging of posterior cruciate ligament (PCL) reconstruction: normal postsurgical appearance and complications

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Abstract This article reviews the normal postsurgical anatomy and appearance of PCL reconstructions on MDCT and MRI with the different operative techniques considering the type of tibial fixation, use of a single or double bundle, type of tendon graft and the fixation material. Tunnel positioning, appearance of the ligament graft and findings at the donor site are considered. Imaging signs of PCL graft failure and its possible causes are discussed. Imaging manifestations of other potential complications of both the PCL graft and donor sites are described, such as laxity, impingement, arthrofibrosis, ganglion cyst formation or complications related to the fixation material.

Keywords Posterior cruciate ligament reconstruction · Ligament plasty · Postsurgical imaging · Postsurgical complications · Knee

Introduction

Posterior cruciate ligament (PCL) lesions are much less frequent than anterior cruciate ligament (ACL) injuries, and many are partial-thickness tears that can be managed conservatively [1–4]. Current knowledge of the impact a PCL deficiency has on the biomechanics of the knee, which may derive from early osteoarthritis due to chronic instability, and the advances in the surgical techniques have motivated an increase in the number of surgeries [1–4]. Imaging has also experienced significant progress, yet PCL reconstruction remains an almost unexplored territory for radiologists, possibly because it is performed less often and there is a lack of standardization of the surgical techniques [1, 4]. A brief description of the most widespread surgical techniques for PCL reconstruction and their normal postsurgical appearance on MDCT and MRI is presented, including findings at the donor sites. Signs of graft failure and its possible causes are evaluated, including tunnel placement and other relevant parameters, as well as potential complications.

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Surgical techniques

The indications for PCL reconstruction are: acute PCL lesions with significant instability (grade 3+), bone avulsion fractures, combined multiple ligament injuries or chronic symptomatic PCL laxity [1, 2, 4]. PCL reconstruction techniques have developed considerably in the last decades, although there is no accepted standard technique [3, 5]. The PCL can be repaired in isolation or together with other ligaments [3, 7].

The native PCL is formed by two bundles, the anterolateral (AL) and posteromedial (PM), although it could be described as a continuity of fibers that rotate during the flexion-extension cycle of the knee [3]. Knowledge of the insertion sites of the native PCL in the femur and tibia helps in the positioning of the tunnels for PCL reconstruction (Fig. 1). It is generally accepted that the optimal positioning of the graft is that which most closely resembles the native PCL [6–8] and that femoral tunnel placement is more important than the tibial tunnel position [2, 5, 7, 8].

Surgical techniques vary according to [3, 9, 10]:

The type of tibial fixation (Fig. 2): tibial inlay or transtibial techniques. In the *inlay* technique, the graft is directly fixated to the tibia [2, 6, 10] and should

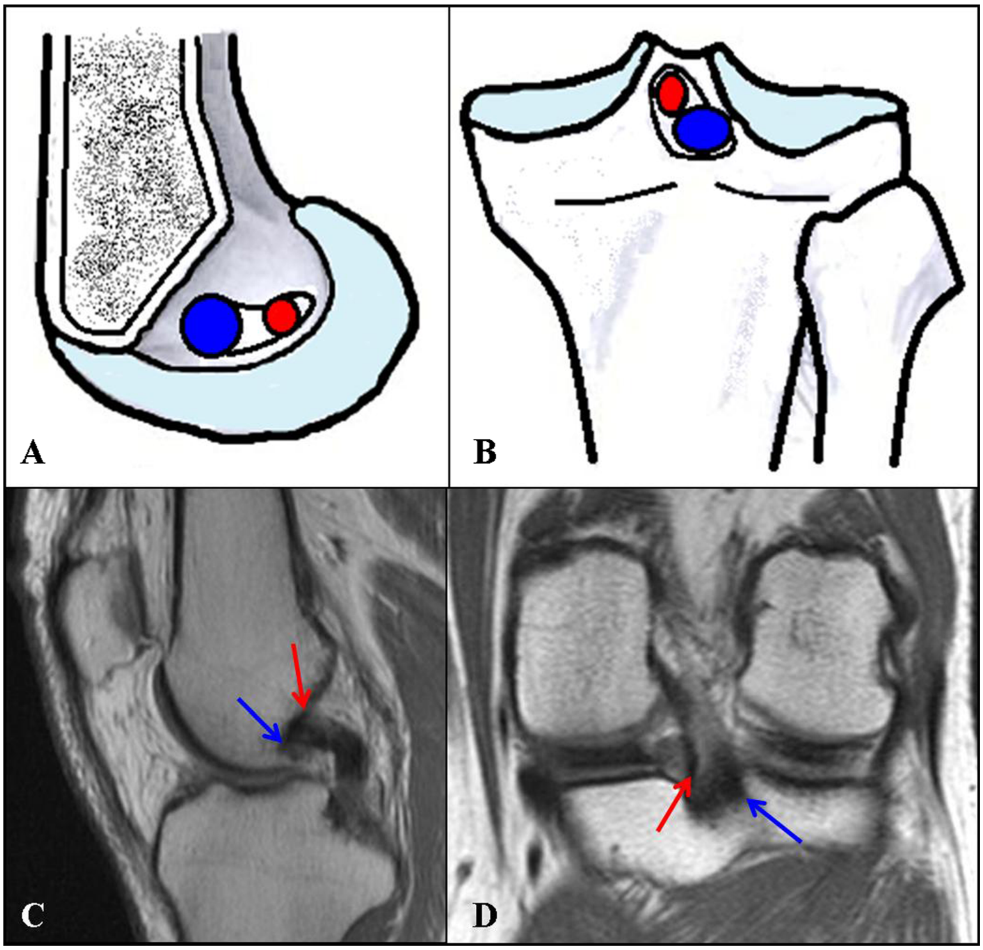

Fig. 1 Insertion of the native PCL, showing the AL bundle (*blue*) and PL bundle (*red*) insertion sites. **a** Sagittal drawing of the femur at the intercondylar notch. **b** Posterior view of the tibial plateau. **c** Sagittal PDI at the intercondylar notch. **d** Coronal T1-weighted image (T1WI) at the posterior region of the intercondylar notch

supposedly avoid the so-called *killer turn* (Fig. 2d), which occurs at the opening of the tibial tunnel in the *transtibial* technique [3, 9].

