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REVIEW ARTICLE

ACL tear

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KEYWORDS
ACL;
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Summary Anterior cruciate ligament (ACL) reconstruction has evolved considerably over the past 30 years. This has largely been due to a better understanding of ACL anatomy and in particular a precise description of the femoral and tibial insertions of its two bundles. In the 1980s, the gold standard was anteromedial bundle reconstruction using the middle third of the patellar ligament. Insufficient control of rotational laxity led to the development of double bundle ACL reconstruction. This concept, combined with a growing interest in preservation of the ACL remnant, led in turn to selective reconstruction in partial tears, and more recently to biological reconstruction with ACL remnant conservation. Current ACL reconstruction techniques are not uniform, depending on precise analysis of the type of lesion and the aspect of the ACL remnant in the intercondylar notch.

Over the last decades, an increasing participation in sports has been accompanied by an increasing incidence of knee trauma and anterior cruciate ligament (ACL) injury. ACL reconstruction has thus become a common procedure, with 36,000 performed yearly in France.

This has led to significant progress over the last 30 years, with improved knowledge of ACL anatomy and to its mechanism of injury. It is this evolution that is the subject of the present article, leaving aside the meniscal and cartilage issues that are often associated.

Anatomy

The ACL is involved in connecting the femur to the tibia, and plays a prime role in the kinematics and stability of the knee. Anatomic knowledge is the foundation of surgical technique.

Femoral insertion

The femoral insertion (Fig. 1) lies on the axial side of the lateral condyle, bordered behind by the condylar cartilage and in front by a more or less convex semicircular or oval contour. Its area is 18 × 10 mm, vertically oriented at a 26° angle, opening posteriorly, to the axis of the femoral shaft [1—3]. The ACL comprises an anteromedial (AM) and a posterolateral (PL) bundle, with a footprint often contoured on the axial side of the lateral condyle by the lateral

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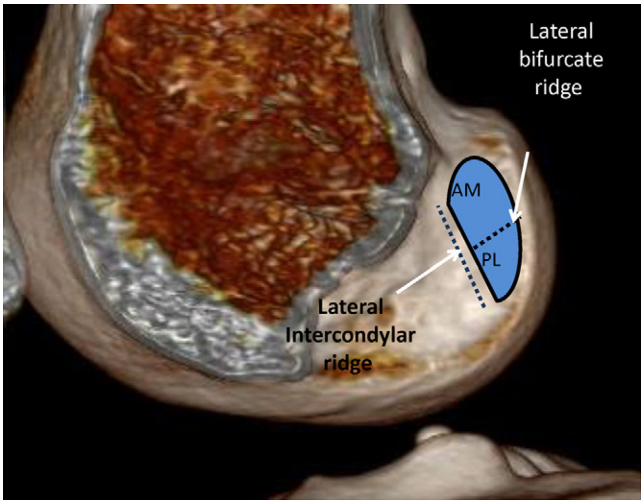

Figure 1 Femoral insertion.

intercondylar ridge anteriorly and by the lateral bifurcation ridge between the two bundles [3].

Tibial insertion

The tibial insertion (Fig. 2) is 120% broader than that of the femur, measuring 19×13 mm. It lies on the prespinal surface, between the cartilage borders of the tibial plateaux [1,4]. Its anterior edge is about 14 mm from the anterior part of the tibial plateau, with the center of the ACL 46% of the way along the anteroposterior length of the medial tibial plateau. The AM and PL bundles are named for the location of their tibial insertions. The former lies on the anteromedial part of the ACL's tibial footprint, against the anterior horn of the medial meniscus, and comprises 52% of the total insertion area [1]. The latter occupies the posterolateral part, against the lateral tibial spine and anterior horn of the lateral meniscus.

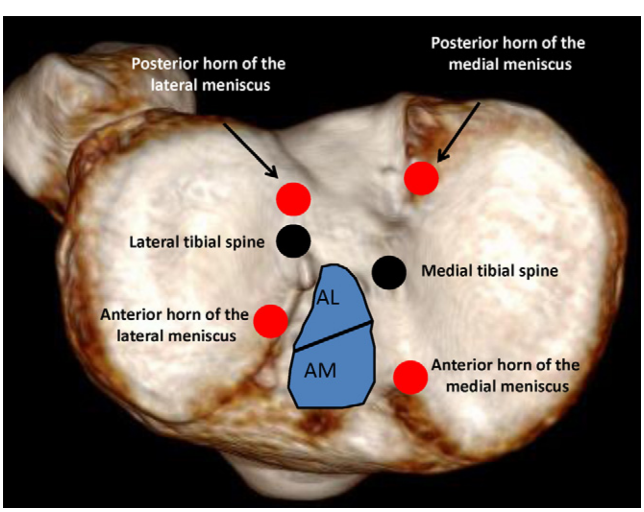

Figure 2 Tibial insertion.

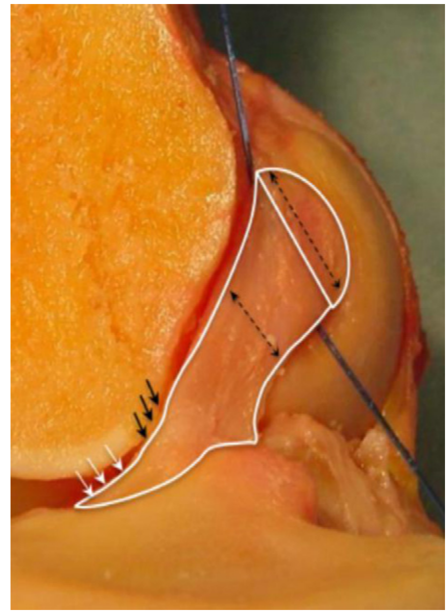

Figure 3 Hourglass anterior cruciate ligament (ACL) aspect with impingement between its distal part and the anterior part of the intercondylar notch.

