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REVIEW ARTICLE

The evolution of ACL reconstruction over the last fifty years

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Abstract 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.

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Introduction

By the mid 19th century [1], anatomists and surgeons showed interest in the pathology of the Anterior Cruciate Ligament (ACL) and provided clinical descriptions.

Appearing in the literature at the beginning of the 20th century [1] were proposals for ACL repair by suture or reconstruction.

It is only since the late 1960's, that support for ACL injuries truly began. It seemed interesting to us to make a point regarding the evolution of its surgical concepts. It encompasses a Lyonnaise vision, of which this city's School of Knee Surgery is involved, under the direction of Albert Trillat, in this pathology for several decades as evidenced by the organization of its "Journées Lyonnaises du Genou", held since 1970.

Late 1960's, early 1970's

During this period, making the diagnosis of ACL tear was not obvious. Clinically, the insufficiency was diagnosed by looking for the anterior drawer at 90° of flexion, the foot being positioned in internal rotation, external rotation and neutral positions. These tests could not diagnose isolated ruptures and were positive only when meniscal or capsuloligamentous damage was present.

The treatment therefore then logically proposed as its goal, a reduction of this drawer at 90° of flexion and aimed at restoring tension in the medial capsuloligamentous structures in accordance with the techniques described by O'Donoghue [2], Nicholas [3] and Hughston [4]. The surgical procedure was followed by a period of cast immobilization and an often laborious period of rehabilitation. No surgery was performed on the remnant ACL itself.

Such an operation could only have a certain benefit by creating a relative stiffness in the knee which in turn reduced

the feeling of insecurity, but not by limiting the functional anomalies associated with the absence of the ACL.

1970's

The real turning point corresponded to English language journal publications of clinical tests which afforded clinicians a means of making the diagnosis of ACL insufficiency.

The first was the "Pivot Shift" (Mac Intosh) described by Galway [5], corresponding to the shift that occurs with the leg held in internal rotation and the knee being flexed from an extended position while applying a valgus stress to the leg, then the "Lachman test" described by Torg [6], corresponding to the anterior translation of the tibia relative to the femur. The surgeons' acquisition of these tests allowed for the making of a diagnosis of ACL tear.

Previously in 1967, Lemaire [7] had described a dynamic test in internal rotation which had the same significance as the "Pivot Shift", as did Noulis [8] in 1875, when he described anterior translation in extension. Numerous subsequent publications described dynamic tests executed in different ways that, in an index knee, were also effective in showing lateral condyle subluxation or reduction from a subluxed position on the lateral tibial plateau.

These tests were helpful to the clinician and the patient to the extent that they afforded different ways to clinically reproduce a sensation similar to the one the patient felt when their knee gave way. It also aided in a better understanding of the role the ACL plays.

It became evident in cases of ACL deficiency, that subluxation occurred with the knee closer to extension than 90° of flexion. Any surgery being proposed therefore had, as its goal, a method for opposing the sliding of the lateral condyle at a position near extension.

In 1967, Lemaire [7, 9] described an anterolateral tenodesis using the fascia lata which limited the gliding. Such an operation had previously been proposed by Matti [10], Bennet [11] and Bosworth [12]. Other surgeons subsequently proposed similar techniques: MacIntosh [13], Jaeger [14], Losee [15], Ellison [16], Müller [17] and Andrews [18].

It was Marcel Lemaire's technique of lateral tenodesis that we adopted in Lyon. At first, we combined it with a posteromedial imbrication followed by cast immobilization. This resulted in poor outcomes. It was then performed as an isolated procedure. If at first, this anterolateral reconstruction gave quite good results, we soon noticed a clinical deterioration in outcome. This evolution was later confirmed by Dodds [19] who, in 2011, wrote: the technique (extra-articular reconstruction) has not gained favor due to the residual instability and the subsequent development of degenerative changes.

With peripheral reconstructions not affording long term stability to the knee, it became evident that attention needed to be directed to reconstructing the ACL. Albert Trillat began this journey based on the technique described by Jones [20], using the patellar tendon (PT) with some modifications (drilling a tibial and femoral tunnel from outside to inside), with the technique subsequently modified by using the medial third of the patellar tendon as described by Erikson [21], in a manner as to where it was left attached distally. This technique was similar to that described by Brückner [22], known only by German surgeons, who in 1966 also proposed to use the medial third of the patellar tendon. In our practice these techniques were all cast immobilized post operatively. Rehabilitation was difficult, with postoperative stiffness due to immobilization and incorrect positioning of the graft.