The single or double bundle and accordingly the single or double femoral tunnel (Fig. 3). The *single-bundle* technique reconstructs the more potent AL bundle, but does not limit the posterior displacement of the tibia in 90° flexion. Hypothetically, the *double bundle* technique, which more closely resembles the native PCL, would be more effective in controlling posterior stability in flexion,

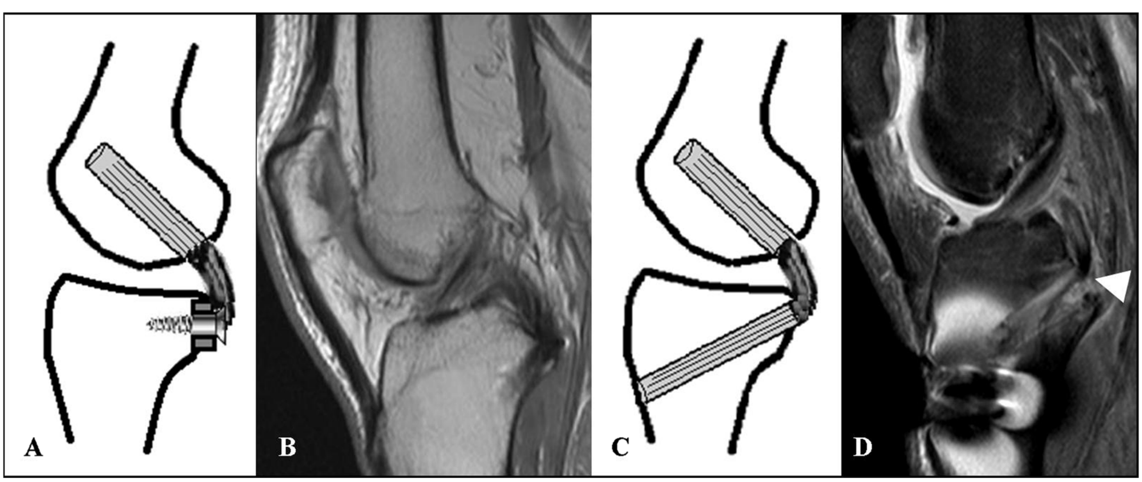

Fig. 2 Tibial fixation techniques. **a** Drawing and **b** sagittal PD MR image of a tibial inlay technique. **c** Drawing and **d** sagittal FS PDI of the transtibial tunnel technique. Note the “killer turn” in the opening of the tibial tunnel (*arrowheads*), associated with impingement

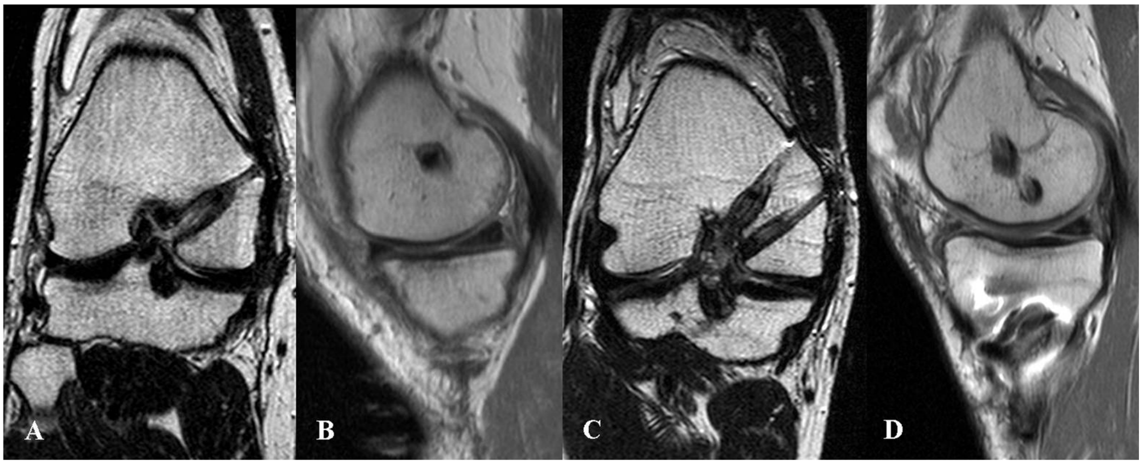

Fig. 3 Single- and double-bundle techniques. **a** MR coronal T2WI and **b** sagittal PDI in a single-bundle reconstruction. **c** Coronal T2WI and **d** sagittal PDI of a double-bundle reconstruction

but there is no consensus in the literature and it adds technical difficulties [3, 5, 11].

The type of tendon graft. *Bone-tendon-bone* (*BTB*) *grafts* are generally chosen in young athletes, since they allow a quick re-establishment of physical activity [1, 6]. The graft is usually harvested from the central third of the patellar tendon along with bone plugs from both insertions [1, 2, 6]. *Hamstring grafts* have several advantages, including the absence of complications in the anterior region of the knee and the fast regeneration of the tendons [1]. They are usually obtained from the gracilis and semitendinous tendons, harvesting long fibers, which are folded over, resulting in a graft composed of several bundles [1, 2].

The fixation material, of which there are two main categories with an ample range of options, bone plug graft fixation and soft-tissue fixation (metallic or resorbable) [1].

Postsurgical imaging

Radiographs are routinely obtained in the immediate postoperative period for overview assessment of tunnel placement and the position of the fixation material, but interpretation is variable [6–8]. Postoperative imaging with MRI or MDCT is generally requested only in symptomatic patients.

