Case resolution

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DIAGNOSIS

ACL re-rupture (graft rupture).

DISCUSSION

Ruptures of the ACL are common sports injuries, usually in people who practice sports involving deceleration, torsion, sudden stops and jumping, such as football, basketball, skiing, and rugby, which are among the most common sports in Argentina. Ruptures due to activities different than sports comprise injuries combined with high-energy trauma, such as car accidents, motorcycle accidents, etc. Chronic instability associated with untreated ACL ruptures can result in secondary injuries, such as chondral injuries, meniscus tears, and associated injuries to other ligaments, which ultimately leads to early knee osteoarthritis. Rupture of the ACL, isolated or combined with meniscus or collateral ligament tears, produces degenerative radiographic changes in 60-90% of patients, from 10 to 15 years after the injury. Therefore, surgical treatment is especially indicated in young patients who practice sports, to restore normal knee function and reduce the risk of meniscus-ligament injuries and secondary knee osteoarthritis. In addition, the improvement of surgical approaches and postoperative rehabilitation during the last decade has led to a considerable increase in ACL reconstruction surgeries. Although the majority of patients treated with ACL reconstruction achieve excellent results, up to 15% experience persistent instability and pain. Surgical approach is critical for the success or failure of the procedure.

X-rays, computed tomography (CT) and MRI are imaging studies used for follow-up of ACL reconstructions. X-rays and CT scans allow the evaluation of tunnel direction, path and angle, while MRI is the preferred imaging technique to evaluate graft integrity, signal, and type, as well as the condition of the soft tissues adjacent to the knee joint. For its correct interpretation, it is important to consider some factors such as the time elapsed since the surgery, type of graft (autograft, allograft, xenograft or synthetic graft) and the presence of metal fixators. The examination of bone tunnels by MRI can have certain disadvantages, such as the presence of artifacts due to magnetic susceptibility (impaired recording and signal void) caused by the materials used for the surgery (iron, titanium, etc.) that are capable of producing heterogeneity of the magnetic field.

The adequate analysis of the scans is of the utmost importance not to overdiagnose or underdiagnose neo-ligament ruptures, since the surgical approach will depend on it.

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TIBIAL AND FEMORAL TUNNELS

Correct location of the tunnels is critical for maintaining the integrity and stability of the graft. Incorrect tunnel placement is one of the most common technical errors in ACL reconstruction procedures, and it is estimated that up to 80% of graft failures are due to this.

Several methods have been described to evaluate the position of the tunnels by imaging tests. Some use a clock-face analogy in which, in coronal scans, the femoral tunnel opening must be above the outer femoral condyle at the 10- to 11-o'clock position on the right knee, and at the 1- to 2- o'clock position on the left knee.

Currently, the quadrant method is commonly used to locate and position the femoral tunnel. It reflects more closely the proximal insertion of the native ACL. A lateral X-ray is taken with the knee flexed at 90º. A square is drawn with the upper border along the Blumensaat's line; the lower border, on the lower border of the femoral condyles; and the anterior and posterior borders, on the anterior and posterior borders of the femoral condyles. This square is divided into a grid dividing the anteroposterior diameter and the height of the intercondylar notch. The optimal placement of the opening of the femoral tunnel is on the anteroinferior corner of the posterosuperior quadrant (Figure 6).

Tibial tunnel placement is critical to avoid impingement of the graft against the roof of the intercondylar notch in the sagittal plane, or the posterior cruciate ligament or the lateral femoral condyle in the coronal plane. In sagittal scans, the tunnel should be oriented parallel to the Blumensaat's line when the knee is in full extension, and the intra-articular opening should be posterior to where the Blumensaat's line crosses the tibia when the knee is in full extension.

