



## Anterior cruciate ligament reconstruction best practice: A review of graft choice

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**Core tip:** There is no "ideal" graft to be used in anterior cruciate ligament reconstruction surgery and each of the four major graft choices has its advantages and disadvantages. Success or failure of the procedure depends heavily on surgical technique. Surgeons should be aware of the evidence behind the use of each graft and thus be able to make an informed decision of its appropriateness.

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### Abstract

There is much literature about differing grafts used in anterior cruciate ligament (ACL) reconstruction. Much of this is of poor quality and of a low evidence base. We review and summarise the literature looking at the four main classes of grafts used in ACL reconstruction; bone-patella tendon-bone, hamstrings, allograft and synthetic grafts. Each graft has the evidence for its use reviewed and then compared, where possible, to the others. We conclude that although there is no clear "best" graft, there are clear differences between the differing graft choices. Surgeon's need to be aware of the evidence behind these differences, in order to have appropriate discussions with their patients, so as to come to an informed choice of graft type to best suit each individual patient and their requirements.

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### INTRODUCTION

Anterior cruciate ligament (ACL) reconstruction is a common operation<sup>[1]</sup>. The aim of surgery is to restore functional stability to the ACL deficient knee. The functional stability provided by the normal ACL is both in resisting anteroposterior translation as well as rotational subluxation. ACL reconstruction can be performed using a variety of different surgical techniques as well as different graft materials.

The choice of whether to operate or not is multifactorial and is highly dependent on patient's degree of symptoms and requirements in terms of activity level and participation in pivoting sports<sup>[2]</sup>. Many patients can become asymptomatic following a course of proprioceptive rehabilitation<sup>[3]</sup>. Timing of any ACL reconstruction is also crucial, it is commonplace to allow the acutely injured knee to settle, giving time for resolution of effu-

sion, restoration of range of motion and recovery from of concomitant ligamentous injuries<sup>[4]</sup>. Furthermore a delayed reconstruction allows patients to trial conservative therapy to see if surgery is indicated.

The three categories of commonly used grafts are autograft, allograft and synthetic graft<sup>[5]</sup>. Autografts usually consist of either hamstrings tendons (HS) or Bone-patella tendon-bone (BPTB). Allografts are varied but can consist of tibialis posterior tendon, Achilles tendon, tibialis anterior tendon, BPTB and peroneus longus tendon<sup>[6,7]</sup>. Synthetic grafts have been developed over the years and are currently on their “third generation” but have encountered considerable problems in the past<sup>[8-11]</sup>. Currently the most widely accepted synthetics are the Ligament Augmentation Reconstruction System (LARS; Corin, Gloucestershire, England) and the Leeds Keio (Xiros plc, Neoligaments, Leeds, United Kingdom) however their use remains somewhat controversial<sup>[12-15]</sup>.

The surgical technique used during ACL reconstruction varies widely not only from country to country but even within departments of the same hospital. Different techniques include arthroscopic *vs* open surgery, intra *vs* extra-articular reconstruction, femoral tunnel placement, number of graft strands, single *vs* double bundle and fixation method<sup>[16-20]</sup>. This heterogeneity of techniques makes comparison of graft choice difficult.

The choice of which graft and which technique to use are often dictated to the surgeon by the patient's anatomy, previous surgical history, concomitant injuries as well as patient choice. Surgeon's choice is dictated by a combination of factors including perceived functional outcome, rehabilitation speed, graft incorporation, graft availability and donor site morbidity. Surgical familiarity also dictates which technique is used as well as the graft choice.

Much research has been done in trying to identify which particular graft or technique is best. Some of this research has been of good quality including meta-analyses, systematic reviews and randomised controlled trials (RCT). Yet, there continues to be wide variation in the choices made by surgeons. Long-term outcomes are not immediately available for newer techniques which fuels further debate.

Our aim is to bring together current literature in order to allow surgeons to make decisions based on current evidence.