Ligament

In the ligamentary part, the AM bundle has a more anterior, distal and medial orientation than the PL bundle. Surrounded by the synovial membrane, the ACL is intra-articular and extra-synovial, with an hourglass aspect and a medial cross-section comprising a third of the femoral and tibial bone insertion areas. In extension, its flared distal part fills the anterior part of the intercondylar notch, its congruence contributing to stability in extension, where its anterior fibers wind around the anterior part, curving to produce a superior concavity (Fig. 3) [5].

Functional anatomy, biomechanics

The ACL is not isometric: the distance between fiber insertion points varies during flexion-extension [6,7], under the control of the femoral insertion. During flexion, the PL bundle insertion turns around the AM bundle insertion, passing from a distal and slightly posterior 0° position to an anterior position at more than 90° to the AM bundle (Fig. 4).

The most isometric fibers are the anterior ones of the AM bundle, with a mean length of 37 mm. They are, however, less tense between 0° and 30° flexion, to allow them to be deformed into a superior concavity by contact with the anterior edge of the intercondylar notch, with tension thereafter becoming constant between 30° and 130° flexion.

In contrast, the least isometric fibers are the posterior ones of the PL bundle, with a mean length of 24 mm. They are tense in extension, and progressively relax to 90° flexion, thereafter tensing again.

From the most anterior to the most posterior part of the ACL, fibers become progressively less isometric, enabling progressive recruitment and tensing, from most anterior to

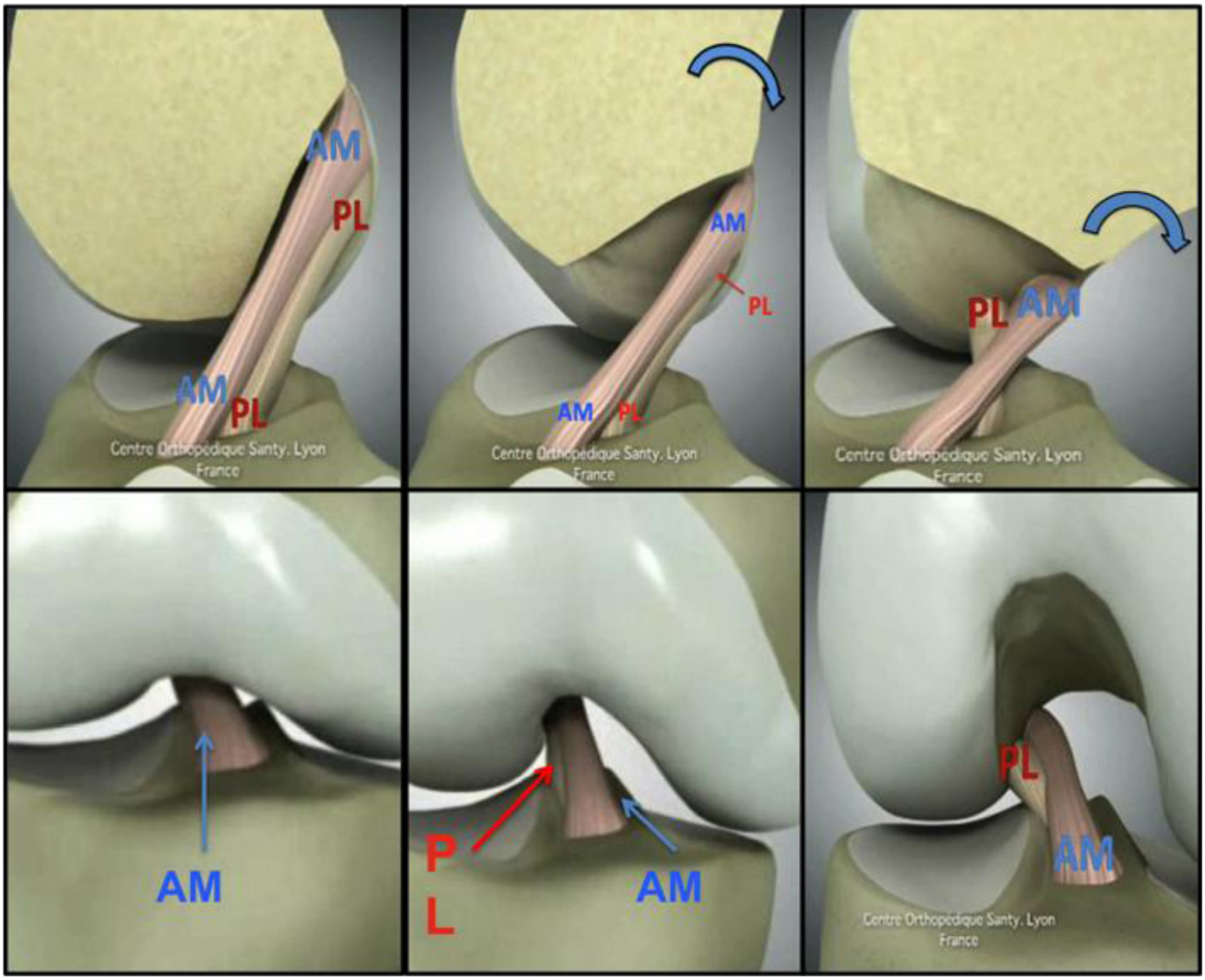

Figure 4 Posterolateral (PL) bundle fiber insertion turning round the anteromedial (AM) insertion during flexion (image courtesy of the Santy Orthopedic Center, Lyon, France).

most posterior, as the knee moves into extension, at which point all the ACL fibers are in parallel.