During this same period, perhaps because of the difficulties encountered using the PT, surgeons offered other techniques using fascia lata (FL) or the extensor mechanism. The former was described in operations by Insall and MacIntosh (MacIntosh II). Insall's operation [23] consisted of harvesting a band of FL and freed at its distal attachment with a bone block. This was passed "over the top" and secured with a screw to the anterior tibial plateau. The MacIntosh II operation described by McCulloch [24] freed a strip of FL proximally and passed it "over the top" to then assume the path of the ACL and insert into a tibial tunnel. The first description using the extensor mechanism was also attributable to MacIntosh (MacIntosh III) described by McCulloch [24] who harvested a continuous strip of PT, pre-patellar fascia throughout its pre-patellar surface and a tubularized strip of quadriceps tendon. The proximal portion was passed through a tibial tunnel, "over the top" and then fixed to the femur. Marshall then suggested adding a synthetic ligament to the pre patellar portion (weak point of the previous operation) to strengthen it.

This technique, known most commonly as the "Marshall MacIntosh", was most popular in the late 1970s, some surgeons enhancing the technique by tenodesing the proximal end of the quadriceps tendon to reinforce the antero lateral corner.

Years 1980–2000

A free patellar tendon graft

Regarding the use of the patellar tendon, its use seemed possible again after hearing Franke's presentation in Lyon for the first meeting of the International Society of Knee in 1978, which revisited his 1976 publication [25]. The novelty consisted of harvesting the middle third of the patellar tendon and uses it as a free graft, hence, affording a perfect anatomical position. This option had previously been proposed by Brückner [22] in 1966 to reconstruct the ACL

when the ipsilateral patellar tendon was injured. Brückner then recommended the use of the contralateral tendon.

This operation became increasingly popular, the patellar tendon becoming the "gold standard" for ACL grafts. Some authors proposed maintaining some continuity between the patellar tendon and Hoffa's ligament in order to improve its vascularization. Others proposed associating this intra-articular plasty with a lateral tenodesis [26, 27] to protect the graft during the process of "ligamentization", with an effort to better control internal rotation stresses to the neo-ligament. During this period, the femoral tunnel was drilled from outside to inside. Fixation of the graft was initially done with wires and extra-articular screws and subsequently greatly improved by the use of interference screws. The original idea is attributed to Lambert [28] who proposed AO screws, Kurosaka [29] then developing a more specific screw design.

As these techniques improved and gained in reliability, the indication for antero lateral tenodesis became progressively less necessary. They increased the surgical burden to the knee and rendered rehabilitation more difficult without a proven functional benefit. The indication for lateral tenodesis persists for some surgeons in cases of significant laxity or a proven antero lateral ligament injury.

The introduction of the arthroscope in the late 1970's for meniscal lesions began playing a role in ACL surgery in the 1980's. Dandy [30] was the first to use it to reconstruct the ACL using a synthetic ligament. Since the mid 1980's we used the arthroscope to assist, at first only to drill the tibial tunnel under anterior portal visualization, the femoral tunnel being drilled through a postero lateral arthrotomy using a "rear entry guide". With the development of specific femoral guides, we were then able to create the femoral tunnel from outside to inside [31] under arthroscopic control. The goal was to reproduce the anterior portion of the ACL, namely the antero medial bundle. Its femoral insertional position is located on the axial wall of the lateral femoral condyle behind the "pseudo" femoral isometric point of the ACL. This gives the neo-ligament a "favorable nonisometry" (relaxed in flexion, taught in extension), and addressed the parameters in which the ACL deficient knee seemed to cause the greatest sense of instability.

The problems posed by the passage of PT bone blocks into the femoral tunnel drilled from "outside-in" brought some medical companies to introduce new guides that facilitated drilling the femoral tunnel "inside-out". This option facilitated the passage of the transplant. This also introduced new concepts and understandings of the insertional anatomy of the ACL as it relates to arthroscopy. The "inside-out" techniques remain in use today but, in our opinion, do not offer an ideal anatomic position with real bone (as opposed to a mixed fibrous and bone) tunnel.