## DISCUSSION

The question of how best to assess results has been recently addressed by a review from the Dutch Orthopaedic Association. They recommended the use of a combination of physical examination using Lachman, pivot shift and anterior drawer tests, level 1 evidence, together with the following outcome scores-International Knee Documentation Committee Subjective Knee Evaluation Form Score (IKDC), Knee Injury and Osteoarthritis Outcome Score (KOOS) or Tegner Score from level 2 evidence<sup>[21]</sup>.

## Graft choice

**Hamstring tendon grafts:** Hamstring tendons are one of the more commonly used grafts for ACL reconstruction since Lipscombe in 1982 and arthroscopically assisted four stranded grafts by Friedman in 1988. The semi-tendinosus tendon with or without the gracilis tendon is harvested, typically from the ipsilateral leg. The resultant tissue is fashioned into a four strand graft which is then used to reconstruct the ACL as per the surgeon's favoured technique. It is common for the tendons to be folded over each other in order to increase the thickness of the donor graft. In order for the folded tendons to act as one unit they are sutured together using a whipstitch technique. The donor graft is then fed through the tibial tunnel and into the femoral tunnel and secured using a variety of fixation methods including screws, suspensory apparatus and transfixion devices which may be metallic, polymer or bio-absorbable.

Morbidity specifically associated with HS grafts include decreased knee flexion strength and tibial rotation although these do not usually translate into noticeable deficits in patients<sup>[22]</sup>. Other complications include sciatic or saphenous nerve damage, although again this is rare and may resolve with time<sup>[23]</sup>.

The long term follow-up results of HS grafts are sparse and many studies use differing outcomes to report success and/or failure. Recently the 14 year results of 74 patients with HS graft reconstruction were reported by Leiter *et al*<sup>[24]</sup> looking at patient outcome scores as well as re-rupture rates. They used the IKDC Score and found that 75% of patients scored normal or nearly normal, however radiographic changes of Kellgren-Lawrence grade 3 were 19% in operated knees compared to 4% in the contralateral knee, this finding reached significance even after controlling for medial meniscal surgery. They found re-rupture rates of the reconstructed ligament at 9% compared to contralateral ACL ruptures at 5%. Other studies of HS tendons with similar follow-up are uncommon. Leys *et al*<sup>[25]</sup> reported results from a cohort study with 15 years follow-up comparing HS to BPTB. In the HS arm they had 15 year results on 51 patients. Re-rupture rates were 17% in the HS group and 12% in the contralateral knee. Re-ruptures were more common in men, patients with non-ideal tunnel position. Mean IKDC Subjective symptom scores were 90 (out of 100) and mean functional scores 9.1 (out of 10). Shorter term studies but with larger study group sizes are available. Streich *et al*<sup>[26]</sup> reported a single blinded evaluation of 40 patients with 4 strand HS grafts at 10 year follow-up. They report 8% re-rupture rate and an IKDC score of 90.3 and all joints were either grade A or B (normal or nearly-normal). Asik *et al*<sup>[27]</sup> reported the results of 271 patients with 4 strand HS grafts fixed using a transfix pin. Their follow-up length was a mean of 6.8 years and 86% scored normal or nearly normal on IKDC score. Re-rupture occurred in 1.5% of patients in this shorter follow-up study. Maletis *et al*<sup>[6]</sup> reported retrospectively from the prospective Kaiser Permanente ACL Recon-

struction Registry revision rates after HS grafts in 3012 patients was 1.56% (1.1% revision rate per 100 years of observation), however follow-up was short at a mean of 1.5 years. No assessment of patient outcome/satisfaction was performed.