The ACL provides posteroanterior knee stability [8]. Anterior translation is controlled by the PL bundle between 0° and 30° flexion, and by the AM bundle thereafter. There is also a clear contribution to rotational stability [8]. ACL sectioning displaces the center of rotation of the knee medially, increasing the range of internal rotation which, associated to anterior translation, induces the snap phenomenon in internal rotation typical of ACL tear. Within the ACL structure, the PL bundle has the greater impact on rotations, due to its lateral position on the tibia [9,10].

ACL reconstruction

AM bundle reconstruction

By the end of the 1970s, the need for ACL reconstruction had become obvious. Surgeons initially associated anterolateral tenodesis; isolated reconstruction began in the 1980s.

Attention first focused on anterior translation, with the 4-bar paradigm [7] (Fig. 5). In this system, the central pivot comprises two segments uniting the most isometric points of the ACL (most anterior fibers) and of the posterior cruciate ligament (most anterior fibers). The ACL fibers lie behind the intersection of the two segments; their insertion points approximate in flexion and move apart in extension. These fibers are thus not isometric, but are effective in extension (where the knee is unstable in absence of the ACL), displaying ''effective non-isometry''. This AM positioning was the objective of surgery. Although this model analyzed ACL function only in the sagittal plane, it provided rapid visualization of femoral positioning on lateral X-ray for reconstruction.

In our own experience, from 1989, ACL reconstruction was performed under arthroscopy, using a free middle-third patellar ligament graft (perversely known surgically as the patellar tendon: PT), then considered to be the gold standard.

Attention focused on femoral positioning with ''favorable non-isometry'', the femoral tunnel orifice being placed

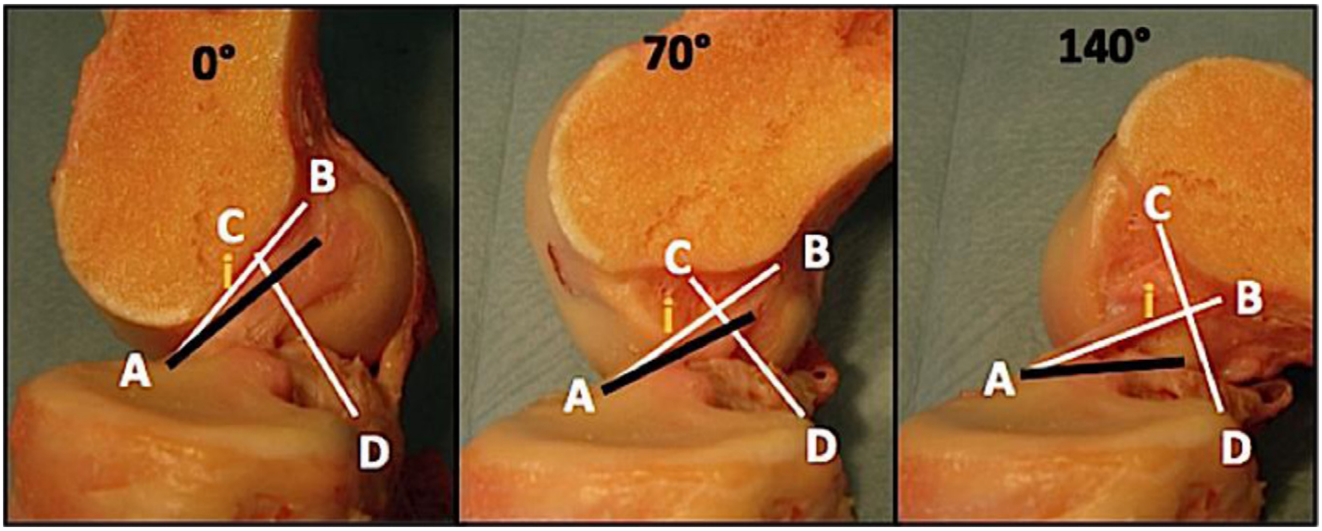

Figure 5 Four-bar system. AB represents the ACL and is situated in its most isometric anterior part. CD represents the posterior cruciate ligament and is situated in its most anterior fibers. The reconstructed ligament fibers should pass behind the AB/CD intersection. Their insertions move apart and display effective non-isometry in extension.

behind the most isometric point of the ACL, which itself lay just behind the intersection between Blumensatt's line and the posterior femoral cortex (Fig. 6). An out-in technique provided the best means of achieving anatomic AM positioning with a bone tunnel that was homogeneous rather than a mixed bone and fiber ''tunnel''. A dedicated visor positioned (Fig. 7) at 10 o'clock for a right knee in 90° flexion was equipped with a palpator which hooked onto the posterior and superior part of the axial side of the lateral condyle (reference area) and a cannon allowing a K-wire 8 mm forward of the palpator to be introduced into the joint. The tibial tunnel was likewise positioned anteromedially.

