Joints

Review article

ACL Reconstruction: Choosing the Graft

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Summary

Rupture of the anterior cruciate ligament is one of the most common ligament injuries in sports traumatology. The need for surgical anterior cruciate ligament reconstruction is justified by its anatomical characteristics. Key considerations when choosing a graft include the potential for bone integration and the risk of failure. Bone sclerosis around the tunnel affects the integration of the graft. For this reason, one aspect upon which orthopedic surgeons should focus is the biology of the bone-graft interface. Although the BPTB graft is still used, hamstrings and synthetic grafts have become increasingly widespread and popular over the years. An allograft certainly requires more long-term follow-up to validate its use in response to functional, clinical and biological requirements.

Key words: *allograft, anterior cruciate ligament, hamstrings, synthetic, patellar tendon, graft.*

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Introduction

Rupture of the anterior cruciate ligament (ACL) is one of the most common ligament injuries in sports traumatology. More than 3% of athletes in a 4-year period of sporting activity sustain a rupture of the ACL and the risk is higher in females.

The incidence rate of of this kind of injury is 200,000 cases/year in the USA; accurate prevalence studies are difficult because not all injuries are diagnosed (1).

The need for surgical reconstruction of the ACL is justified by its anatomical characteristics. The branch of the genicular artery responsible for the vascularization of the ACL gives rise to terminal branches; this precludes potential repair of this ligament. Unfortunately, ligament reconstruction cannot recreate the anatomical, biological, biomechanical and neurophysiological properties of a native ACL (2,3).

Ideally, a graft used for surgical ACL reconstruction should be one that, as far as possible, recreates the anatomical and biomechanical properties of the native ligament, that guarantees safe fixation, and that provides rapid biological integration, reducing recovery time and donor site morbidity.

Although, over the years, autogenous, allogenic and synthetic grafts have been suggested, to date none meet all the criteria previously described (4,5) (Tab. I).

Many studies have been published in recent years in support of various grafts, but there is still no gold

standard for choosing the right graft for ACL reconstruction.

The history of a surgical technique

The first ACL reconstruction was performed by Sir Arthur Mayo-Robson, an English surgeon from Leeds who carried out the innovative surgery on a 41-year-old miner (6).

Although this was a simple surgical repair, it was the forerunner of surgical techniques for stabilizing the knee joint. The use of the fascia lata as a "replacement" began in the second decade of the last century: in 1917, Grekov and Grooves had the idea of using this structure to create a new ligament (7). The quadriceps tendon was used for ACL reconstruction by Campbell in 1935 (8), while the bone-patellar tendon-bone (BPTB) graft was introduced in 1963 by K.G. Jones (9). For many years, the BPTB graft was considered the only way to ensure mechanical success.

In the past, the hamstring tendon (HT) graft was poorly considered because used in a single-strand or double-strand fashion (10, 11). This resulted in an unacceptable mechanical behavior. Friedman first used quadrupled hamstrings; however, post-fixation with bicortical screws resulted in a poor fixation strength of the graft (12). The emergence of new fixation systems, such as cortical buttons (Endobutton; Smith & Nephew, Inc., Andover, MA, USA) and interference screws ushered in a new era for ACL reconstruction. Biomechanical studies showed that quadrupled HT graft offered greater strength and the same stiffness as the patellar tendon (13). By the 1990s, more and more surgeons were using quadrupled HT graft.

Patellar tendon

Since its advent in 1963, BPTB graft has been widely used in the primary surgical reconstruction of the ACL due to its strength, stiffness and potential for bone integration (due to the presence of bone plugs at its ends) (9).

Biomechanical studies on cadavers have shown that the middle third of the BPTB graft has an initial

Tabella 1. Quadro sinottico sulla scelta del trapianto nella ricostruzione del LCA.

GRAFT	ADVANTAGES	DISADVANTAGES
BPTB	• Excellent tensile strength • Good bone integration • Good return to pre-operative condition	• Extensor mechanism morbidity • Quadriceps weakening • Anterior knee pain
Hamstrings	• Good tensile strength • Good return to pre-operative condition • Larger graft diameter • Integrity of the extensor mechanism	• Longer recovery time • Lower mechanical strength • Longer time for bone-graft integration
Quadriceps	• Low patellar tendon morbidity • No damage to the infra-patellar branch of the saphenous nerve • Lower incidence of anterior knee pain	• Poor mechanical strength • Lack of long-term follow-up studies • Lack of meta-analyses
Allograft	• Reduction of surgical time • Lack of donor site morbidity • Less post-operative pain	• Infection risk • Immune reaction risk • Delayed bone integration
I.A.B. (Intra Articular Brace)	• Reduction of surgical time • Lack of donor site morbidity • Less post-operative pain • Quick recovery	• Delayed bone integration • Immune reaction risk • Only for selected patients (>40years, motivated, symptomatic, needing quick recovery)