MRI is the technique of choice in these patients as it permits an overall evaluation of the PCL reconstruction [8, 10, 12], including the ligament graft itself, which can only be evaluated by this technique, although indirect signs of its status are reckonable with other modalities. MRI also allows appraisal of the tunnels and the surrounding bone, and it serves to assess bone and soft tissue complications, including the donor sites. Tunnel positioning may be checked at a glance on sagittal images, but all planes have to be reviewed for precise assessment of tunnel placement and graft status. MRI protocols may vary, but as a general rule it is convenient

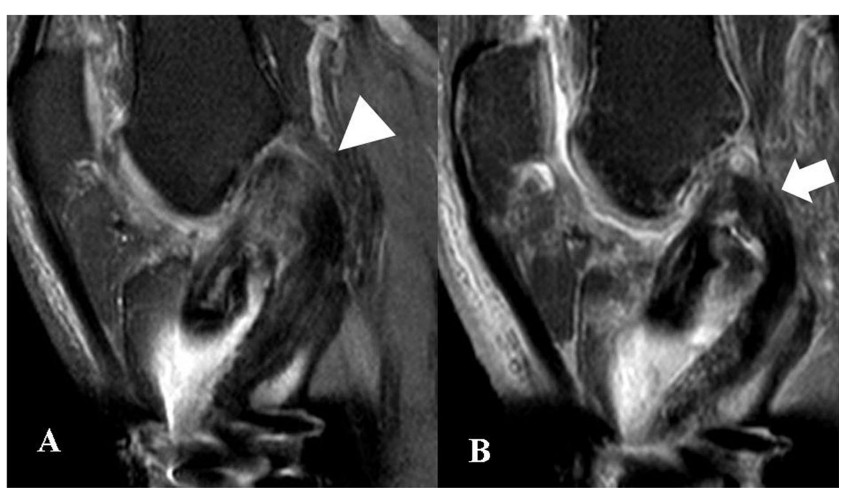

Fig. 4 MRI in a 32-year-old patient with double ligament reconstruction (PCL and ACL) shows variation of the signal intensity with the age of the graft. **a** Sagittal PD FS 3 months after surgery shows increased signal intensity and slight thickening of the PCL graft (*arrowhead*). **b** At 1.5 years after the surgery, normalization of the signal intensity with hypointensity throughout the PCL graft is observed (*arrow*)

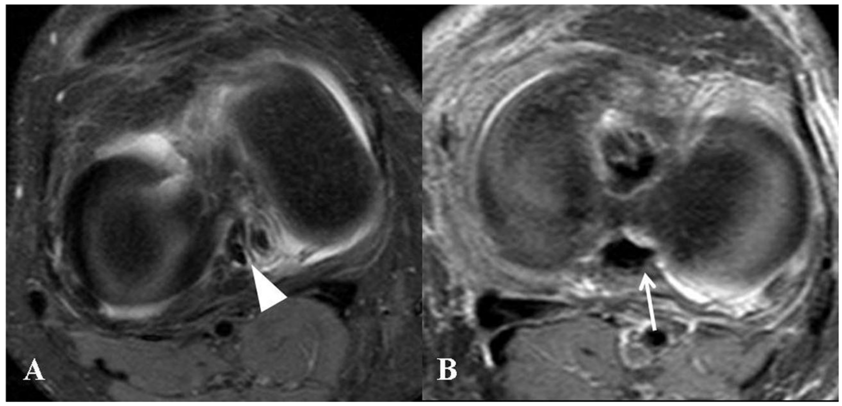

Fig. 5 Graft types on axial PD FS MRI. **a** Hamstring graft with high signal linear intensities indicating fluid between graft bundles, a normal finding (*arrowhead*). **b** BTB patellar tendon graft in a patient with double cruciate ligament reconstruction shows homogeneous low signal intensity (*arrow*)

to include at least one T2-weighted sequence (T2WI) for optimal evaluation of the ligament graft [1, 5], ideally an oblique sagittal plane following the course of the ligament graft. In PCL reconstructions, contrasting with ACL plasties, magnetic susceptibility artifacts may truly hinder the evaluation of the graft because of a more proximal location of the

