Joints

Pre-operative planning in anterior cruciate ligament reconstruction revision surgery

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Summary

Primary reconstructions of the anterior cruciate ligament are common and increasing in number, a trend inevitably paralleled by an increase in the number of revision procedures. Failure of primary ACL reconstruction can appear as objective residual laxity, subjective instability, severe and persistent postoperative stiffness and/or pain, or infection. Revision surgery is a complex procedure, in which the expected clinical outcome is inferior to that which can be expected from primary reconstruction, and patients have a 5.4% risk of undergoing a second revision after five years. This type of procedure demands correct and exhaustive preoperative planning so as ensure optimal treatment of accompanying lesions and of any complications arising during surgery. It is important to know, in detail, the patient's clinical history (when the primary surgery was performed and the technique used, the cause of the recurrence, the degree of functional recovery, etc.), to perform a thorough clinical examination (to evaluate alignment, gait cycle, skin color, the trophic condition of the muscles, joint laxity), and to have available the results of a detailed and specific imaging study and also of blood tests, in order to exclude the presence of an infection.

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Introduction

The annual incidence rate of anterior cruciate ligament (ACL) rupture is between 36.9 and 60.9 per 100,000 individuals (1, 2), and in the United States between 100,000 and 200,000 new occurrences are recorded among individuals who participate in amateur or competitive sports activities (3-7). For this reason, the number of primary ACL reconstruction procedures is rising all the time. It is estimated that around 175,000 primary ACL reconstructions are performed each year in the USA (4), whereas in Europe the figure stands at around 100,000 per year (8). Numerous factors contribute to a good outcome of ACL reconstruction: the surgical technique used, the graft chosen, the graft fixation, the post-operative rehabilitation, and patient "education". With good or satisfactory results obtained in 75-97% of cases, primary ACL reconstruction can certainly be a very gratifying procedure (9). However, the growing number of pri-

mary procedures is inevitably bringing with it an increase in the number of revisions: it is estimated that 3,000/100,000 patients are candidates for this type of surgery each year (10).
Failure of primary ACL reconstruction can manifest itself in different ways: residual or recurrent objective laxity, a subjective perception of instability, severe and persistent postoperative stiffness and/or pain, or post-surgical infection (9, 11). Revision surgery will require the application of specific techniques to deal with a range of situations and complications. It is a complex procedure, whose expected clinical outcome is inferior to that which can be expected from primary reconstruction, and patients have a 5.4% risk of undergoing a second revision after five years. Furthermore, since revisions account for less than 10% of all knee ligament reconstructions, it is difficult to obtain objective data on the real indications for this procedure and the relative outcomes (7).
In view of these considerations, it is mandatory to perform correct and exhaustive preoperative planning, so as to ensure optimal treatment of the accompanying joint injuries and of any complications arising during surgery, and thus increase the likelihood of a successful outcome.

Clinical history

It is very important, as part of the correct planning of ACL revision, to know when the primary surgery was performed and the cause of the recurrence of the instability (i.e. whether or not a new trauma has been sustained and the way in which any trauma has acted on the knee in question). It is also important, if possible, to review the clinical records relating to the first operation, as these can provide information on the type of reconstruction performed (single-/double-bundle) and the type of graft used (autograft, allograft or synthetic), on the tunneling technique (all-inside, anteromedial, transtibial, out-in, in-out, or over-the-top), on the type of femoral and tibial fixation and, above all, on which (if any) any other surgical procedures were performed (meniscal and/or cartilage surgery, extra-articular reconstructions). It is also useful to review previous imaging studies and arthroscopic images to gather additional information on the extent of the primary damage and, above all, details of the surgical technique used (tunnel placement the type of meniscal and/or cartilage treatment), and also on any complications arising during surgery (e.g., blow-out of the posterior wall of the femoral tunnel). Other aspects to consider – these should always be carefully documented – are the level of functional recovery of the knee and the patient's resumption of sporting activities. Indeed, failure to return to close to preoperative levels of activity may indicate a technical error related to the initial procedure (Fig. 1), a postoperative complication, or inadequate rehabilitation. Even when a new trauma is thought to be responsible for the recurrence, it is important to know what level of activity the patient had regained after the primary surgery in order to assess whether any of the problems were already present before the new trauma, how many appeared after it, and, finally, how many are linked to the progression of a degenerative disease.
It is crucial to know what the patient's own expectations are and what level of activity he can realistically be expected to attain; in other words, to determine whether the patient's expectations are compatible with a knee that has to undergo an ACL revision procedure or whether the patient is a "knee abuser" with unrealistic expectations that could affect the outcome of a new surgical procedure. A patient who is a candidate for ACL revision must be appropriately educated and made well aware that these procedures demand a long post-operative rehabilitation and also that the results obtained do not always achieve complete joint stability. It must be made quite clear to the patient that this is rescue surgery whose aim is to allow him to perform everyday activities without instability, but that a return to sporting activities cannot be guaranteed (12, 13).