Hamstrings grafts

The use of the PT graft posed problems not only encountered during passage of the bone block portions of the graft. In addition, risks of patellar fracture and secondary problems of patellar tendinitis, residual flexion contracture and anterior knee pain were discovered.

The use of the hamstring was thought to be a solution to all these problems. Before becoming a now widely used technique, many surgeons had previously used this graft. The first descriptions are attributable to R. Galeazzi (1934) [32], H. Macey (1939) [33] and K. Cho (1975) [34], all using the semitendinosus or gracilis tendon, freed proximally to reconstruct the ACL. JC. Puddu [35] used the same technique with the semitendinosus but the tibial tunnel had an extra articular orifice positioned quite medially, in a manner to preserve the internal rotational action of the semitendinosus.

The first publication describing a technique using both the semitendinosus and gracilis was that of Lipscomb B. [36] in 1982. The principle, with a number of variations relating to the graft being free or attached at its distal end, be it single (2 strands) or double (4 strands) bundled, along with a multitude of proposed graft fixation techniques [37], would be adopted by all surgeons utilizing this graft. Subsequently techniques developed using the semitendinosus in triplicate. Marcacci [38] meanwhile proposed using one of the strands of the graft to perform an antero lateral tenodesis.

The two choices, patellar tendon or hamstring graft, are popular today with no real modifications except for different fixation techniques for the hamstrings. Meta-analysis [39–42] comparing both graft choices showed better control of laxity using the patellar tendon yet no difference in functional outcome. There were fewer problems with the patella, loss of extension and pain with kneeling in the hamstring grafts and in one study, more recurrent ruptures with hamstrings.

After 2000

Double bundle

Even though the results of conventional reconstructions (PT or Hamstring) were satisfactory and reliable over time, a positive "Pivot Shift" test of varying grades and proportions up to 25 % persisted during clinical examination [43]. This lack of rotational control possibly responsible for secondary meniscal or cartilaginous problems, led surgeons to reconsider the anatomy and biomechanics of the ACL. The importance of the postero lateral bundle, whose action is effective for control of recurvatum, of the anterior drawer between 0 ° and 20° and of internal rotation was until now, ignored. An awareness of the importance for an anatomical

reconstruction of the ACL with two bundles became elementary. Many techniques had been proposed in the 1970's, 1980's and 1990's, but all had the inconvenience of only having one tunnel in the tibia or the femur to mirror the anatomy. Muneta [44] in 1999 was the first to publish a preliminary series of patients operated on using these techniques, but it was Yasuda's article [45] in 2004 that allowed for a perfect definition of what anatomical zones needed to be chosen for an anatomical positioning. The realization of this double bundle theory and procedure raised certain technical problems. We remain committed to drilling the femoral tunnel from "outside-in" and have developed a specific guide for the postero lateral bundle [46].

A meta-analysis [47] published by R. Meredick and based on four randomized studies, noted an improvement in arthrometer differentials of 0.52 mm without a statistical difference in normal or subjectively normal (pivot glide) rotary subluxation. Yasuda's 2010 publication [48], reviewed ten randomized trials comparing the single and double bundle reconstruction and showed a seven fold significantly better result in anterior laxity for the double bundle technique. Statistically, it was eight times better for dynamic tests that were positive (variability of 5 % to 20 %). One study noted a better IKDC objective outcome. Two authors reported a higher percentage of re-ruptures in the single bundle reconstructions.

This interesting technique has a long and difficult learning curve. It doubles the possibility of committing an error in positioning. Medium and long term complications, especially those regarding lytic lesions of bone, are not well arrested and a longer follow-up is necessary to judge its superiority over conventional techniques.

Partial reconstructions

Arthroscopic double bundle reconstruction has allowed us to progress by understanding the anatomy and also reflect on partial tears of the ACL. Revealed on MRI and suspected on clinical examination, this diagnosis should be confirmed peri-operatively. The greater the time between the trauma and the surgery, the more the evaluation becomes difficult because of the evolution of healing of these ACL lesions that leads to a retraction of the remnants. It is also very difficult to say that the supposed healthy bundle doesn't have a lesion, at a minimum, intra ligamentously or at its insertion. The percentage of these lesions confirmed in the operating room after a thorough arthroscopic examination varies according to the literature and represents 10–15 % of the anatomical lesions of the ACL [49–51]. The techniques used to reconstruct the affected bundle is variable but we remain confident that the "outside-in" techniques can preserve as much of the supposed healthy bundle as possible

The results of patients operated on following this approach are, in the literature, very satisfactory with a significant improvement in anterior translation of the tibia relative to the pre-operative measurement and a differential laxity measured at 1 mm [52, 53]. One must note in these patients, a very small percentage of positive dynamic tests (5 %) [52, 53] and a significant improvement in knee's proprioceptive qualities compared to a knee undergoing a conventional intervention.