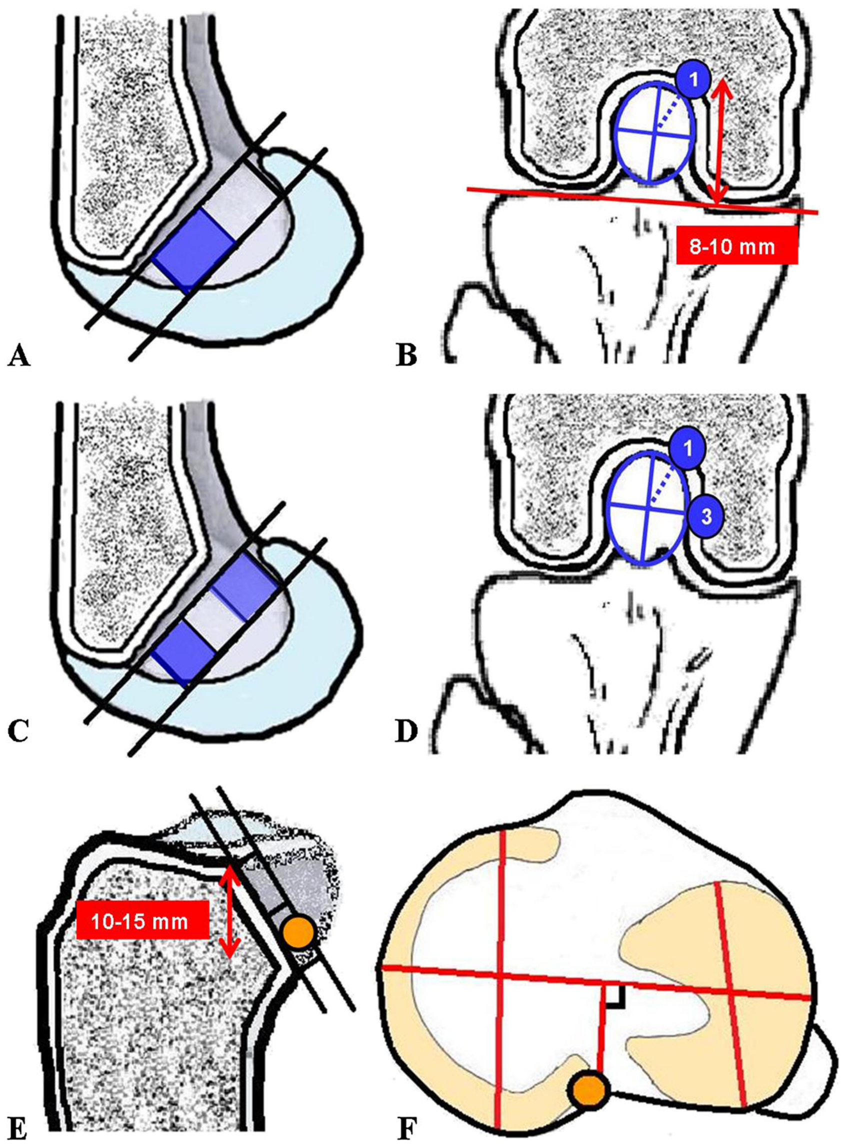

Fig. 6 Optimal tunnel positioning. **a**–**b** Femoral tunnel placement in a single bundle technique: **a** In the sagittal plane the opening (*in blue*) should be located in the anterior half of the insertion site of the native PCL and (**b**) in the coronal plane, at 1 o'clock or 11 o'clock in the right (as shown) and left knee, respectively, 8–10 mm from the articular margin. **c**–**d** Femoral tunnel in double bundle reconstructions. **c** In the sagittal plane, the articular openings should be located with one in the anterior third of the native PCL insertion site and the other in the middle to distal third and (**d**) in the coronal plane at 1 o'clock and 3 o'clock (right knee, as shown) and at 11 o'clock and 9 o'clock (left knee). **e**–**f** The tibial fixation site (*orange circles*) in both techniques (inlay and transtibial) should be located (**e**) on the sagittal plane, in the middle of the posterior half of the retrospinal surface, 8–15 mm distal to the articular surface, and (**f**) on the axial plane immediately medial to the articular midline

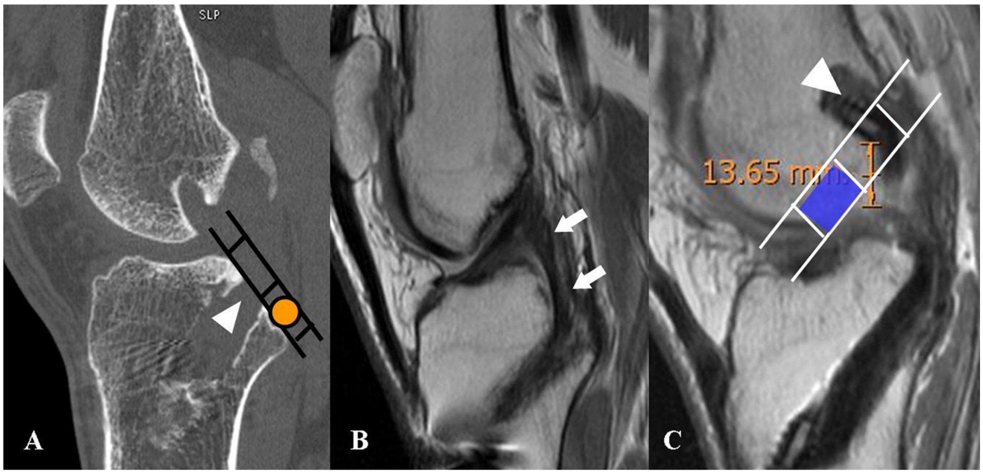

Fig. 7 Examples of incorrect tunnel positioning. **a**–**b** Excessively proximal position of the tibial tunnel in a patient with instability. **a** Sagittal MDCT image shows high articular opening of the tibial tunnel (*arrowhead*) in the central region of the retrospinal line. Note the optimal position (*orange circle*). **b** Sagittal PD MRI shows a PCL graft with a very vertical course, associated with a diminished capability to resist posterior tibial translation. **c** Sagittal PDI shows the femoral tunnel opening in an excessively posterior and high position (*arrowhead*) outside the optimal position (*blue rectangle*) and exceeding the desired height

tibial fixation, especially in the tibial inlay technique [1, 2]. Nonetheless, an acceptable evaluation of the intraarticular course of the graft is usually possible in isolated PCL reconstructions [1, 2, 12], but not in combined multiple ligament reconstructions. In general, gradient echo sequences are discouraged, and the use of fat saturation (FS) sequences will be limited by the number of artifacts, which depends on the type and quantity of fixation material [1]. Resorbable materials produce fewer artifacts, which tend to diminish over time [1, 12].

MDCT offers a more precise vision of the bony tunnels [5, 7, 8] and serves to evaluate the status of the fixation material. A certain degree of assessment of soft tissue structures is sometimes possible, and signs of instability may be appreciated, suggesting disruption or laxity of the plasty. CT scans are usually requested in patients with a known failed PCL