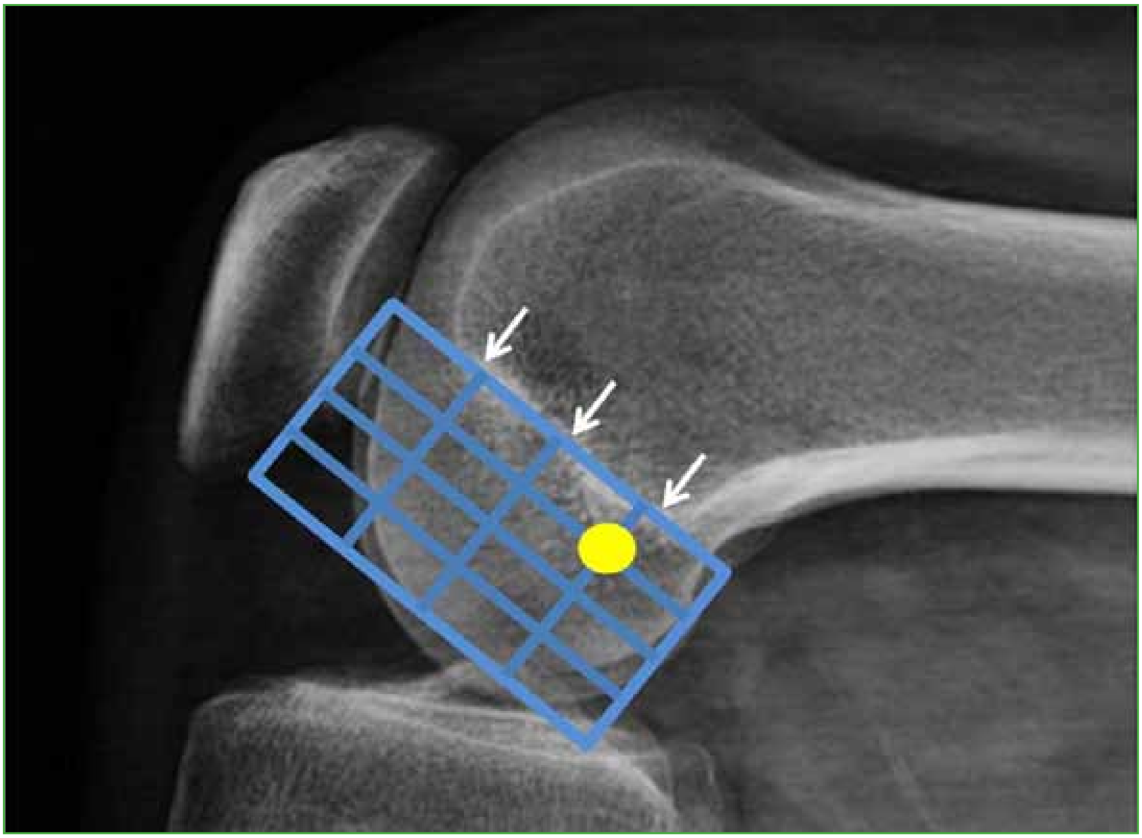

Figure 6. Quadrant method. Lateral X-ray with 90º flexion: Blumensaat's line and the borders of the femoral condyles are used as reference, dividing each side of the square into four parts. The optimal location of the femoral tunnel is located in the anteroinferior corner of the posterosuperior quadrant.

The method of Stäubli and Rauschning can also be used: the center of the opening of the tibial tunnel is 43% along the Amis and Jakob's line (a horizontal line drawn from the anterior to the dorsal surface in the sagittal plane, passing through the medial tibial plateau) (Figure 7). In the coronal plane, the distal end of the tunnel should begin medially to the tibial tuberosity, and the proximal end should enter the joint between the two tibial spines and should be oriented at 65-70º with respect to a horizontal line drawn along the tibial plateaus.