strength and stiffness comparable to, or maybe even greater than, those of the native ACL.
The mechanical strength of the BPTB graft has been documented by numerous clinical studies and meta-analyses published in the literature. Noyes et al. showed that the BPTB graft had a tensile strength four times greater than that of normal ACL (14). Freedman et al. (15) performed a systematic literature review and meta-analysis on arthroscopic ACL reconstruction to compare BPTB and HT autografts and found less residual anterior knee laxity in reconstructions performed using the BPTB graft (15). Beasley et al. (16), in a systematic literature review, reported residual anterior knee laxity greater than 5 mm on KT-1000 testing in 8% of the patients treated with a BPTB graft, while 70% of the patients returned to pre-injury levels of sporting activity.
Recently, Li et al. (17) observed that ACL reconstructions performed with BPTB graft were significantly more stable than those performed using HT graft, albeit the results in terms of subjective residual instability were similar. Reconstructions with HT graft were characterized by a lower incidence of complications.
Of course, the outcome of a graft implanted *in vivo* depends on many factors, such as the type of fixation, the extent of necrosis, and the remodeling process.
There is much debate over the question of whether or not to use the PT graft, due to its many possible post-operative complications related to donor site morbidity, such as: patellar fractures, weakening of the quadriceps muscles, patellar tendon rupture and patellar tendonitis (18,19). The incidence of medium- and long-term complications varies: loss of extension of more than 5° in 2% of cases, anterior knee pain in 17% of cases, and infections at the surgical site in 0.5% of cases (15). Anterior knee pain is the most feared and frequent complication in ACL reconstruction with this type of graft, having an incidence that ranges from 5 to 55%. It is not clear why this complication arises, although it seems to be linked to the removal of bone plugs: many patients feel pain either at the patellar donor site or at the tibial donor site. This makes this surgery contraindicated in patients whose job or profession involves kneeling, such as priests, builders, plumbers, mechanics, etc. (1). Whether the mere removal of the PT could lead to an anterior knee pain syndrome remains unclear (20,21). As regards the degree of extension, it is important to emphasize that the PT does not have a true functional substitute; its role as part of the extensor mechanism is unique. Extension loss is significantly greater in patients with a BPTB graft. Furthermore, Removal of this tendon, even partial, may alter the biomechanics of the extensor mechanism, leading to pathological conditions such as patellar instability and maltracking (1). Finally, a prospective study by Pinczewski et al. (22) highlighted a significant difference in clinical and radiographic evidence of knee osteoarthritis: about 26% at 5 years and 39% at 10 years for the BPTB graft compared to 8% at 5 years and 18% at 10 years for HT graft.
Even though the BPTB graft is associated with a higher incidence of complications than other types of graft and also has some important contraindications, such as pre-existing anterior knee pain or having to kneel as part of one's work or lifestyle, it is still an option chosen by many surgeons for patients with short-term high functional demands (23).

Hamstrings

To overcome the problems associated with BPTB graft morbidity, many surgeons have started, systematically, to use the tendons of the gracile and semitendinosus muscles (hamstrings).
The advantages of this choice are: a greater cross-sectional area and maintenance of the integrity of the extensor mechanism. Furthermore, tensile strength of the quadrupled HT graft is nearly three times greater than that of the normal ACL (24). The rate of return to pre-surgical levels of sporting activity is 69%, while residual anterior knee laxity greater than 5 mm on KT-1000 laxity testing was reported in 8% of cases (16). Complication rates (extension loss, anterior knee pain and infections) are lower than those reported for BPTB graft (24).
A prospective randomized study by Aglietti et al. (25) reported similar results between quadrupled HT and the BPTB graft in terms of subjective and objective outcome. In both groups there were no complications or failures and patient satisfaction was 100%.
Recently, a decision analysis study showed that, reconstruction with hamstrings is low cost and offers high reliability (26).

The disadvantages of HT graft may include a longer healing time and graft integration time within the bone tunnel because of the absence of bone plugs at the ends of the graft. Moreover, the lack of both hamstrings eliminates the protective and stabilizing action that these muscles exert on the knee during specific movements; this condition predisposes to rupture of the ACL graft: the hamstrings and ACL together create a reflex-arc that contributes to proprioceptive control (27).
Patients with a HT graft have a significantly lower bending force than those with a BPTB graft, both at the speed of 60°/sec and at that of 180°/sec (1). This reduced bending force, however, does not affect an individual's sporting activities and lifestyle and, in particular, can be made up for by training the femoris biceps, the main flexor muscle of the thigh. The decrease of isokinetic muscle peak torque that follows the removal of hamstrings generally tends to improve one year after surgery (28).
It is also necessary to consider the possible "lizard tail" phenomenon shown on imaging (magnetic resonance and ultrasonography), histological and observational studies: the regrowth of a tendon-like structure in place of the semitendinosus several months after harvesting was found in 80% of cases (29-32).

Quadriceps tendon

The first use of the quadriceps tendon (QT) graft dates back to 1979 (33). However, its poor biomechanical strength and the unsatisfactory clinical outcomes meant that this choice remained unpopular throughout the 1980s (34).
Its theoretical advantages include the fact that the harvesting does not affect the patellar tendon and thus reduce the risk of intra-patellar scarring. Also, there is no risk of injury to the infra-patellar branch of the saphenous nerve, which is a common complication during PT harvesting (35).
Han et al. (36), in a short-term follow-up study, reported results of QT graft comparable to those of the BPTB graft in terms of post-operative laxity, clinical aspects, and patient satisfaction, with a much lower incidence of anterior knee pain. However, the lack of trials with long- term follow-up means that the quadriceps tendon is still a difficult choice for surgeons, who prefer grafts that have been shown to be safe and clinically efficient in the long term.