Clinical examination

The clinical examination is performed taking into consideration both legs, to evaluate their alignment, the patient's gait cycle, the color of the skin and the muscle strength.
During the examination of the lower limbs it is necessary to look for varus or valgus deformities, which can be confirmed by weight-bearing X-rays. A goniometer must be used to evaluate range of motion (ROM) and identify any extension deficits (the patient can also be examined prone in order to facilitate this diagnosis).
It is important to examine carefully the color of the patient's skin because any discoloration observed may be a sign of a previous vascular or inflammatory/in-

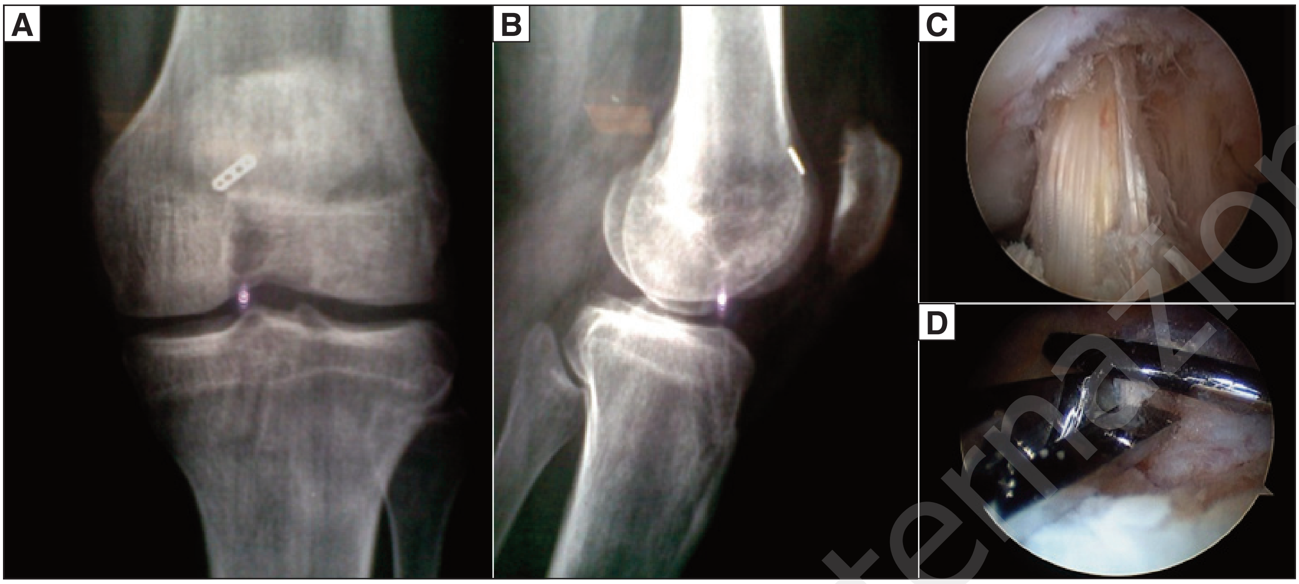

Figure 1. X-ray image, in the AP (**A**) and lateral (**B**) projection, of a knee after ACL reconstruction surgery. It is possible to see incorrect placement of the femoral tunnel. (**C**): Arthroscopic image showing malpositioning of the new ligament. (**D**): Arthroscopic image of ACL revision.

fectious condition, of hormonal imbalances, or of endocrine problems; discoloration may also indicate the site and state of previous incisions.