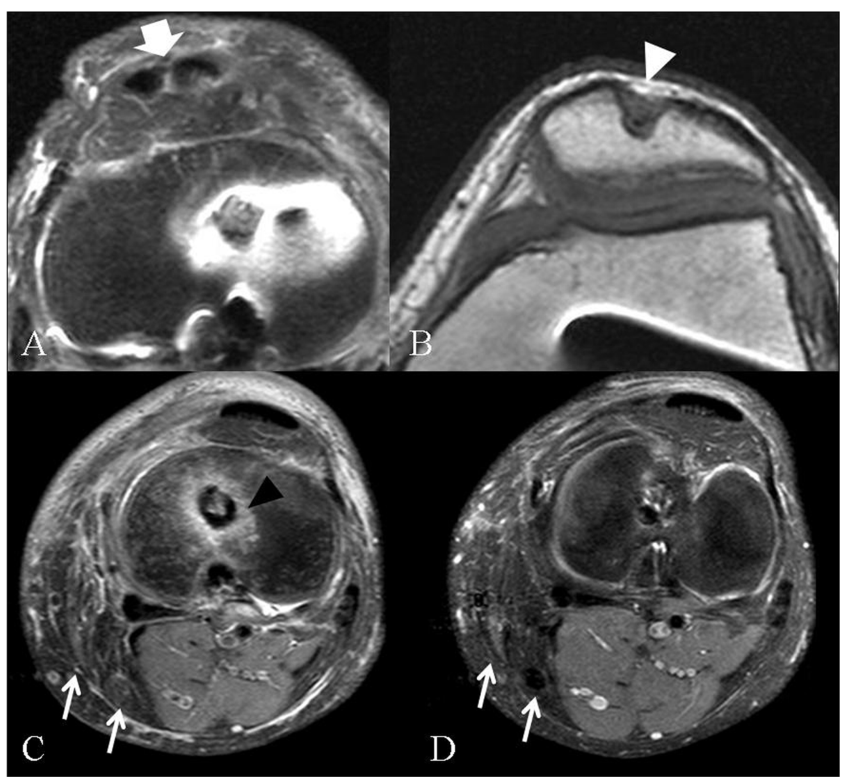

Fig. 8 MRI of normal postsurgical appearance of the donor sites. **a**–**b** Donor site of a BTB patellar tendon graft. **a** Axial FS PDI shows a central defect and slight thickening and increased signal intensity in the patellar tendon, a normal finding in the early postoperative period. **b** Axial T1WI demonstrates a bone defect in the inferior pole of the patella. **c**–**d** Donor site of a hamstring graft. **c** Axial FS PD 1 month after surgery shows small fluid laminar collections around the course of the gracilis and semitendinous tendons. The tendon remnants are markedly thin and show attenuated signal intensity (*arrows*). **d** Follow-up 8 months after surgery demonstrates resolution of the soft tissue findings in the medial region and restoration of the normal thickness and signal in the donor tendons (*arrowheads*)

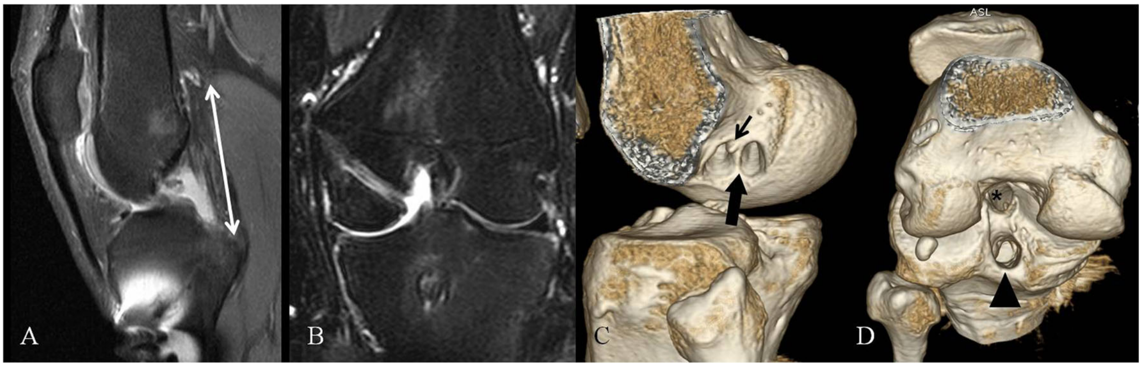

Fig. 9 Chronic disruption of the graft. **a** Sagittal PD FS MRI and **b** coronal T2WI FS. No graft is identified in the intercondylar region, with fluid occupying the theoretical course of the graft. As an indirect sign of disruption, there is posterior displacement of the tibia (*arrow* in ***a***). **c** MDCT 3D VR for new ligament plasty planning shows the intercondylar notch and double femoral tunnel (*thick arrow*). Note slight bone spurring in the anterior tunnel opening (*arrow*). **d** MDCT 3D VR shows tibial tunnel opening (*arrowhead*). The articular opening of an ACL ligament reconstruction may be appreciated anteriorly (*asterisk*)

reconstruction who are to undergo a new ligament reconstruction and to determine the tunnel position, the condition of the articular openings of the tunnels in search of stenosis and bone spurs, the tunnel inner contour and width, and the state of the surrounding bone so as to decide whether the existing tunnels are viable for the new reconstruction. In this setting, 3D volume-rendered reconstructions are helpful to surgeons since they clearly depict the position and shape of the articular tunnel openings and the intercondylar notch (see Fig. 9c–d).

The following information should be included in the postoperative imaging report: the employed surgical technique and the type of fixation material, the status of the ligament graft, and the morphology and position of the tunnels. Deformity of the articular tunnel openings and abnormalities in the bone surrounding the tunnel courses need to be described. Preservation of the femorotibial alignment on sagittal images should be assessed for signs of instability. Posterior translation of the tibia with respect to the femur, the imaging equivalent to the posterior drawer test, is an indirect sign of graft insufficiency [1, 7, 10]. Evidently, signs of complications, both intraarticular or at the donor sites, need to be signaled. Any fixation material displacement or rupture should be noted.

Normal postsurgical findings

Ligament graft

The MRI appearance of the PCL plasty varies significantly depending on the type of graft, fixation technique and time elapsed since the surgery [1, 10].

The MR signal intensity changes with the age of the graft, i.e., the time elapsed since the surgery [1, 5, 10]. In the first 3–4 months, the graft is avascular and will show hypointensity on all sequences, similar to the donor tendon [1]. At 4–8 months after the surgery, the tendinous graft undergoes a remodeling and resynovialization process called "ligamentization," transforming into a tissue similar to the native PCL [1, 2, 4, 10]. During this phase, high T2WI signal intensity may appear that should not be mistaken for a tear or impingement. The signal intensity should always be lower than fluid signal [1], and fiber continuity must be observed. At 1–2 years after surgery, the appearance of the graft should be similar to the native PCL, hypointense on all sequences [1, 2, 4, 10] (Fig. 4).