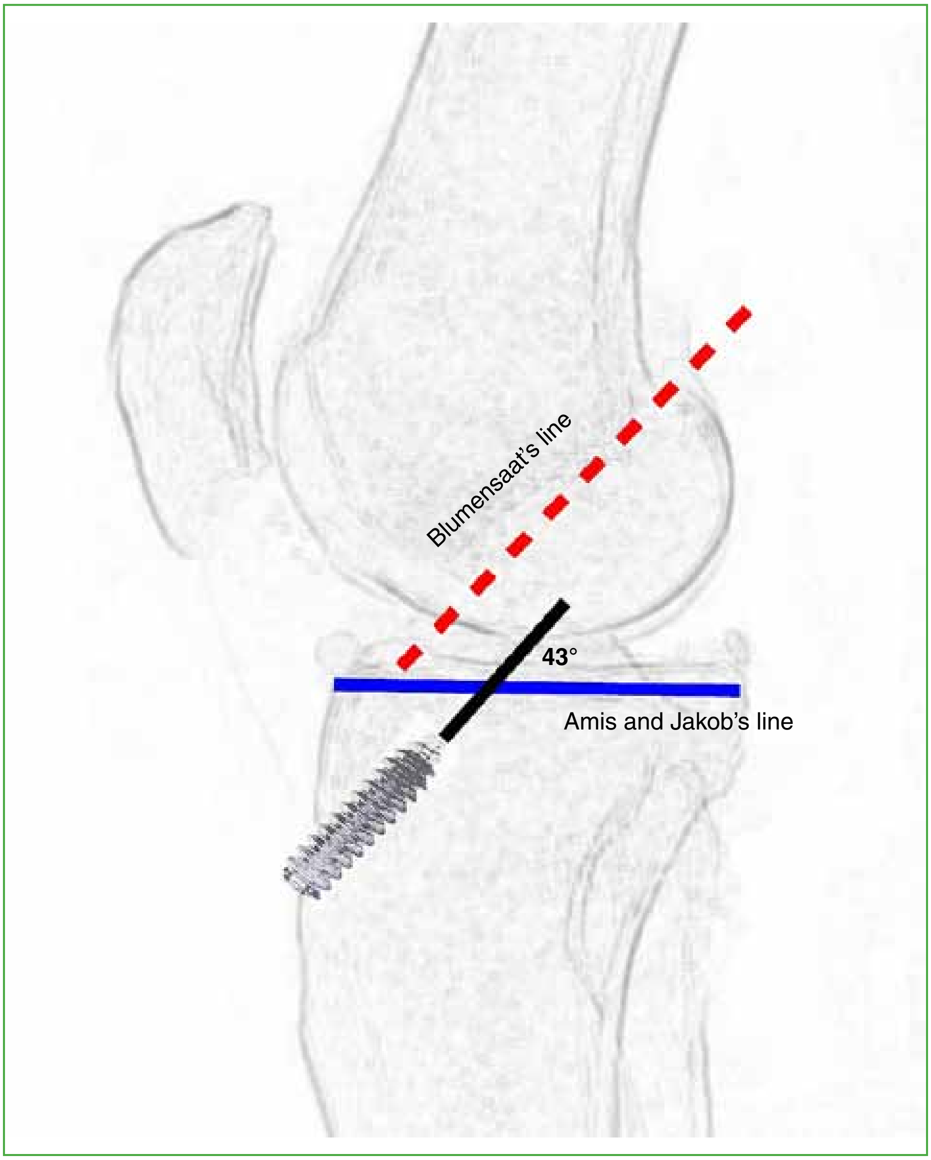

Figure 7. Stäubli and Rauschning method: the center of the opening of the tibial tunnel is located 43% along the Amis and Jakob's line.

It is worth noting the role of CT when evaluating tunnel shape, direction and joint exit. As an advantage, it does not cause artifacts due to the metallic fixation material, so it allows for the accurate evaluation of the size and position of the femoral and tibial tunnels, which is useful after failed interventions, and to plan the surgical revision for a secondary ligament repair.

The widening of the tunnels has multiple causes, both mechanical and biological. It could be due to the expansion caused by the inner graft movement during activity or by longitudinal migration micromotions of the graft along the tunnel. Tunnel widening is confirmed if there is a 2mm increase compared to the previous CT scan.

GRAFT TYPES

Surgical approaches reproducing the normal anatomy of the ACL, respecting the double band, the femoral and tibial insertion points, the obliquity of the primitive ligament with its biomechanical properties, as well as improving knee stability, especially rotational, are the most sought-after.

There is a tendency to perform intra-articular repairs with different types of grafts and different fixation systems, reproducing the anatomical reference points and the intra-articular path of the native ACL.

While this paper is not intended to describe the technical details of each procedure, we will mention some of them:

BPTB autograft

During the last two decades, ACL repair using BPTB autografts has been the preferred approach. When compared with other autografts, their assimilation is faster and there is a lower incidence of rupture or revision surgery. The graft is obtained from the central third of the patellar tendon with its corresponding bone fragments from the lower pole of the patella and the tibial tuberosity. It usually has a diameter of 9 to 11mm. Both ends are fixed securely to the femoral and tibial tunnels with biodegradable and metallic interference screws that minimize the possibility of graft loosening and loss of fixation.