Allografts

The use of allogenic tissues has become more common and more popular in recent years in the USA. It offers several advantages: a shorter surgical time, the possibility of using any type of graft, less donor site morbidity, a lower risk of post-operative pain, and quicker patient recovery. Moreover, surgical morbidity is very limited, which translates into esthetic benefits for the patient (37,38).
The disadvantages of this approach include the risk of transmission of infectious diseases (viral infections like HIV and HCV), immune rejection, delay in the remodeling and integration processes due to the sterilization methods (gamma rays), as well as an inevitable increase in costs (39,40).
Reduction of the risk of transmission of infections through better controls of the origin of tissue will increased interest in allografts. At present, however, there is still a lack of long-term follow-up studies on subjective and objective stability outcome and return to sporting activities supporting this choice (41,42).

Synthetic grafts

The first attempt at ACL reconstruction with synthetic material, by Alwyn-Smith, dates back to 1918, and it gave poor results. However, since the late 1990s, the availability of better surgical techniques and materials has generated greater optimism and confidence. Currently, there exist clinical studies on patients who underwent ACL reconstruction with synthetic grafts who showed good results at medium and long-term follow-up. Lavoie et al. (43), at 8-45 months' follow-up, reported 0 failures out of 47 patients, while Ventura et al. (44) reported 14 failures at 19-year follow-up of 51 patients. In both studies the KOOS scores were good to excellent, ranging between73.5 and 93 for the first study, and between 81 and 91 for the second one (43,44).
In view of its structural and mechanical characteristics, the artificial ligament must be regarded as an intra-articular brace (IAB), and for this reason it should be reserved for patients who meet the precise and well-coded surgical indications for its use: symptomatic and motivated subjects over 40 years of age, needing a quick recovery and therefore with little time available for rehabilitation, less than that required for a biological graft or allograft. Rarely, in

exceptional circumstances, such as a once-in-a-life time sporting event, the indications may be extended to patients under the age of 40. Although the synthetic graft decreases surgery time and eliminates complications due to donor site morbidity, it is still not widely used. This is due to negative previous experiences or to the fact that it is judged on the basis of poor results, probably linked to incorrect indications. When the correct indications were respected, residual instability was observed in approximately 5.5% of cases (45).

Discussion

Key considerations when choosing a graft include the potential for bone integration and the risk of failure. Bone sclerosis that occurs around the tunnel affects the integration of the graft. For this reason, the biology of the graft involved is one of the aspects which orthopedic surgeons should evaluate closely. From this perspective, the choice of BPTB graft appears somewhat contradictory. We know that the bone plugs at the harvesting site of the patellar tendon can rapidly become necrotic: graft strength at 6 month is lower than at baseline; it improves and subsequently reaches ideal levels about 3 years after transplantation. Furthermore, a bone plug cut that is not perfectly circular will increase the integration time due to the lack of contact between the surfaces (46).

Unfortunately, the use of two hamstrings also has its disadvantages. In addition to flexion deficit and muscle weaknesses, it also results in reduced stability (47,48). Preserving at least one hamstring is very important in order to prevent excessive anterior translation when the knee is at its greatest degrees of extension (45). Zamarra et al. (49) demonstrated the possibility of reducing donor site morbidity by using only one of the two hamstrings.

Another unresolved problem is the lack of true entheses after ACL reconstruction. Although numerous studies have been conducted to date, entheses cannot yet be restored with any surgical technique. The all-inside technique is a minimally invasive surgical technique that uses a single tendon and preserves both the proprioceptive and the biomechanical system of the knee. It restores stability in both anterior and rotational loading of the knee. Other benefits include less bone loss and quicker ligamentization, limited esthetic damage, and a low risk of infection. The all-inside technique is characterized by two half-tunnels created by in-out manual milling; this, reducing the thermal stress on the bone, reduces necrotic processes and increases the release of growth factors which enhance the fibroblastic and osteoblastic activity that facilitates graft integration (50).

Conclusions

Choosing the right graft for ACL reconstruction depends on several factors such as age, functional demands and pre-existing anterior knee pain.

Both synthetic grafts and, even more so, allografts certainly need further long-term follow-ups that can validate their use in response to patients' clinical, biological and functional demands.

Although the BPTB graft is still used today, over the years the hamstrings have increased in popularity, becoming the graft most widely used by surgeons. In fact, improvements in the techniques for fixing soft tissue have allowed better results to be obtained with hamstrings than with BPTB grafts; this is a choice that provides many advantages, and reduces complications, even though the use of HT graft is still conditioned by certain short- and long-term complications. In this context, the all-inside technique is a good surgical response not only to purely biological demands, but also to clinical, functional and biomechanical ones.

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