Hamstring tendon grafts present a notable difference compared to BTB grafts due to their internal configuration with

Fig. 10 Sagittal PD MRI in a patient with graft laxity shows buckling of the PCL graft and posterior displacement of the tibia (*arrow*), indicating instability

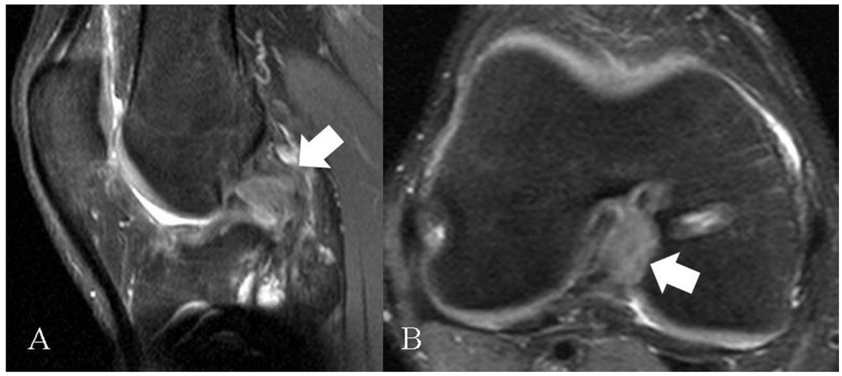

Fig. 11 PCL graft impingement in a patient with flexion-extension limitation. **a** Sagittal and **b** axial PD FS MRI shows thickening and increased signal intensity of the intraarticular course of the graft (*arrows*)

several bundles: longitudinal linear images of intermediate or high signal intensity may be observed between the bundles, representing a normal finding that would be clearly abnormal in a BTB graft, formed by a single bundle (Fig. 5) [1, 2, 4]. These laminar collections are usually reabsorbed during the first or second year after surgery [1].

Arthrofibrosis is a very frequent finding in PCL reconstructions, much more than in ACL plasties, owing mainly to movement restriction in the immediate postoperative period. It is hypothesized that it may actually contribute to stabilization of the knee, and therefore a certain degree of arthrofibrosis may be considered a normal finding, considering it does not limit the range of motion [1, 2, 13].

Tunnels

There are few publications on tunnel positioning in PCL reconstructions [1, 2, 8]. Mariani et al. [8] published a method for evaluation with MRI and Gancel et al. [7] with CT, both for reconstructions with a single femoral tunnel. Unifying both authors' criteria and according to other publications in the literature [2, 3, 5, 6, 11], the optimal location of the tunnels may be simplified as follows (Fig. 6). The location of the articular opening of the femoral tunnel depends on the number of bundles. In the single bundle technique, the opening will be located in the anterior half of the insertion site of the native PCL (near the femoral insertion of the native AL bundle), at 1

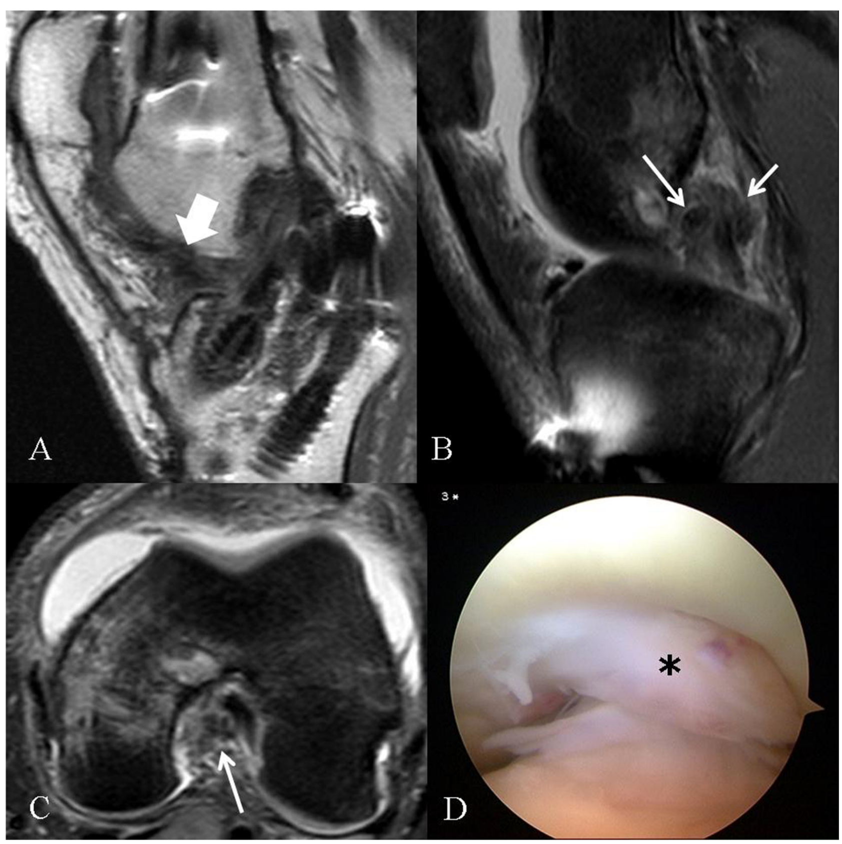

Fig. 12 Arthrofibrosis. **a** Sagittal PD MRI in a patient with a flexion-extension limitation following BTB grafting and diffuse anterior arthrofibrosis. Note the spiculated ill-defined mass with low signal intensity in Hoffa's pad (*thick arrow*). **b** Sagittal PD FS and **c** axial PD FS in a patient with focal arthrofibrosis. A hypointense nodule surrounding the intercondylar course of the PCL graft may be identified (*arrows*). **d** Arthroscopic image of the "cyclops" lesion (*asterisk*)