Hamstring tendon autografts

Hamstring tendon autografts have gained popularity due to the incidence of postoperative pain, as well as complications of the donor site and the extensor mechanism related to BPTB autografts. The graft consists in a hamstring tendon (semitendinosus) and an adductor muscle tendon (gracilis) removed from the tibial attachment to the myotendinous junction. They are usually stitched together and folded to create a four-flap graft. One limitation of hamstring tendon grafts is that the size of the graft depends on the size of the tendons of the patient's hamstrings, and grafts with <7 mm in diameter are associated with an increase in laxity. This differs from BPTB autografts, in which the surgeon can determine the diameter of the graft during preparation of the bone plug. Another disadvantage of using these tendons is the residual weakness of the hamstrings that can hinder the patient's running speed and the loss of the dynamic restraint capacity of the hamstring muscles, that is considered protective against a new ACL injury.

Allografts

Allografts are tendons extracted from corpses. The most commonly used tendons for grafting are: BPTP, Achilles, hamstrings, quadriceps, tibialis posterior, tibialis anterior and peroneus longus. The advantages of allografts include elimination of donor site morbidity, reduction of operating time, smaller incisions and a lower incidence of arthrofibrosis. However, the approach is not without disadvantages: graft incorporation and "ligamentization" tend to be slower, the incidence of bone tunnel enlargement is higher, and the mechanical properties of the graft can be altered during sterilization and preparation. In addition, although low, there is a risk of transmission of viral and bacterial infections. For these reasons, they are usually reserved for cases of multiple ligament injuries, revision reconstructions, or older patients who resume sports more slowly or participate in activities that are less demanding on the graft.

Synthetic grafts

In the 1980s, synthetic grafts became an attractive alternative to biological grafts due to the absence of donor site morbidity associated with autografts, synthetic graft resistance, immediate weight-bearing capacity, and a short postoperative rehabilitation period. The synthetic materials used include carbon fibers, polypropylene, Dacron and polyester. They also have potential complications: infection, host immune responses, rupture, synovitis, chronic effusions, recurrent instability and osteoarthritis. Due to these complications, the use of synthetic grafts has been limited. However, recent studies revealed that, under specific conditions, synthetic grafts can be appropriate. Research to find the ideal synthetic substitute with respect to biocompatibility and mechanical characteristics is underway with a renewed interest.

NORMAL GRAFTING UNDER MRI

MRIs are preferably performed with high-field (1.5T or 3T) MRI scanners and a dedicated knee coil. It is useful to add a 3D volumetric sequence to the usual knee MRI protocols (T1, proton density and fluid sensitive sequences, such as fat-suppressed proton density or STIR) , which allows reconstructing the neo-ligament in different planes. It should be borne in mind that gradient echo (GRE) sequences are highly susceptible to metal, and sometimes generate artifacts.

It is important to assess the intrinsic neo-ligament, as well as its continuity and signal, and direction of the fibers (following Blumensaat's line), considering tunnel appearance (however, CT scans have proven to be superior in defining the size and the shape of the exit site of the tibial and femoral tunnels). One should attempt to define the graft throughout its length in order to differentiate surrounding synovial membranes.

Attention must be paid to adjacent structures and possible associated complications.

To evaluate the neo-ligament, sequences follow the sagittal plane, considering ligament maturation times (up to 2 years).

- In the **immediate postoperative period** (less than a month), the signal intensity of the native patellar tendon in T1- and T2-weighted scans is low, which is attributed to the avascular nature of the graft. Therefore, a thick homogeneous band of hypointense signal should be seen in all sequences.
- After **one month and up to 1-2 years** after surgery, the signal intensity may be increased in T2-weighted sequences, which may be due to a process of revascularization and secondary sinovialization, a phenomenon known as "ligamentization" of the graft. Therefore, this signal increase should not be misinterpreted as a rupture, unless fluid signal intensity is observed. As an example, we present the case of two professional football players who underwent ACL reconstruction, within one year of surgery, one with a low-signal graft (Figure 8) and one with an increasing signal due to "ligamentization" (Figure 9).

Figure 8. 35-year-old professional football player, 5 months after surgery. **A.** PD sequence (3000/23) in the sagittal plane. **B.** PD sequence (2500/25) in the oblique coronal plane. Fiber continuity, well-defined borders, and a hypointense signal of the ligamentous graft are observed.

Figure 9. 23-year-old professional football player, 10 months after surgery. **A.** PD sequence (3000/23) in the sagittal plane. **B.** PD sequence (2500/25) in the oblique coronal plane. Orientation and continuity of the graft fibers are preserved. However, in this case, there is a neo-ligament signal increase due to ligamentization. The hyperintense signal can be observed up to two years after surgery. It was a clinically stable knee.