It is important to measure the circumference of the quadriceps, comparing the measurement with the contralateral one to ascertain whether there is any hypotrophy.

The clinical examination should also include the following tests:

- Lachman test to determine the degree of anterior laxity compared with the normal contralateral knee:
  – grade I (0-5 mm)
  – grade II (6-10 mm)
  – grade III (> 10 mm).
- Posterior drawer test and active quadriceps test to assess for posterior instability.
- Pivot shift test to assess the degree of rotatory instability:
  – grade 0 (the same as the contralateral knee)
  – grade I (glide)
  – grade II (pivot shift)
  – grade III (with subluxation).
- Dial test at 30° and 90° of knee flexion to assess for posterolateral and posteromedial instability.
- Varus and valgus stress tests at 0° and 30° of knee flexion to assess for instability of the medial and lateral collateral ligaments.

Finally, it is necessary to assess patellar mobility and whether there is any patellar crepitus.

In some cases it may be necessary to perform the surgery in several steps, especially in the presence of a knee with a >5° extension deficit and a >20° flexion deficit, or a severe varus or valgus deformity (14).

Laboratory examinations

As already mentioned, infection is one of the possible causes of a failed primary ACL reconstruction. Therefore, before performing a new reconstruction it is necessary to be sure that the infection has been completely eliminated.

Septic arthritis is a relatively rare complication that occurs in 0.14-1.70% of cases (15-17). However, it must be diagnosed rapidly and treated promptly with a targeted antibiotic therapy in order to avoid possible complications reported in the literature (18-20), namely:

- Residual stiffness and arthrofibrosis
- Osteomyelitis
- Rejection or rupture of the graft (weakened by the infection?)

- Cartilage degeneration (glycosaminoglycans and collagen reduced by more than 50% within 7 days of the onset of the infection) with full-thickness chondral lesions (21, 22).

The microorganisms most frequently responsible for septic arthritis after ACL reconstruction are: Staphylococcus aureus, coagulase-negative staphylococcus, and, although more rarely, non-hemolytic streptococcus, peptostreptococci (especially Enterobacter), and other gram-negative and anaerobic organisms.

In cases of proven antibiotic resistance, polymicrobial infection should be suspected. At present, given the scarcity of available data, there are no specific guidelines on the surgical strategy and the timing of intervention in these cases. The treatment most frequently mentioned in the literature is arthroscopic debridement with preservation of the graft, the aim of this approach being to reduce the bacterial load through thorough synoviectomy and also to remove necrotic tissues and any clots (21, 23, 24). Some authors, however, prefer to remove the graft immediately since, being essentially non-viable tissue, it may provide a good growth medium for bacteria (25, 26).

Treatment of septic arthritis after ACL reconstruction is intended first to protect the joint cartilage and second to protect the graft. The treatment should include the prompt administration of intravenous antibiotics (initially broad-spectrum antibiotics and subsequently targeted ones, on the basis of culture results and relative antibiograms) for at least 6 weeks and, in any case, until normalization of C-reactive protein (CPR) values. Thereafter, the treatment can continue with oral therapy for approximately 2-4 weeks, and in any case until such time as two successive assessments, performed two weeks apart, have both shown normal CPR values.

Non-steroidal anti-inflammatory drugs (NSAIDs) should be administered to anyone showing clinical signs of infection, despite having negative cultures (27). Arthroscopic debridement can be repeated, should the erythrosedimentation rate (ESR) and CPR values fail to fall (21). However, if the infection persists, the graft, together with its fixation devices must be removed and the tunnels thoroughly cleansed (28). The graft should be removed immediately if the knee is unstable and the ligament is lax, or if, during the arthroscopy procedure, in addition to signs of possible bone involvement (cartilage softening and swelling), the graft is found to be surrounded by a persistent purulent exudate (whose removal would, in any case, damage the graft).