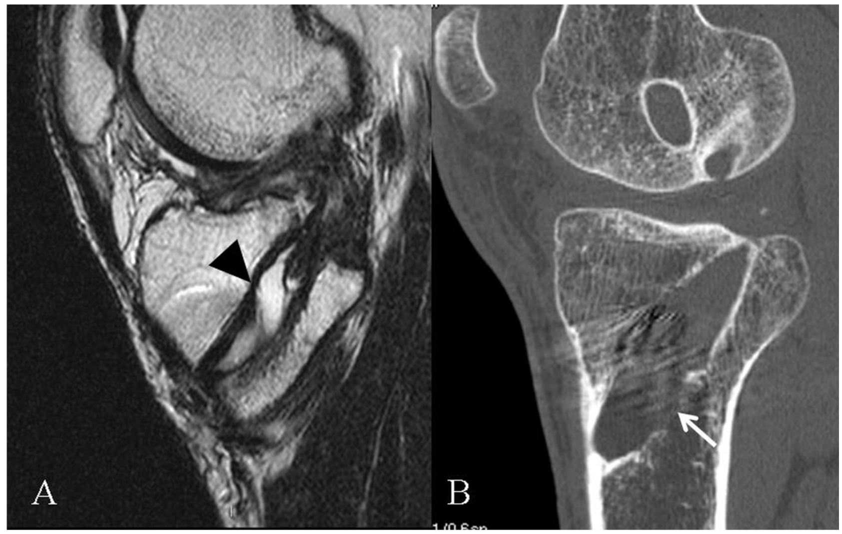

Fig. 13 Ganglion cyst formation and widening of the tibial tunnel in hamstring tendon grafts. **a** Oblique sagittal T2WI shows a fluid collection in the tibial tunnel consistent with a ganglion cyst (*arrowhead*) and mild widening of the tunnel. **d** Sagittal MDCT shows widening of the tibial tunnel and focal irregularity of its cortical lining (*arrow*)

o'clock or 11 o'clock in the right and left knee, respectively, and 8–10 mm from the articular margin [2, 5–7]. In double femoral bundle reconstructions, the articular opening sites should be located with one in the anterior third of the native PCL insertion site and the other in the middle to distal third, at 1 o'clock and 3 o'clock (right knee) and at 11 o'clock and 9 o'clock (left knee) [5–11]. The tibial opening in both the inlay and transtibial techniques should be located in the middle of the posterior half of the retrospinal surface, immediately medial to the articular midline, 8–15 mm distal to the articular surface. A small variability in tunnel positioning is allowed, and it is not clear what degree of precision is required to avoid complications [2, 3, 7, 8]. It is considered that a tunnel is abnormally placed when 75 % or more of the articular opening lies outside the anatomic insertion site [5].

The most frequent mistakes in tunnel positioning (Fig. 7) are an excessively high and posterior situation of the femoral tunnel or an excessively proximal position of the tibial tunnel, determining a vertically oriented graft with limited competence to resist posterior tibial translation [5].

In the early postoperative period and up to 12 months following surgery, a variable degree of persistent bone marrow edema may be seen around the tunnels and in the fixation sites on MRI [1]. A slight radiolucency around the tunnels may be appreciated on MDCT before fixation material incorporation, and with time sclerosis of the tunnel margins may occur [6].

Normal postsurgical appearance of the donor sites (Fig. 8)

In the BTB technique, a central defect of about 5 mm in the patellar tendon and small bone defects in the inferior pole of the patella and tibial tuberosity will be appreciated. Initially, the patellar tendon will appear thickened and with increased signal intensity on T1- and T2WI. In the first 2 years following surgery, this defect will be occupied by a tissue indistinguishable by MRI from the native tendon, showing hypointense signal intensity on all sequences.

At the donor site of hamstring grafts, it is usual to see small laminar fluid collections following the course of the grafted tendons during the 1st months after surgery. In the following 6–12 months, signs of tendinous regeneration will be progressively appreciated, and after the 1st year, it is difficult to detect the postsurgical changes, except at the tibial insertion of the

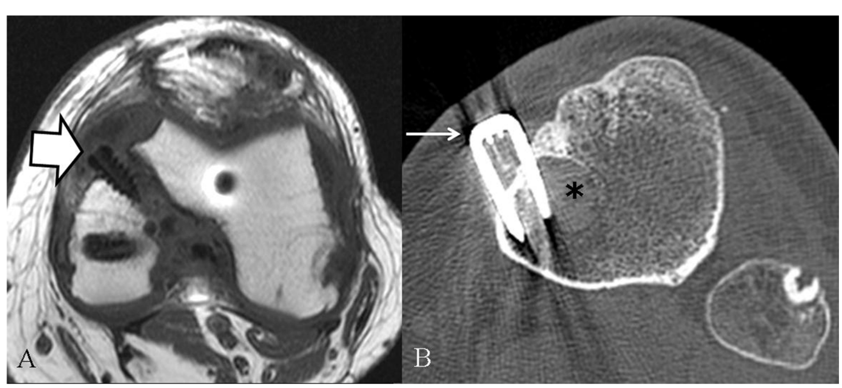

Fig. 14 Complications with the fixation material. **a** Axial PD MRI shows an extruded interference screw (*arrow*) protruding on the soft tissues of the anteromedial region of the knee. **b** Axial CT image shows a superficially placed Richards staple (*arrow*), protruding on the soft tissues adjacent to the extraarticular opening of the tibial tunnel (*asterisk*)

grafted tendons (the distal 1–2 cm), which do not recover. There is generally no significant atrophy of the corresponding muscles [1].

Complications

Complications of the ligament graft

According to the clinical symptoms, different complications may be distinguished:

1. An *unstable knee* indicates graft failure due to disruption or laxity.
2. *Limitation of flexion-extension* of the knee may be secondary to graft impingement, arthrofibrosis or intraarticular loose bodies [1, 12].
3. *Persistent knee pain* may be due to multiple causes.

Disruption of the PCL graft (Fig. 9) can occur at any moment following reconstruction, but the graft is most vulnerable during ligamentization [1, 10]. Rupture of the graft may be caused by a new traumatic mechanism or by chronic impingement. Absence of visualization of the graft and presence of a full-thickness defect of fluid signal intensity are the most specific signs of graft disruption [1, 2, 10]. Posterior displacement of the tibia may be present as an indirect sign of disruption [1, 7, 10].