- After **two years**, signal intensity was low in T1- and T2-weighted scans, similar to the one of the native ACL.
- However, small hyperintense intrasubstance foci can be observed after four years or more of surgery, and this does not correlate with joint instability or functional limitation. Importantly, due to its four-flap structure, the quadrupled semitendinosus-gracilis autograft can, at first, show an intermediate and even a fluid signal between the graft flaps in T2-weighted sequences. This intermediate or high signal is parallel to the fibers of the graft, unlike in a tear, that would show a signal abnormality perpendicular to the graft. This normal finding with a hamstring graft would be abnormal with a BPTP autograft.

- Allograft “ligamentization” is less uniform and longer than with autografts.
- In the case of a primary ACL repair, the first scans taken after the procedure may show that the native ligament has a heterogeneous signal, probably secondary to sutures passing through the ligament and postoperative edema (this signal increase may persist for a year). It is important to note that repaired native ligaments do not undergo “ligamentization”, and any new increases in signal within the repaired ligament should be taken seriously.

Regarding donor sites, in the case of BPTP grafts, the MRI shows a thickened patellar tendon with a defect in its central region, which may persist up to two years after surgery, after which the tendon regains its normal appearance. A defect in the donor site of the patella can be seen up to one year after surgery. The defect of the donor site may persist even longer in the case of the tibia. An MRI of the hamstring grafting site initially reveals the absence of tendons with a fluid-filled defect. Tendons tend to regenerate during a period that ranges from 2.5 and 3 years, in a proximal to distal direction.

COMPLICATIONS ASSOCIATED WITH THE ACL GRAFT

It is estimated that the rate of complications associated with the reconstruction of the ACL is 10-25%, according to different reports. They can be classified into those that result in an increase in laxity (partial or complete tears, stretching or elongation, graft misplacement or fixation failure, etc.); those producing decreased range of flexion, extension or both (roof impingement, arthrofibrosis, osteophyte formation, intra-articular bodies, mucoid degeneration or ganglion formation, etc.); and miscellaneous (widening of the tunnel, device complications, complications at the donor site [patellofemoral pain, patellar fracture, patellar tendinosis, etc.], extensor mechanism dysfunction, osteoarthritis, infection, rejection, screw migration, pseudoaneurysm of the popliteal artery, etc.).

GRAFT RUPTURES

ACL graft rupture can be acute, due to a single injury, or insidiously, due to implant fatigue through a repetitive mechanism; ruptures due to a single injury, in turn, can be caused by a casual or sports accident on a functional or correctly placed graft, or by injury of a mechanically and functionally weak graft. Fatigue or insidious ruptures often result from secondary impingement, usually due to technical defects.

Grafts are more susceptible to injuries during “ligamentization”, particularly in the first eight months.

If the grafts ruptures within six months after surgery, it is likely that the cause is technical. Among surgical technical errors, poorly positioned tunnels are the most common.

In the case of partial ruptures, the MRI shows hyperintense focal areas in T2-weighted scans, as well as partial discontinuity of the fibers with adjacent intact fibers. In complete ruptures, usually due to recurrent injury, complete fiber disruption is observed, together with a fluid-filled defect signal in T2-weighted scans.

Direct (or primary) and indirect (or secondary) signs of graft rupture have been described by MRI:

1) Direct signs

a. Discontinuity of the graft fibers: continuity of the graft fibers in the coronal plane and preservation of the thickness of 100% of the graft in the sagittal or coronal planes are the most predictive findings for the exclusion of complete tears.
b. Diffuse or focal enlargement of the graft signal (in its proximal, middle or distal third). Time elapsed since surgery should be considered. The focal or linear increase in graft signal intensity, produced by fibrous and partially fatty tissue, should not be mistaken for a re-rupture. In this group of patients, the contrast medium may be useful to assess periligamentous tissue.
c. Focal thinning and alteration in orientation (horizontalization and laxity) of the graft in the sagittal planes.

2) Indirect signs

a. Anterior tibial translation: it is known as the “anterior drawer sign” on MRI and is an indicator of graft failure or laxity. This sign is considered positive if the posterior cortex of the lateral tibial plateau migrates more than 5 mm anterior to the posterior cortex of the femur in sagittal scans.