ACL revision can be performed after an interval of 6-9 months (28), as long as the blood inflammatory markers and instrumental examinations have normalized.

Imaging

When planning ACL revision it is necessary to be aware of all the anatomical factors that could influence the outcome of the procedure (mechanical axis, combined instability, cartilage and meniscal injury); the management of the tunnels is another aspect that must be evaluated in advance (taking into account the position of the previous tunnels, the quality of the tibial and femoral bone, and the presence of any osteolysis and metal hardware); it is also necessary to consider the type of new graft and fixation system to use and, finally, what additional procedures (on ligaments, cartilage or menisci) might be necessary. Therefore, proper preoperative planning should include an integrated imaging study, comprising standard radiographic examinations, magnetic resonance imaging (MRI) and/or computed tomography (CT) scans.

Standard radiography

It is necessary to take weight-bearing standard X-rays of the lower limbs in two projections in order to assess whether the failure of the primary procedure might be linked to mechanical axis deviations, which may already have shown up on the clinical examination, and to quantify this deformity. In addition, the following special views should be used:

- Rosenberg view, to assess the condition of the tibio-femoral joint and view the intercondylar notch.
- Merchant view, to reveal degenerative changes in the patellofemoral joint that could lead to changes in the therapeutic approach and in the likely outcome of the revision surgery, both of which must be made clear to the patient.

Plain radiographs are also recommended to evaluate the tibial slope (angle of inclination, in the sagittal plane, of the tibial plateau to the diaphyseal axis), and to detect any associated fractures in individuals who have suffered new traumas, such as avulsion fracture of the lateral or medial capsule associated with tears

of the posterior cruciate ligament (PCL) and medial meniscus, otherwise known as Segond-type and medial (reverse) Segond-type factures (29); avulsion fracture of the fibular head, which is an indicator of posterolateral damage; posterior tibial spine fracture, and so on.
Standard X-rays also serve to evaluate three elements:

- *The presence of metallic hardware*

If the planned revision procedure will not be affected by pre-existing metallic fixation devices, incorrectly placed in the primary reconstruction surgery, they can be left in place to avoid causing further bone defects. If, on the other hand, they are likely to interfere with the revision reconstruction, they will need to be removed and, in this case, sets of surgical screwdrivers and/or scalpels and a universal screw removal instrument set will need to be available in the operating theater. Access to reports on the previous operation may facilitate the removal of this hardware, making it possible to identify the specific instruments that will need to be used.

- *The position of pre-existing tunnels*

Since the position of the tunnels determines the isometry of the graft during movement, their malpositioning may result in incorrect tension of the graft (30). Howell and Taylor (31) carefully documented the importance of the correct positioning of the bone tunnels and affirmed that on a lateral projection with the knee in maximum extension, the tibial tunnel must be positioned and angled in such a way that the anterior wall of the tunnel lies posterior to the ideal distal continuation of the Blumensaat line (a landmark corresponding to the roof of the intercondylar notch). If this condition is not met, the roof of the intercondylar notch could impinge on the graft, and result in an extension deficit. Furthermore, still on the lateral projection, both the tibial plateau and the Blumensaat line can be divided into four equal quadrants: in order to avoid influencing the graft tension and joint stability in flexion-extension, the position of the tibial and femoral tunnels should coincide, respectively, with the posterior third of the second tibial quadrant and the posterior femoral quadrant (32). On the anteroposterior projection, the tibial tunnel should be seen to reach the joint surface at the midpoint of the tibial plateau: a medial or lateral position will result in graft impingement by the walls or the roof of the intercondylar notch, leading to chronic synovitis and residual laxity (33). The anteroposterior view is also very important for evaluating the obliquity of the femoral tunnel: a vertical femoral tunnel associated with fixation to the anterior rather than the lateral wall of the tunnel, even though it may appear well-positioned on the lateral X-ray, is indicative of an excessively vertically positioned graft and associated with the risk of rotational instability (34).