**BPTB grafts:** BPTB grafts for ACL reconstruction have been around since the pioneering work of Franke in 1969 and are still very popular in certain countries and in specific patients. BTPB has historically been considered the gold standard for ACL reconstruction. The method of harvest includes a horizontal or longitudinal skin incision followed by resection of the mid-portion of the patella (inferior pole) and tibial tuberosity with the intervening tendon as a complete unit. Thus the graft has bone block at both ends which allows potentially superior integration of the graft into the tibial and femoral tunnels. The graft is then detached and fed through the tibial tunnel into the femur in the same way as a hamstrings graft. Fixation can take place using a variety of different methods ranging from an interference fit with no fixation device to screw or suspensory fixation<sup>[28]</sup>.

There are many reports of the morbidity and complication associated with BTPB grafts. Complications include patella tendon rupture, patella/tibial fracture, quadriceps weakness, loss of full extension, anterior knee pain and difficulty kneeling<sup>[29,30]</sup>. Typically the cosmetic result is inferior to hamstrings harvest which may be of concern for some patient groups.

Long term results after BTPB graft reconstructions have been studied by many authors. Mihelic *et al*<sup>[31]</sup> retrospectively studied outcome of 33 operated BTPB grafts with 17 to 20 year follow-up with 83% of patients having stable knees with normal or near normal IKDC grades and an IKDC score of 83.15, they do not however report re-rupture rates. Gerhard *et al*<sup>[32]</sup> report 16 year mean follow-up of 63 patients after BTPB ACL reconstruction with 84% returning to previous sporting levels with 78% normal or near normal IKDC grades and a KOOS score of 84. Nineteen percent of patients had radiographic evidence of moderate to severe osteoarthritic changes, worse with meniscal injury at the time of ACL reconstruction. One point six percent of patients needed revision ACL reconstruction but a total of 33% needed further knee surgery during follow-up. Leys *et al*<sup>[25]</sup> who compared HS to BTPB showed in the BTPB arm of their study that there was no significant difference to HS in overall IKDC grade, whereas radiographic evidence of osteoarthritis was significantly more common in BPTB. Ahn *et al*<sup>[33]</sup> looked at 117 patients with mean 10.3 year follow-up after BTPB reconstruction and showed 90.6% normal or nearly normal IKDC subjective scores. Re-rupture rates were 5.1% and all were reported after additional injury. They did also report other complications including arthrofibrosis, limited range of motion, synovitis and patella fracture. Ninety-four point eight percent of patients complained of pain when kneeling on soft ground and 61.5% complained of knee pain on walking. Pernin *et al* reviewed 24.5 year data on 100 patients after

a combination of BTPB reconstruction with lateral extra-articular augmentation with iliotibial band. IKDC subjective scores at final follow-up were 74.7, however overall only 46% had IKDC grades A or B. They report 19.5% clinical failures of which 72.2% had a meniscal injury at the time of first operation. It is important to note that they acknowledge a drop-out rate of 75% from initial enrolment which may bring a large bias into the results. Maletis *et al*<sup>[6]</sup> reported from 2791 BTPB autograft patients a revision rate of 1.18% at 1.5 years (or 0.66% per 100 years observation) which was favourable in comparison to both HS and Allograft.

**Allografts:** Donor site morbidity particularly in BTPB grafts has led to the search for alternatives. Also in the case of revision surgery where autograft options have already been exhausted an alternative graft choice may be required. The use of allograft is appealing particularly to the complete lack of donor site morbidity, reasonably good availability and a range of graft sizes with the options of bone blocks attached to the graft. Allograft material does come with its own unique risks including risk of an immunogenic reaction or disease transmission and is an expensive option when compared to autograft which costs nothing in monetary terms.

The most commonly used allograft tendons are tibialis posterior/anterior and Achilles tendon allografts however patellar tendon and HS are also widely available in some countries. Sterilisation has been an issue for allografts and older studies often used high dose irradiation or ethylene glycol which led to structurally inferior grafts. Cost availability, variability in graft tissue and storage are all important issues with allograft.