Figure 6 Anteromedial (AM) bundle positioned behind the intersection between Blumensatt's line and the posterior cortex of the femoral shaft.

The PT middle-third graft had the advantage of allowing high-quality initial fixation using an interference screw, which may be resorbable, and secondary fixation by consolidation of the bone block in the bone tunnel, providing direct fixation between the bone fragment and PT that lasts throughout the evolution of the reconstructed ligament, completed after the 12th week by Sharpey fibers growing at the tunnel-tendon interface to create an indirect insertion. The press-fit technique further improves the PT graft, achieving the same initial femoral or tibial fixation without the need of an interference screw.

For this technique [11], the middle third of the PT is passed down from above, with a trapezoid-shaped tibial bone block to enable a press-fit in the femoral tunnel, which has a diameter of 10 mm. The tibial tunnel has a diameter of 98 mm, with interference screw fixation of the patellar bone fragment.

A retrospective study [12] with 15 years follow-up of patients managed with this technique confirmed its success. Fifty-seven patients (60% male) were examined at follow-up with ligament testing, laximetry, fill radiological assessment and objective and subjective International Knee Documentation Committee (IKDC) scoring. Mean age at surgery was 26 years (range, 15—47 years); mean time to surgery was 22 months (range, 15 days to 241 months), and mean follow-up was 182 months (i.e., greater than 15 years). There were six preoperative medial meniscectomies, four peroperative meniscal procedures (two sutures, two meniscectomies) and four postoperative meniscectomies. There were eight ACL tears, treated or not during surgery, plus nine occurring postoperatively; 29% of patients had bilateral involvement. At such a long follow-up, joint range of motion was not an issue, with no deficits greater than 5°. Clinically, 95% of patients had firm endpoint on the Lachmann test, 68% had no pivot, 25% a pivot glide and 7% a pivot clunk. On IKDC laximetry, 67% of patients were class A, 31% class B and 2% class D, with a mean differential of 1.8 mm when the contralateral knee was healthy. On AP weight-bearing views in 30° flexion, 86%

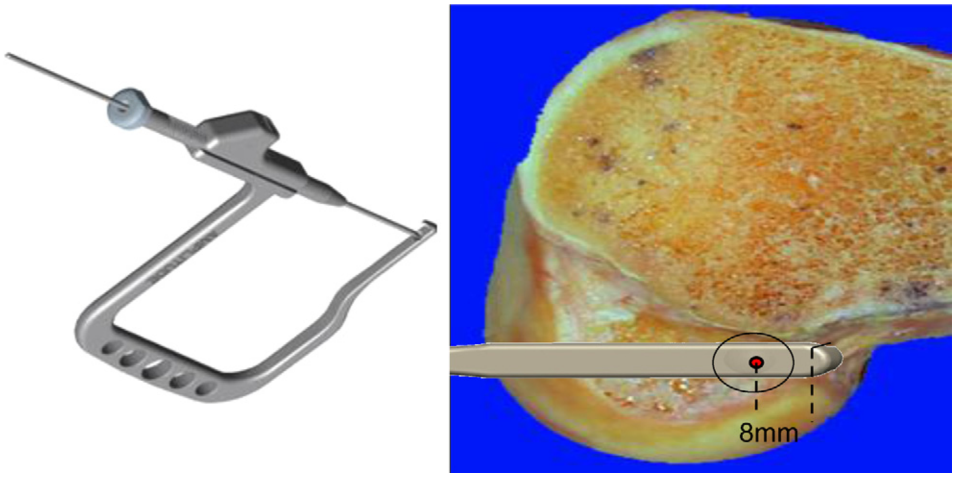

Figure 7 Out-in femoral tunnel using a dedicated guide.

of patients had normal images, 9% showed remodeling and 5% true osteoarthritis. Objective IKCD scores classed 83% of results as excellent or good, with a mean subjective score of 85.8/100.

Discussion

This study, with more than 15 years follow-up, demonstrated that the technique was satisfactory and reliable in the short- and long-term. Results were better than those reported for single-bundle arthroscopic reconstruction at similar follow-up. This difference may have been due to the AM bundle reconstruction, as well as to a much lower rate of meniscectomy. Internal rotation, however, remained insufficiently controlled, with a 25% rate of pivot glide, whereas posteroanterior laxity was satisfactorily controlled; the same problem is found in all single-bundle reconstruction reports and, however minor, may account for secondary meniscal and cartilaginous complications. The PT graft technique was reconsidered in the light of onset of anterior pain on resuming sport, related to the patellar tip rather than to patellar cartilage issues, and this led to the use of hamstring tendon. In our experience, the tunnels are identical in both techniques. The harvested semitendinosus and gracilis tendons remain attached distally, and are prepared for four-strand intra-articular positioning with double fixation (conserved distal insertion plus tibial interference screw, and interference screw plus femoral anchorage).

Double (anteromedial and posterolateral) bundle reconstruction

The relative insufficiency of single-bundle surgery with respect to rotational control, and hence snap, found in the above study, is confirmed throughout the literature [13] and in anatomic studies [6,14]. In the 2000s, this insufficiency combined with a desire to approximate ACL anatomy led to the search for a double-bundle reconstruction technique. In our own experience, which began in 2005, this consisted in adding the PL to the AM bundle, to help control anterior drawer between 0° and 30° rotation.