- *Tunnel widening and bone loss*

This complication, whose etiology is still not completely known, usually arises within the first six months of surgery, although it can occur even two years after the procedure (35, 36). As well as affecting the placement of the new tunnels, it also limits the options for fixing the new ligament and generally makes it necessary to opt for cortical fixation. However, in the presence of tunnel widening greater than 16-17 mm, primary fixation of the graft may not guarantee the necessary strength. In these cases it is therefore advisable to perform a two-stage procedure, i.e. filling the tunnel with bone grafts in the first phase and then proceeding with the revision surgery 6-12 weeks later (8).
Radiographs obtained under stress through the application of external forces are also important in the definition and quantification of possible combined posterior and extra-articular laxity. Examples include:

- the axial view (under the force of gravity) proposed by Puddu et al. (37) and the "gravity sag view" described by Shino et al. (38);
- views obtained using instrumental systems such as Telos® (39);
- views obtained during flexor muscle contraction (40), or the kneeling view (41).

Computed tomography

A CT scan is important in order to study possible associated tibial plateau fractures and to have, also thanks to the 3D reconstruction, an accurate and complete view of the derangement. A recent study showed that CT is the most reliable imaging modality for evaluating bone tunnels, in terms of its capacity to identify them correctly and, through cross-sectional area (CSA) calculations, to measure tunnel widening (42). On the strength of this reliability, a system for classifying femoral tunnel positions based on 3D CT reconstructions was recently proposed (43):

- type I: well positioned tunnels that can be reused;
- type II: slightly malpositioned tunnels creating a potential risk of convergence between the old and new tunnels (two-phase revision procedure recommended);
- type III: significantly malpositioned tunnels, creating the need to drill new tunnels that will not present a risk of convergence.

Computed tomography was recently used to evaluate and quantify rotatory instability in patients with associated posterolateral injury. The patient, lying supine, is positioned inside the CT scanner with his legs resting on a cushion and positioned at approximately 30° of knee flexion. The patient's thighs are secured with tape to maintain a slight internal rotation. An examiner, standing at the foot of the scanner bed, externally rotates the patient's two feet. In this position, axial scans of the distal femur and proximal tibia are acquired. Standard CT software is used to trace lines corresponding to the outline of the posterior aspects of both femoral condyles and the posterior profiles of the tibial plateau, thereby making it possible to measure the angle of rotation between the femur and tibia (44). It is important to have a CT scan in order to decide whether the revision should be performed as a single-stage or two-stage procedure and whether bone grafts (autologous and/or homologous) will be needed.

Magnetic resonance imaging

Magnetic resonance imaging is another valuable tool for correct planning of the surgical procedure as it provides information on the status of the ligament: joint instability in the presence of an intact ligament, for example, should imply inadequate primary tension or combined posterolateral or posteromedial instability that has led to "fatigue"-induced loosening of the graft. Through MRI it is also possible to verify whether there is any impingement by the roof of the intercondylar notch and whether there is any combined meniscal, cartilage or ligament injury. It is also necessary to take into account indirect signs of ligament injury, such as: diffusion of fluid into the synovial space behind the ligament, tibial and/or femoral bone bruising caused by a new, recent trauma or by overloading linked to chronic ligament deficiency. Therefore, MRI is necessary to evaluate the need to perform additional surgical procedures, such as:

- meniscectomy for recurrent meniscal tear or failure of previous repair
- meniscal allograft transplantation (in the case of total or subtotal tears), or reconstruction with a scaffold (in the case of partial tears)
- cartilage repair (which depends on the quality of the healing following any previous treatments, the location and extent of any new cartilage defects, and the condition of the subchondral bone)
- reconstruction of combined ligament injuries (PCL and extra-articular ligaments).