Long term results are not readily available yet, however, Almqvist *et al*<sup>[34]</sup> report 10.5 year follow-up of 50 patients with a mean IKDC score of 97. Graft failure rate was quoted at 5.45% and all were due to new significant knee trauma. Edgar *et al*<sup>[35]</sup> compared 47 patients after allograft ACL reconstruction with autograft with 48 mo average follow-up. They reported IKDC grades A or B in 82.6% of patients with subjective scores of 86.8%, which were similar to autograft. They reported a revision rate of 4.3% for allograft reconstructions. Kleipool *et al*<sup>[36]</sup> again compared small numbers 26 autograft *vs* 36 BPTB with 46 mo follow-up and reported 85% IKDC grade A or B compared to 70% in the autograft group, however, these results were not statistically significant. Foster *et al*<sup>[37]</sup> performed a systematic review of allograft *vs* autograft and found little difference between the two and reported pooled results of 82.9% IKDC grades A or B (compared to 87.2% for autograft). They also pooled failures and showed a graft failure rate of 8.2 per 100 reconstructions which performed poorly compared to 4.7 per 100 reconstructions for autograft. However none of these trends reached statistical significance. Siebold *et al*<sup>[38]</sup> compared two different allografts in ACL reconstruction, fresh frozen patella tendon *vs* Achilles tendon. In total they evaluated 251 patients with a mean follow-up of 37.7 mo. IKDC grades were normal or nearly normal

in 75.3% and 76.2% of patients undergoing patella and Achilles allografts respectively. Whilst this was not significant there was a significant difference in re-rupture with 10.4% of patella grafts re-rupturing compared to 4.8% of Achilles grafts. They do further note that these rates were high in comparison to autograft studies with similar length follow-up. In the recent study by Maletis *et al*<sup>[6]</sup>, they included 4014 allograft patients and reported a re-rupture rate of 1.74% for allograft (1.23% per 100 observation years). A ready supply of allograft tissue requires a well co-ordinated and reliable human tissue bank with a consistent tissue cleaning and decontamination processes. The cost of providing this is typically high and is limited to the most developed healthcare systems.

**Synthetic grafts:** The concerns over both autograft and allograft have led to the development of synthetic alternatives which ideally have no risk of donor site morbidity but also lack the risks associated with allograft of possible disease transmission, can be widely available with a long shelf life and simple storage and inventory arrangements. Synthetic ligaments are now into their third generation. First generation ligaments were knitted, woven or braided. These early ligaments were subject to early breakage and tended to elongate. Second generation ligaments had additional longitudinal and transverse fibres woven into the braid or knit. The materials also advanced to use Polyethylene Terephthalate or Dacron to act as a permanent replacement and allow fibroblastic ingrowth. These ligaments also suffered with wear, fraying and low abrasion resistance. Both first and second-generation synthetics were plagued with problems related to wear debris and subsequent catastrophic synovitis. This led of large cohorts of patients with problematic knees and a general aversion to the use of synthetics for ACL reconstruction in the soft tissue knee surgery community. Third generation ligaments such as the LARS are similarly constructed of Polyethylene Terephthalate, however, they are now designed to specific indications. The ACL replacement has a knitted extra-articular portion with free longitudinal fibres which resist elongation but without any braids to cause intra-articular wear and the generation of biologically active wear debris.

The latest generation of synthetics have different indications from conventional graft choices. The design rationale is that the synthetic is used to augment the healing of a freshly injured ACL. Surgery should take place as soon as possible aft the acute injury and every effort must be made to preserve the native ACL stump and draw the stump up to its femoral attachment using the synthetic to then protect the graft whilst tissue ingrowth and healing occur. Thus the synthetic is used as an augmentation device alongside biological tissue, not as a substitute graft in isolation.

As well as availability, convenience, lack of disease transmission risk and cost, the other advantage of synthetic graft reconstruction is the potential for dramatically accelerated rehabilitation with return to sport significantly earlier than for autograft and allograft. This is because

biological grafts require prolonged period (probably at least one year) for incorporation of the graft tissue into the host bone.