Technically, after attempts using the quadriceps tendon [15], we turned to the semitendinosus and gracilis tendons. Fixation is by Sharpey fibers within the bone tunnel (indirect insertion), which physiologically leaves a slight residual laxity. The AM bundle is managed as described above on an out-in approach with the visor at 10 o'clock for a right knee via a small 20 mm skin incision. Tunnel diameter is adapted to the semitendinosus transplant used for the AM bundle. The tendons are prepared for double or triple intra-articular use, and conserve their distal insertion. The knee is held in 90° flexion, and the PL bundle tunnel is drilled out-to-in via the same skin incision using a dedicated guide positioned on the intra-articular orifice of the AM bundle (Fig. 8). The intra-articular exit of the guide wire is at 6 to 9 mm, depending on the size of the knee, with a 30° posterior angle to the femoral shaft. Tunnel diameter is adapted to the gracilis tendon graft used for the PL bundle. Using a classic guide, a single tibial tunnel for both bundles is drilled, stopping a few millimeters below the prespinal surface. The last millimeters after the tunnel position the AM and PL bundles. Double fixation is performed. In the tibia, the conserved

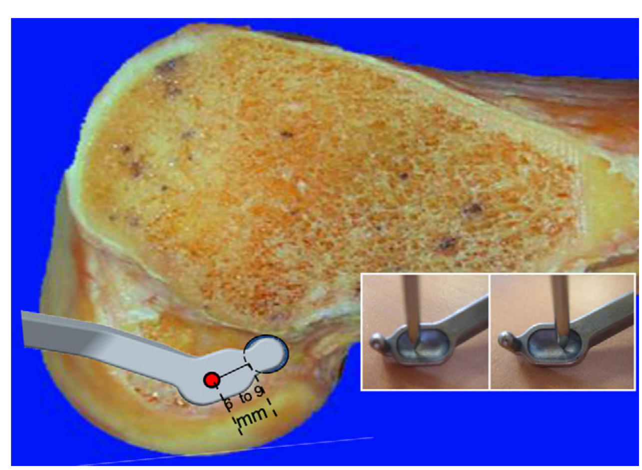

Figure 8 Out-in drilling of the posterolateral (PL) bundle from the anteromedial (AM) bundle, at a distance adjusted to the size of the knee.

distal insertion has to be reinforced by an interference screw, and femoral fixation uses an interference screw in each tunnel, with a knot between the traction sutures.

Discussion

Since 1999, a number of techniques have been described for reconstructing both ACL bundles, using hamstring muscle, PT or quadriceps tendon. In 2004, a truly anatomic technique was described, with two tibial and two femoral tunnels, each centered on the anatomic insertion of the AM or PL bundle. A 2010 review [16] of 10 randomized studies (level of evidence 1 or 2) with 2 years follow-up, comparing single and double bundle reconstruction, reported significantly 7-fold better results with the latter for anterior laxity and 8-fold better for the rate of positive dynamic tests, although the latter varied from 5 to 20%. Only one study reported better objective IKDC scores with double bundle reconstruction. Two studies reported higher rates of iterative tear with single bundle reconstruction. A meta-analysis [17] of four randomized studies with 2 years follow-up found a 0.52 mm differential on arthrometry, and no significant difference for normal or nearly normal rotational snap.

The technique is interesting, but requires a long and difficult learning curve, perfect knowledge of ACL anatomy, and technical skill to locate insertions arthroscopically. Considering the number of positioning problems encountered in single bundle reconstruction, double bundle reconstruction obviously greatly increases the risk of error. As with any novel technique, medium to long-term complications rates remain little known. The presence of two intra-articular bundles may induce cyclops lesions by impingement between the notch and the posterior cruciate ligament. Multiple tunnels, with possible secondary enlargement, reduce bone capital and may weaken the epiphysis, complicating surgical revision. These considerations have led to considerable technical progress, but longer follow-up will be needed to assess benefit with respect to the single bundle attitude.

Partial anteromedial or posterolateral reconstruction

Armed with improved knowledge of ACL anatomy and the development of anatomic double bundle reconstruction, surgeons [18] turned to the problems of partial tear, whether AM or PL. The underlying traumatic mechanisms here are different: an anteroposterior direction in the case of the AM bundle, and rotational in that of the PL bundle. The particularity of the mechanism of injury is that it is low-energy, and is exhausted by the first tear [19]. Isolated tear seems to be more frequent in the AM than in the PL bundle. When clinically suspected and suggested but not proven on MRI, diagnosis has to be established peroperatively.

The longer the trauma-to-surgery interval, the more difficult assessment is, due to cicatricial retraction of the remnant [20]. Exploration should be meticulous, using a palpator, with anterolateral and AM arthroscopic approaches, with the knee in flexion (AM bundle tension), extension (PL bundle tension) and Cabot's position (PL bundle tension) (Fig. 9). While PL bundle integrity is easily judged visually, the AM bundle is much more problematic.

It is also very difficult to be sure that the supposedly healthy bundle has no intraligamentary or insertional lesion; the rate found on meticulous peroperative arthroscopy varies according to reports from 10 to 15% [18,19,21]. The most widely used graft is the semitendinosus, with a conserved distal insertion, prepared for double or triple intra-articular use. The torn bundle is resected, respecting the presumed healthy bundle, so as to avoid impingement within the notch. To avoid destroying the superior PL bundle insertion, the AM bundle's femoral tunnel requires a cautious, minimal approach to the posterior axial part of the lateral condyle.