It is always necessary to bear in mind the difficulties associated with interpreting MR images, which can often be further complicated by the presence of metal-induced artifacts. In particular, it is important to remember that:

- false-positive diagnoses of meniscal tears are possible, since the lesion and degenerative changes in the meniscus look the same on MRI, both being associated with an increased signal in the meniscal tissue. The lesion is diagnosed in the presence of signal alteration extending to the articular surface of the meniscus (45).
- a lateral meniscus tear can be wrongly diagnosed (false-positive diagnosis) on the basis of incorrect interpretation of the signal from the inferior genicular artery (38% of cases) (46).
- there is a risk of failing to diagnose a torn ACL (false-negative diagnosis) due to integrity of the ligamentum mucosum, or when the ligament is torn close to its insertion.
- ACL rupture can be wrongly diagnosed (false-positive diagnosis) due to the presence of graft eosinophilia following a trauma (47, 48).
- chondral defects with bone involvement risk being wrongly interpreted (false-positive diagnosis).

Nuclear medicine

The instrumental investigations that can be used to diagnose delayed onset of infection and remission of the same, making it possible to proceed with the revision surgery, are MRI and bone scan, possibly in association with new nuclear medicine examinations.

Bone scan with labeled white blood cells

This is a diagnostic examination performed to identify the presence of any foci of infection in the body. White blood cells (WBCs), which are crucial in defending the body against infection, accumulate in these foci to fight the infection.

The examination is performed by injecting the patient with WBCs that have first been labeled, under sterile conditions and without damaging the cells, with a radiopharmaceutical (99mTc-HMPAO). Thanks to this marker it is possible to identify the sites where these cells accumulate, thereby revealing foci of infection. Depending on the clinical hypothesis, the examination may include the whole body (whole-body scintigraphy) or be limited to specific regions (regional scintigraphy), with sequences of images acquired 1, 4 and 24