The results of first and second generation ligaments are not applicable to third generation ligaments due to the substantial re-design. A large scale systematic review was performed by Newman *et al*<sup>[39]</sup> which led to only 9 out of 156 articles being included. This study looked at data from 675 LARS ACL reconstructions and found an overall failure rate of 2.5% of which many of these were reported to be associated with technical errors in tunnel placement. Synovitis, which had plagued earlier synthetic grafts only occurred in only one patient in the included studies. This data suggests the third generation of synthetics have largely solved the problems of synovitis that led to the disrepute of the first and second generation. Dericks<sup>[40]</sup> described his experience of 220 patients reported 3 infections (1.4%) and 9 ligament ruptures (4.1%) with 83% of patients returning to full sports by 6 mo (and 61% by as early as 4 mo). The largest published study of LARS ACL reconstructions is by Gao *et al*<sup>[41]</sup> who retrospectively report on 159 reconstructions. They describe 94% of patients achieving IKDC grade A or B at a mean of 50 mo follow-up. All patients achieved return to sports by 6 mo with a re-rupture rate of only 1.9%. Nau *et al*<sup>[42]</sup> report the 24 mo results of a randomised controlled trial comparing BTPB and LARS ACL reconstruction in 27 and 26 patients respectively. They found no significant differences at final follow-up in the results of either graft with respect to IKDC, KOOS or Tegner scores. They also did not report and ruptures but did list patients lost to follow-up and other complications, with no significant difference. The only difference that they reported is a trend to earlier return to sport in the LARS group possibly allowing a faster rehabilitation protocol. Pan *et al*<sup>[43]</sup> report retrospective follow-up of a minimum of 4 years in 32 LARS reconstructions and compare these to 30 BPTB reconstructions. IKDC grades and Tegner scores were similar in both groups, the LARS group had A or B grading in 87.5% and a score of 6.16 respectively. No ruptures were reported in either group.

## COMPARATIVE STUDIES

There are numerous studies that have compared BPTB grafts to HS grafts for ACL reconstruction. Many of these studies are well summarised by Li *et al*<sup>[44]</sup> in their recent systematic review of the available RCT. After using thorough methods of identifying and processing available data they identified 9 RCTs with useable outcome data. They performed meta-analysis of data where available and showed significant differences between the outcome of BPTB and HS grafts in respect to pivot shift (RR = 0.87 in favour of BPTB), anterior knee pain (RR = 0.66 in favour of HS), kneeling pain (RR = 0.49 in favour of HS) and extension loss (RR = 0.63 in favour of HS). Graft failure was slightly more common in the HS group, however this did not reach significance (RR = 1.37, *P* = 0.38). IKDC scores pooled from the available data



showed normal or nearly normal results in 206/266 HS reconstructions and 169/225 BPTB reconstructions ( $P = 0.41$ ). Interestingly they concluded from this data that HS grafts restore knee joint function in a similar fashion to BTPB, however they comment that they were inferior with respect to restoration of stability.

In the multicentre study of 9817 patients by Maletis *et al*<sup>[6]</sup> they compared revision rate only and found a tendency to increasing revision rates from BPTB to HS to Allograft (1.18%, 1.56% and 1.74% respectively) with 2.7 year survival rates of 98.0%, 96.9% and 96.0% respectively. The other significant findings were increasing revision rates of 3.02 comparing Allograft to BPTB, and 1.82 comparing HS to BPTB grafts. Interestingly there was a 2.26 increased risk of revision in females with HS grafts compared to BPTB which was not reproduced in men. They also reported a protective effect of age of 7% per year which may well be an activity related phenomenon. The data they used to analyse was only related to crude failure and revision rates and no information was given on functional outcome.