Laxity or stretching of the PCL graft (Fig. 10), more likely with hamstring grafts, should be considered if there is knee instability with integrity of the graft fibers on MRI. Bowing or buckling of the plasty may be observed. In the majority of cases, surgical intervention is required to recover stability, by means of either graft tightening or new ligament reconstruction [1].

Graft impingement (Fig. 11) is a noteworthy complication, since it presents with a flexion-extension limitation, but in the long term may derive from a graft tear. Erroneous location of the tunnels or the killer turn (see Fig. 2) in the transtibial technique may cause a forced position of the ligament graft, causing friction with the bony structures, which will eventually cause fraying, fibrosis, tears in the graft bundles and subsequent complete disruption [1]. On MRI, thickening and high signal intensity on T1- and T2WI may be noticed in the intraarticular course of the graft, which will not diminish but will persist or worsen over time [1, 10]. This finding should not be confused with the normal hyperintensity observed during the remodeling phase, which should resolve. Another sign of impingement is buckling of the graft at the articular opening of the tunnels [1].

Significant arthrofibrosis may cause pain and flexion-extension limitation of the knee and requires arthroscopic resection [1, 10]. There are two types of arthrofibrosis (Fig. 12), focal and diffuse [1]. Focal arthrofibrosis is also known as a “cyclops lesion” because of its arthroscopic appearance and consists of a nodule of fibrous tissue typically located around the PCL graft or in Hoffa’s fat pad [1, 2]. Due to its fibrous nature, it appears hypointense on all sequences, although the T2WI signal intensity is variable [1, 2, 10]. The diffuse form generally presents as a spiculated, ill-defined mass of low signal intensity [1].

Ganglion cyst formation (Fig. 13a) is associated with widening of the tunnels, but there is controversy as to its relation with graft failure [1, 10]. It is more common with hamstring tendon grafts and allografts [1, 5]. Ganglion cysts are formed in the interior of the tibial tunnel and as they grow may protrude into the joint or into the soft tissues adjacent to the extraarticular opening of the tunnel [1]. They may be asymptomatic or cause pain, flexion-extension limitation or a palpable mass [1]. On MDCT these lesions appear as a fluid density mass or as widening of the tunnels with wall remodeling and loss of definition of the cortical borders. On MRI, a lobulated cystic structure can be observed [1].

Widening of the tunnels (Fig. 13b) may be caused by incomplete incorporation of the graft in the tunnel or by the

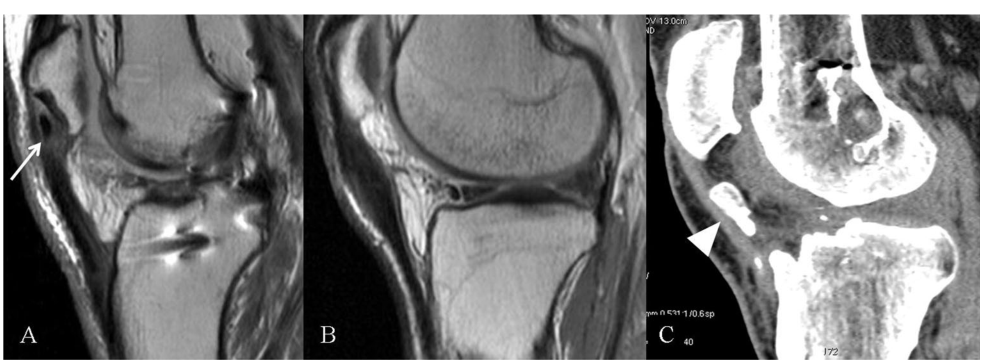

Fig. 15 Complications at the donor site of a patellar tendon BTB graft. **a** Sagittal PD MRI shows altered signal intensity and mild thickening of the patellar tendon, suggesting tendinopathy, and avulsion of a small bone fragment from the proximal insertion (*arrow*). **b** Marked thickening and increased signal intensity in the proximal region of the patellar tendon indicating tendinopathy. **c** Sagittal MDCT image shows heterotopic ossified foci in the patellar tendon (*arrowhead*)

effect of a ganglion cyst, although in the majority the cause remains unknown [10]. Widening is considered significant if there is an increase of 50 % or more in the area of the tunnel [5]. Movement of the graft inside the tunnel may occur, termed the "windshield wiper effect" [10], but it does not usually have relevant consequences.

Fixation material may shift or rupture (Fig. 14) [6]. If fixation material protrudes into the periarticular soft tissues, it may cause pain, inflammatory changes, development of fluid collections, etc. In the case of resorbable material, reactive synovitis in the 1st months following surgery is common. Bone resorption leading to the appearance of cysts may also occur during incorporation.

Complications at the donor sites

Complications at the donor sites are more frequent in the BTB technique (Fig. 15) [1, 10], presenting with pain in the anterior compartment of the knee and patellar tendon degeneration. Thickening>10 mm or hyperintensity on MRI that persists over time suggests patellar tendinopathy and should not be mistaken with the normal findings of the early postoperative period [1, 10]. Residual patella baja, patellar tendon rupture and patellar fracture are rare complications [1, 6, 10].

In the donor site of hamstring tendon grafts, there may be weakness or persistent pain. Rupture of the native tendons, generally due to overharvesting, is exceptional [1, 14].

Other complications

Unnoticed deficiency of other ligaments such as the ACL or posterolateral corner structures causes instability that could derive from the failure of the PCL reconstruction and progression of osteoarthritic changes [5]. Underlying varus malalignment may also contribute to failure of the plasty [5]. The presence of intraarticular loose bodies due to chondral lesions or meniscal fragments may limit knee flexion-extension and produce blocking. Obviously, in PCL reconstructions complications universal for any articular surgery may also occur [6]: reactive synovitis, septic arthritis, deep venous thrombosis, etc., which are not of particular interest in this article.

Conclusions

It is important to acknowledge the different PCL reconstruction techniques and their normal postsurgical appearance. Signs of graft failure must be identified along with the factors that may contribute to it, as well as other potential complications. Further studies are required to establish specific criteria for tunnel positioning in PCL reconstructions.

Conflict of interest The authors declare that they have no conflict of interest.

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