The tunnel should be drilled out-in, not only for optimal positioning, but also to avoid damage to the intact bundle from the drill at the intercondylar notch (Fig. 10). The PL bundle's femoral tunnel is easier, with direct vision allowing a point-to-point guide to be used; we prefer an out-in approach. The respective tibial tunnels are not problematic if due care is taken to avoid sudden intra-articular

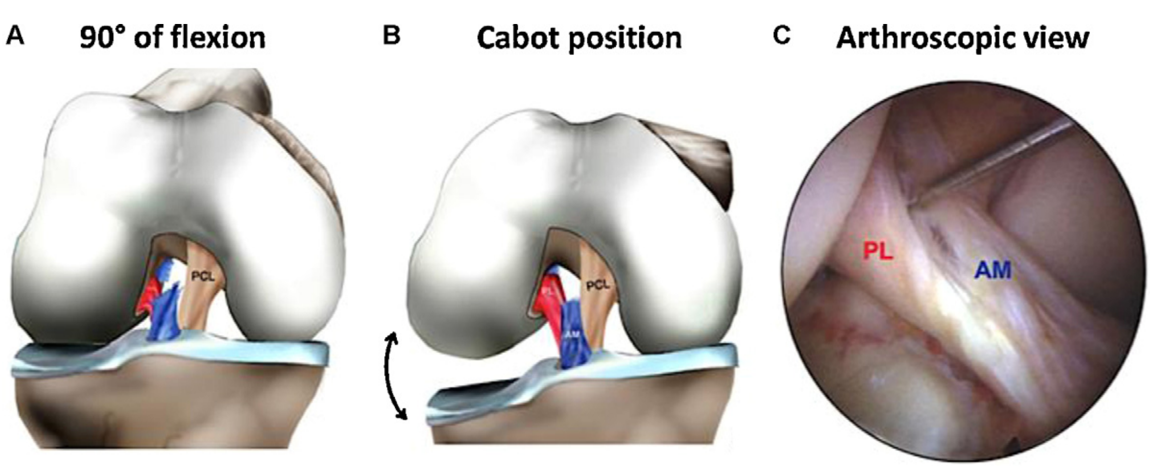

Figure 9 Meticulous arthroscopic exploration to check posterolateral (PL) bundle integrity.

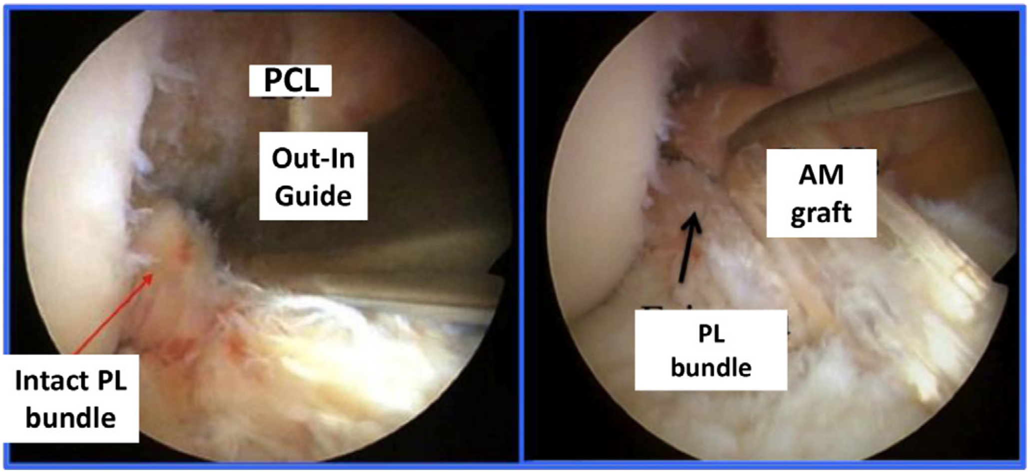

Figure 10 Partial anteromedial (AM) bundle tear. Drilling the femoral tunnel in AM position on an out-in approach to conserve the posterolateral (PL). Tibial tunnel in AM position.

perforation that could threaten the tissue that is to be conserved. Tunnel diameters are adjusted to the cross-sectional area of the prepared graft; double femoral and tibial fixation is again required. A variant for the AM tunnel is easily performed using the middle-third PT on an up-down approach; using the PT for the PL bundle is more difficult, requiring a down-up approach.

Discussion

Results reported in the literature for this technique have been very encouraging, with significantly improved anterior translation of the tibia with respect to preoperative status, and differential laxity of 1 mm [22,23]. The rate of positive dynamic tests is very low (5%) [22,23], and proprioceptive improvement in the knee is appreciably greater than with the classical procedure.

The question arises as to whether to operate on these lesions, which are not very disabling and can be very hard to diagnose. Their natural history is not well determined, but there is an 11 to 61% risk of secondary full tear, depending on interval since trauma. Three particular factors may alert to progression of laxity: anterior translation with respect to the healthy knee; a feeling of insecurity and instability, suggestive of a pivot; and more than 50% torn fibers on arthroscopy [24].

Surgically, conserving the intact bundle has various reported benefits [25]:

- improved postoperative mechanical quality, with a mechanically solid bundle protecting graft and fixation and thus allowing more aggressive rehabilitation;
- conserved synovial envelope vascularization, necessary for graft cicatrization; maturation and complete ligamentization are thus achieved earlier, within 6 to 12 months, versus greater than 12 months with classical techniques [26];
- and conserved existing mechanoreceptors in the intact bundle, improving knee proprioception and thus resumption of physical activity [27].