The largest comparative study of LARS *vs* HS grafts, Liu *et al*<sup>[45]</sup> retrospectively compared 28 LARS and 32 HS grafts and found no significant differences between the two except in KT-1000 examination results showing the LARS to be more stable (1.2 mm *vs* 2.4 mm). However there were no differences in IKDC or revision rates. Similarly when comparing LARS to BTPB Pan *et al*<sup>[43]</sup> found no significant differences in functional outcome or examination findings between the two groups (30 BPTB and 32 LARS). In a large RCT of HS *vs* fresh frozen allograft with 7.8 year follow-up Sun *et al*<sup>[46]</sup> showed that apart from a shorter operative time for allograft procedures they showed no significant differences between the groups and both had similar outcome scores (IKDC 90 Allograft *vs* 89 Autograft). Interestingly they reported no ruptures and no complications apart from two superficial wound infections in the allograft group.

Several studies have investigated the relationship between muscle strength and isokinetic measurements after ACL reconstruction. In a series of patients by Condouret *et al*<sup>[47]</sup>, the outcome of quadriceps and hamstring strength based on the type of graft used (BoB *vs* hamstrings), was evaluated. The review of 127 patients included isokinetic muscle tests, concentric and eccentric extensors/flexors but also internal rotators/external rotators with analysis of mean work and mean power. In their series, the average muscles deficit at two years was 10% for the flexors and extensors. The type of reconstruction (patellar tendon *vs* hamstrings) had an influence on the muscle deficit. For extensors, the recovery was the same in the two groups. For flexors, residual deficits were significantly higher in the hamstrings group on the three studied parameters whatever the speed and the type of contraction (concentric or eccentric) with an average deficit of 14% to 18%, while, in the patellar tendon group, there was a dominance over the opposite side of 2% to 3% in concentric contraction. For internal rotators, a significantly higher deficit is observed in eccentric contraction for the

hamstrings group. The residual hamstrings deficits were related to the number of tendons harvested: -7% when there was no harvest, 7% with one tendon harvested and 17% with two tendons harvested.

A systematic review by Dauty *et al*<sup>[48]</sup> reporting on isokinetic results following ACL reconstruction included 53 studies; 29 reported isokinetic results after ACL reconstruction with patellar tendon graft, 15 reported isokinetic results after ACL reconstruction with hamstring graft, and 9 studies compared the two surgical procedures. Comparing the two graft choices, they found that BOB *vs* hamstring resulted in a larger knee extensor deficit but less knee flexion weakness for up to two years. They found no difference in isokinetic parameters between the two groups. These findings are supported by another metaanalysis conducted by Xergia *et al*<sup>[49]</sup>.

## CONCLUSION

All the different types of grafts used in current everyday practice for the reconstruction of a ruptured ACL have a place in this complex field of surgery. There are good data to support all of them. There is no clear “best” graft to use. However there are some clear advantages with respect to the different grafts. Donor site morbidity has been a problem for the BTPB graft, however it appears to have consistently good results particularly with respect to graft stability and return to high level sports. HS grafts appear to be a good all-round graft choice with fewer donor site complications and good results, both sources of autograft are readily available in most patients and cost nothing, but do have some technical demands for safe and efficient harvest. Allograft generally has slightly poorer results in terms of re-rupture rates, however can be invaluable in certain patient groups, particularly those with multi-ligament deficiencies or in the revision scenario. Allografts are expensive, but save time and undoubtedly remove one of the more technically demanding stages of ACL reconstruction surgery. They remove the potential for donor site morbidity but do not permit faster return to sport. Synthetic grafts are slowly regaining popularity as these too show good general results with no donor site morbidity and the ability to perform multi-ligament reconstructions without compromising the patella or hamstrings. They offer an off the shelf solution which shortens operative time and renders the surgical procedure is somewhat less complex and no graft harvest is required however the surgery is technically different, and should ideally be performed on a different time scale from conventional ACL surgery. Graft choice, therefore, needs to be made after an educated discussion with the patient regarding their requirements and expectations with regards to donor morbidity and speed of rehabilitation as well as the surgeon's personal experience and the surgical units experience and access to graft options. Certainly there is no one-size-fits-all graft yet, however, surgeons should offer the differing graft options and inform their patients of the differences as well as their own personal results with each graft suggested.

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