Surgically speaking, the interest in preserving the intact bundle is beneficial for several reasons, all described in the literature [54]:

- Improvement in the postoperative mechanical quality, with a mechanically solid bundle protecting the graft and its fixation and allowing a more aggressive rehabilitation.
- Preservation of the vascularity at the level of the synovial envelope required for healing of the graft [55].
- Preservation of existing mechanoreceptors in the intact bundle. This improves the proprioceptive qualities of the knee;therefore, its ability to resume physical activity [56]

Technically it is an intervention requiring a lot of attention, with a delicate balance between too much resection which may damage the supposed healthy bundle and not enough which can lead to impingement at the notch.

Reconstruction with preservation of ligament tissue

The benefits associated with conservation of an assumed intact bundle in partial ruptures, has led surgeons to consider the possibility of preserving as much as possible ligamentous tissue, even when ruptures are complete.

The possibility of such a surgical option can be first eluded to on MRI if there is a high avulsion, but it is the arthroscopic exploration that will decide that (high avulsion without retraction). This is possible only if the intervention is performed relatively acutely.

The femoral tunnel is drilled from outside-in with a prudent release of the posterior portion of the axial wall of the lateral femoral condyle. The drilling of the tibial tunnel is even more delicate [57]. The tibial guide is positioned for emergence of the guide pin in the centre of the tibial insertion and the tunnel is drilled with drill bits of increasing diameter. The perforation must stop as soon as the intra-articular bone is crossed and the drill bits must remain strictly within the base of the ACL. This way, the entire residual tissue is preserved. A "shaver" is passed through the tibial tunnel and into the foot of the ACL and used to progressively skewer and emerge in the upper part of the residual ligament, permitting a piercing of the remnant ACL and creating a passage for the future transplant. The transplant (semitendinosus)

harvest may remain attached distally. It can be passed intra-particularly in double or triple, from distal to proximal. At the completion of the procedure the transplant itself is not visible, covered in its entirety by the preserved ACL tissue.

During our experience in 2009, this technique represented 10 % of operated patients. Our short-term review showed no significant differences compared with conventional techniques for range of motion, Lachman test, the "Pivot Shift" and the differential. We performed subsequent MRI studies which at three months showed that the transplant had low signal intensity and was clearly distinguishable from the remnant ACL which showed a hyper signal. At six months the signal intensity of the transplant increased, approaching that of the residual ACL, perhaps signifying an advanced maturation.

The interest in this technique is in some respects, similar to those of partial reconstruction, with a vascularization and proprioception advantage to which must be added:

- Conservation at the tibial attachment of the ACL with a flare shaped filling of the anterior part of the intercondylar notch in extension contributing to stability.
- A recovering of the neo-ligament by well-organized tissue which reduces any aberrant and exuberant healing that might lead to a Cyclops lesion.

This technique does not enhance the mechanical properties of the initial transplant and does not allow for an accelerated rehabilitation program. The weak point remains the upper part of the graft which is not covered by the remnant ACL.

Conclusions

The ACL surgery has evolved considerably over the past 50 years. At first, this involved an awareness of the inadequacy of extra articular procedures and the need to reconstruct the ACL. The use of PT is at first difficult and reconstruction using fascia lata or extensor mechanisms becomes popular. The use of a free PT graft disrupts the hierarchy and becomes the "gold standard". For reasons relating to frequent secondary pain problems, some surgeons gradually move towards the hamstrings. The transition to a double bundle technique is an evolution linked to a better understanding of ACL anatomy. All this evolution is based on the biomechanics of the ACL. Beginning in 2000, a biological and mechanical concept emerges. It is on track to be evaluated and under an interesting evolutionary path that will provide food for thought for young surgeons for many years to come.

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