Technically, the procedure requires great attention, striking a difficult balance between excessive resection, endangering the presumed healthy bundle, and insufficient resection, leading to notch impingement.

Reconstruction with conserved ligament tissue

The benefit of conserving the presumed healthy bundle in partial tear led surgeons to maximize ligament tissue conservation, even in complete tears.

Surgically, the technique can be envisaged from an MRI aspect of superior insertion, but arthroscopic exploration is needed to be sure. The technique is useful when both bundles have superior tears without cicatricial retraction [20]. This is feasible only in early surgery; if, however, there are residual attachments to the posterior cruciate ligament, these may be cautiously released, allowing implementation. An out-in femoral tunnel is drilled by careful release of the posterior part of the axial side of the lateral condyle. The guide-wire's position with respect to the femoral insertion is checked; drill-bit diameter, however, should be increased only with great care, to avoid destroying residual tissue.

Creating the tibial tunnel is even more delicate [21]. The tibial guide is positioned so as to emerge in the center of the tibial insertion and the tunnel is drilled with increasing drill-bit diameters, stopping as soon as the bone is crossed, with the drill remaining strictly within the ACL foot so as to conserve residual tissue. A shaver is passed through the tibial tunnel, penetrating and progressively piercing the foot of the ACL to emerge at the upper part of the residual ligament, so as to hollow out the remaining ACL for the graft. The semitendinosus graft is harvested classically, conserving its distal attachment, and prepared for double or triple intra-articular use. It is passed up from below, with double tibial and femoral fixation. At end of surgery, the transplant itself is not visible, being entirely covered by the conserved ACL tissue. It would seem difficult to use the PT for this technique (Fig. 11).

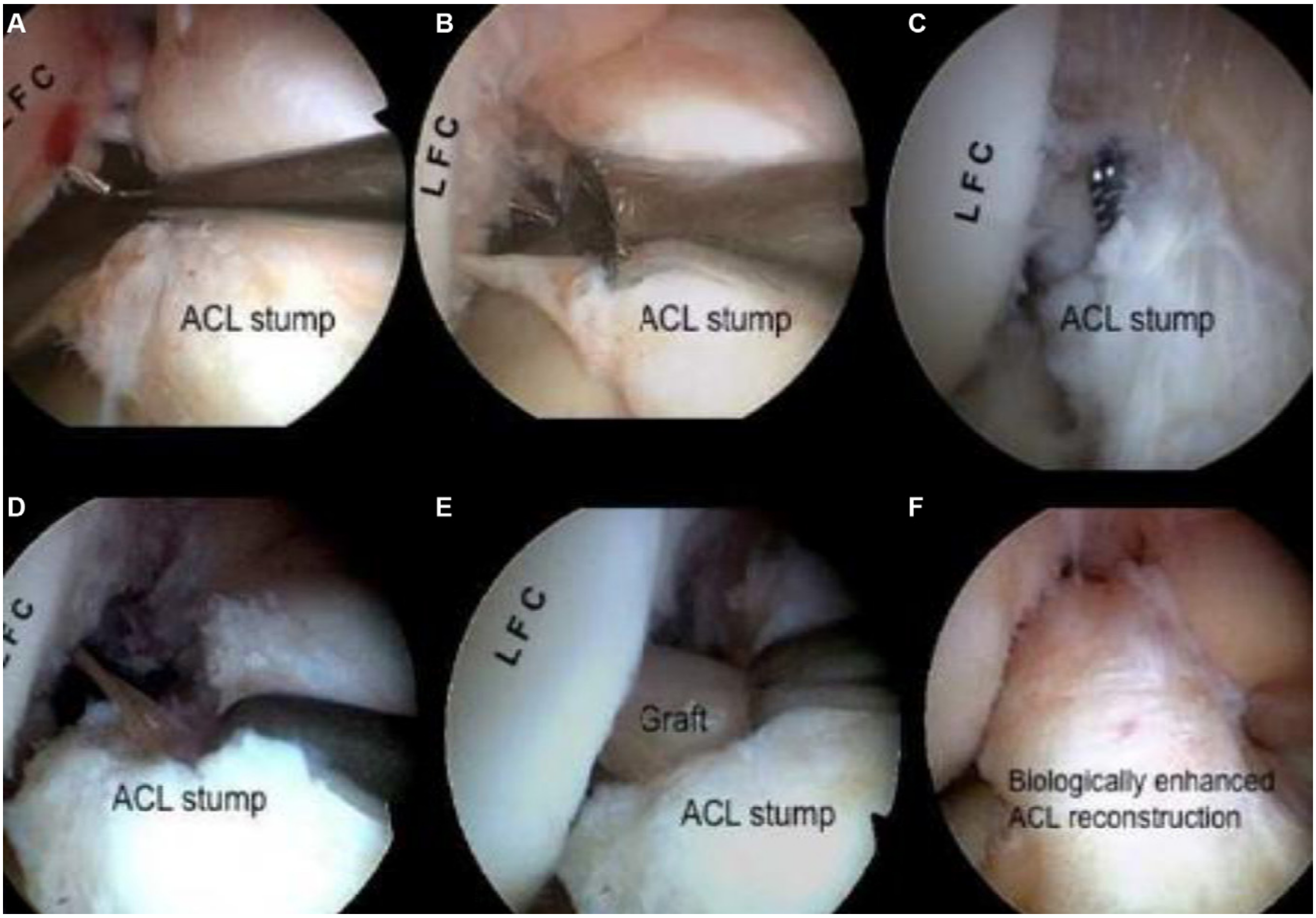

Figure 11 Reconstruction with conserved ligament tissue avec. A. Exploration. Superior tear. B. Femoral tunnel in anteromedial (AM) position. C. The residual anterior cruciate ligament (ACL) is pierced from the tibial tunnel. D and E. Passage of traction sutures and graft through the residual ACL. F. Transplant covered by conserved ACL envelope.