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b. Verticalization of the posterior cruciate ligament: increase in its radius of curvature.

c. Lack of coverage of the posterior horn of the external meniscus: the sign is positive if, in sagittal scans, a vertical line tangential to the posterior cortical margin of the tibia intersects any sector of the posterior horn of the external meniscus. This sign, along with the increased curvature of the posterior cruciate ligament, is a manifestation of abnormal anterior displacement of the tibia.

There may also be clinical instability of the knee with an intact graft in cases of graft stretching or elongation. It can also be the result of poorly positioned femoral and tibial tunnels. On MRI, the graft shows a posterior arch. There may also be anterior translation of the tibia secondary to anterior laxity.

GRAFT IMPINGEMENT

A too anterior position of the femoral tunnel is one of the most common technical errors related to bone drilling. A too anterior femoral tunnel can cause graft tightness upon knee flexion, and laxity upon knee extension. A too posterior position of the femoral tunnel causes the opposite.

However, the position of the tibial tunnel is the main factor that leads to impingement of the graft. If the tibial tunnel is placed too anteriorly, the graft can be impacted by the roof of the intercondylar notch during the terminal extension of the knee (roof impingement). Impingement can also occur due to anterior translation of the tibia, displacing the tibial tunnel anteriorly. In the MRI sagittal plane, it is observed that the graft is posteriorly arched due to the collision with the upper part of the notch, and it may show alteration of the signal in its anterior two thirds. If the tibial tunnel is placed too laterally, the graft hits the medial wall of the external condyle. If the tunnel is placed too medially and vertically, the graft can affect the posterior cruciate ligament. Osteophytes and scars can also cause impingement. It manifests clinically as a loss of extension or a flexion deformity, and it is a disabling complication.

ANTERIOR ARTHROFIBROSIS (CYCLOPS LESION)

The cyclops lesion is an ovoid ACL graft-related lesion located in the intercondylar notch and generally located anteriorly. The origin of the lesion is unclear, but possible etiologies include a reaction to debridement and the drilling of this region during formation of the tibial tunnel, a reaction to a torn ACL stump, and graft microtrauma leading to inflammation and formation of the cyclops lesion. It leads to pain and mechanical block to extension, since it acts as a foreign body.

On MRI, it appears as a well-defined nodule of hypointense to intermediate signal in T1-weighted scans and variable signal in PD- and T2-weighted scans. The differential diagnosis includes pigmented villonodular synovitis and synovial chondromatosis. Diffuse arthrofibrosis is less common than nodular cyclops lesions and, on MRI, it appears as spiculated areas of hypointense signal located in the anterior or posterior compartments and often associated with capsular thickening. It is the result of inflammatory changes that lead to the formation of adhesions and scars.

POSTOPERATIVE INFECTION

Septic arthritis is rare and most frequently caused by *Staphylococcus aureus*. Aspiration is mandatory to confirm the pathogen identity. MRI is usually useful to evaluate the extent of infection, the formation of abscesses, drainage sinuses and osteomyelitis. Sinus tracts extend from the subcutaneous region to the underlying bone, and MRI shows low signal on T1-weighted scans and high fluid sensitive sequences (fat-suppressed proton density, T2, STIR).

GANGLIA

Rarely, they can develop during tunnel creation and represent a cystic degeneration of the graft. Ganglia are frequently associated with increased size of the tunnel.

CONCLUSIONS

The position of the tunnels in ACL repairs is the most important factor in determining if the reconstruction will succeed or fail. The adequate location of the screws is critical for their biomechanical function and for good radiological assessment to determine their optimal position, explored by different imaging techniques.

AP and lateral X-rays are used to evaluate the position of the fixation devices and the possible widening of the tunnels after a ligament repair procedure.

Meanwhile, CT scans are also useful when evaluating the shape, direction and exit of the joint tunnels created during ACL repair; the shape of the notch and the medial wall of the lateral femoral condyle, all in absence of artifacts caused by metallic fixation material. This way, revision surgery for a secondary ligament repair can be planned.

Regarding MRI, it is the method chosen for graft follow-up, with emphasis on evaluating the signal and graft alignment according to the time elapsed since the surgery. Signal changes can be expected during normal progress of the graft, which must be properly assessed and, if necessary, compared with previous tests.

MRI plays a critical role, confirms different related complications and requires experience in interpreting the scans to identify said complications and make the necessary treatment decisions.

Conflict of interest: Authors claim they do not have any conflict of interest.

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