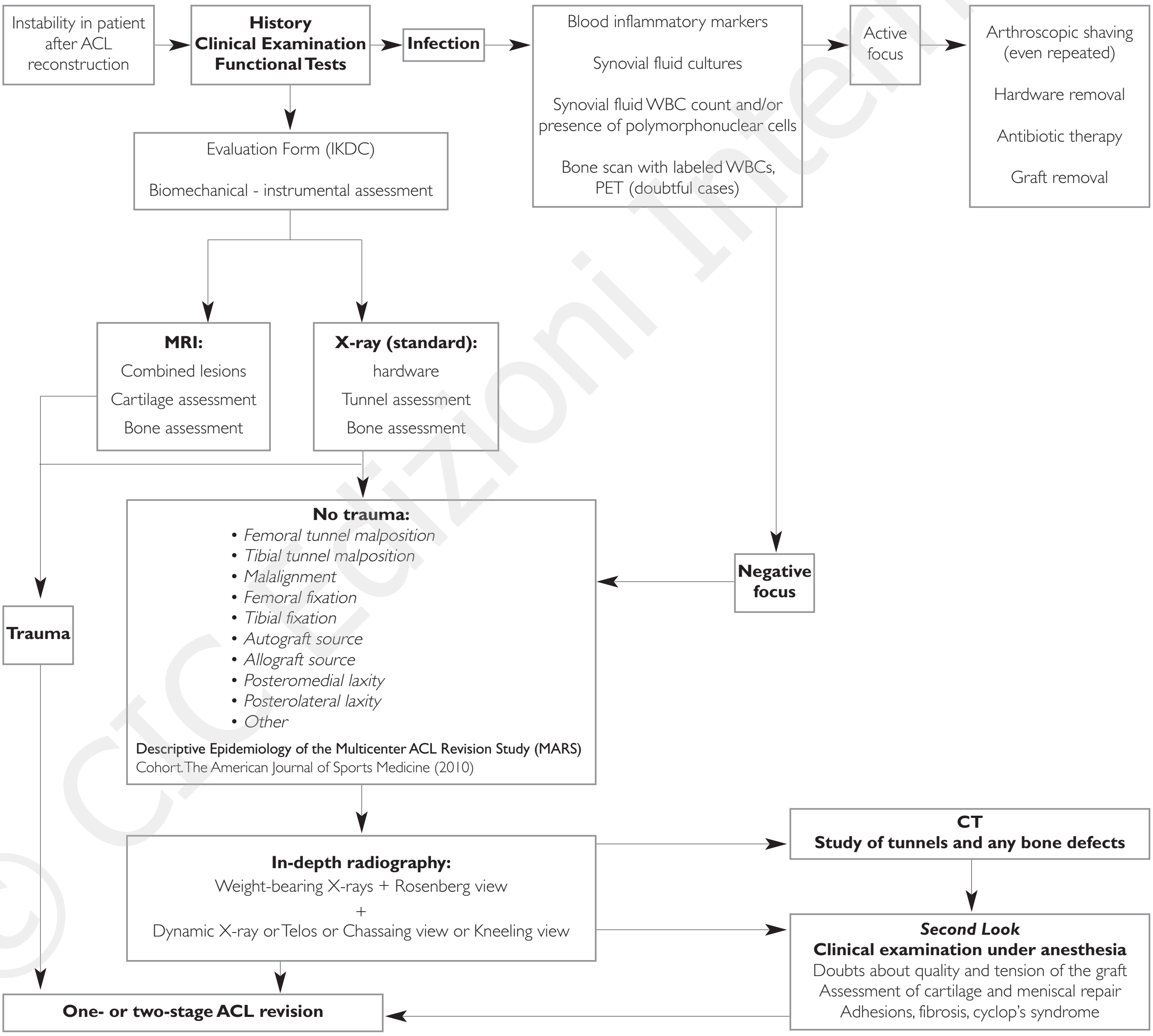

Figure 2. Decision-making algorithm for ACL revision surgery.

hours after administration of the radiopharmaceutical. This is an examination offering high diagnostic accuracy (sensitivity and specificity of 90-95%), but it is a lengthy and costly procedure, also for the patient.
Bone scan with labeled WBCs should be interpreted with caution, bearing in mind the possibility of recording false-negative results due to the "cold areas" (areas of low accumulation of WBCs) that can sometimes be present in cases of chronic osteomyelitis, or false-positive results due to displacement/transplantation of bone marrow following orthopedic surgery (49).

Other procedures

Another useful procedure for diagnosing an infection is positron emission tomography (PET), performed using a marker (F18-FDG) which accumulates in sites of inflammation due to the presence, in these sites, of cells with high metabolic activity (activated leukocytes have a metabolic rate that is twice basal levels). Although it has high sensitivity and specificity for diagnosing infection (sensitivity 96.5%, specificity 82.8%), it is a method that was introduced relatively recently (50) and, as a result, the typical patterns that might allow neoplastic disease to be distinguished from inflammatory/infectious disease remain to be clearly identified.
Scintigraphy performed following administration of Tc99m Infecton exploits the capacity of ciprofloxacin to bind to the walls of live bacteria where it induces inactivation of bacterial gyrase and blocks the synthesis of DNA, killing the bacteria. It shows good tissue diffusion, penetrating the interior of the cells and concentrating in macrophages and polymorphonuclear cells, thereby allowing effective monitoring of bone infections. However, its specificity is low (sensitivity: 100%; specificity: 63.1%; accuracy: 87.5%).

Conclusions

ACL revision surgery demands meticulous preoperative planning in order to make the most appropriate surgical choice. The reasons for the failure of the primary ACL reconstruction must always be identified to ensure optimal management of any complications that may arise during revision surgery and obtain the best possible outcome. The choice of new graft, the removal of the fixation devices implanted during the previous reconstruction, and the treatment of any associated injuries and/or bone defects all need careful consideration and planning in order to avoid failure of the new ligament reconstruction.
A decision algorithm (Fig. 2) that takes into account the different causes of failure can help the surgeon to make the most appropriate choices.

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