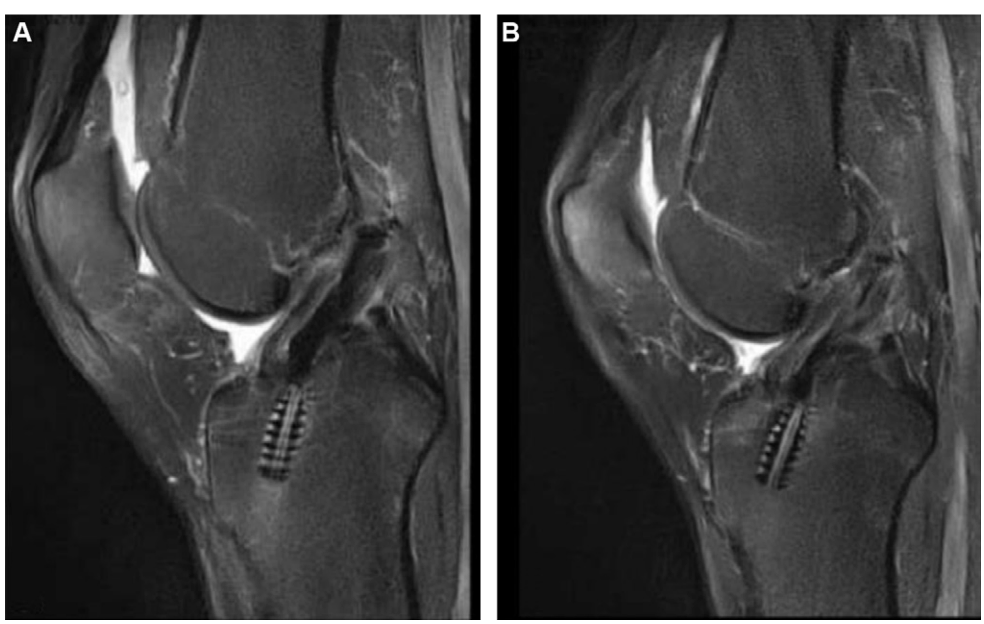

Figure 12 Progressive evolution in graft signal from 3 to 6 months postoperatively, approximating that of the residual LCA envelope.

Discussion

In our experience for the year 2009, this technique was used in 10% of cases. Short-term follow-up found no significant differences from classical techniques in terms of range of motion, Lachmann test or snap differential. On the MRIs taken, the graft appeared in hyposignal at 3 months, clearly distinguished from the residual ACL in hypersignal. At 6 months, graft signal had risen, approximating to the ACL remnant; this may be taken as a sign of advanced maturation (Fig. 12).

The interest of this technique is in some ways the same as that of partial reconstruction:

- improved ligamentization thanks to vascularization from the conserved synovium [28];
- improved proprioception thanks to the mechanical receptors of the residual LCA [29].

Furthermore, however:

- the ACL footprint is conserved at the tibia, with a flared form filling the anterior part of the intercondylar notch and thus contributing to stability in extension;
- the well-organized tissue covering the reconstructed ligament protects it from chaotic and excessive retraction with the subsequent risk of a cyclops lesion.

However the technique does not reinforce the initial mechanical qualities of the graft, and thus fails to enable earlier rehabilitation. The weak point remains the upper part of the plasty, which is not covered by ACL residue.

Conclusion

Changes over the last 10 years influence the choice of techniques when surgery is indicated. There is no one solution, but rather several; the anatomic status of the ACL remnant is decisive, and in turn depends on the trauma-to-surgery interval and any intervening episodes of instability. Surgery should begin with precise exploration of the joint; the technique is to be chosen accordingly, and only then can the graft be harvested.

In the acute phase of a complete superior partial tear, the ACL remnant should be conserved, and the hamstring tendons provide a good solution. Otherwise, minimal cleansing is necessary.

In partial tears, it is vital to conserve the bundle presumed to be intact. Using the hamstring tendons is easy technically, but the PT can be used for the AM bundle.

In chronic lesions, typically there is no well-identifiable structure, although there are often remnants joining the femur to the tibia, and these are to be conserved as far as possible. Double bundle reconstruction is attractive, but has not been shown to provide clear benefit, and requires more thorough cleansing of the notch, which may be a disadvantage. We consider AM bundle reconstruction to be a good option in chronic lesions, and we prefer the PT, although a hamstring graft is worth considering for esthetic reasons (smaller scars) and some particular athletic and occupational considerations (sports with high demand on the extensor system, and jobs involving kneeling).

Even in chronic lesions, the PL bundle may be found to be of good quality, in which case partial reconstruction is to be recommended.

Disclosure of interest

The author declare that he has no conflicts of interest concerning this article.

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