General

What are the Graft Options for Anterior Cruciate Ligament (ACL) Reconstruction?

Jack Thomson, BSc, MBBS[1], Mark Webb, MSc, MBBS, FRCS (Tr & Orth)[1]

[1] St George Hospital

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The anterior cruciate ligament (ACL) of the knee is commonly injured and can lead to joint instability. ACL reconstruction (ACLR) is often required as endogenous healing is limited and the stability provided by dynamic stabilisers is insufficient for complete joint function. A graft, comprising either biological tissue or synthetic material, is used to replicate the biomechanical and structural properties of the native ACL to restore function. Autografts, particularly the quadruple semitendinosus/gracilis tendon (QSGT) and bone-patellar tendon-bone (BPTB), are commonly preferred. However, autograft harvesting can lead to donor site morbidity. Allografts and synthetic grafts avoid this issue but present other complications such as immune response and inflammation. Graft choice is one of several factors influencing ACLR outcomes; fixation method, physiotherapy, and patient-specific variables also play key roles. This review evaluates the current literature on ACLR graft types and highlights distinguishing features.

INTRODUCTION

The anterior cruciate ligament (ACL), one of four key stabilising ligaments in the knee, originates from the medial surface of the lateral femoral condyle and inserts into the anterior tibial eminence. Its primary function is to resist anterior tibial translation and stabilise rotational movement. Proprioceptive feedback is facilitated through embedded mechanoreceptors.[1]

ACL injuries commonly result from sudden directional changes, abrupt deceleration, or direct trauma. The annual incidence is estimated at 68.8 per 100,000, with a higher prevalence among men.[2]

ACL reconstruction (ACLR) is extensively studied due to both the frequency of ACL injuries and the often-prolonged recovery process. Reconstruction rates have steadily increased over the past two decades, with the highest incidence observed in males aged 20–29.[3] Surgical reconstruction is performed in approximately 75% of ACL injuries among adolescents and young adults,[4] with individuals aged 15–40 representing the most frequently treated demographic.[2]

Graft options for ACLR have evolved to include autografts, allografts, and synthetic alternatives. Autografts utilise the patient's own tissue and are commonly harvested from the quadriceps, patellar, hamstring, or Achilles tendons. Allografts are derived from donor tissue of the same species, while synthetic grafts, composed of non-biological materials, offer an alternative to biological sources. Each graft type presents unique benefits and limitations that influence graft selection and clinical outcomes.

Selecting a graft type depends on multiple factors including patient/surgeon preference, age, comorbidities, physical activity level, and graft availability.

This review consolidates current evidence on graft options for primary ACLR to aid clinical decision-making.

AUTOGRAFTS

Autografts offer notable advantages, primarily the absence of immune rejection and disease transmission due to the use of the patient's own tissue. However, harvesting autografts increases operative time and incision size, which may raise infection risk and is often associated with donor site morbidity. Despite these drawbacks, autografts remain widely used in clinical practice.

QUADRUPLE SEMITENDINOSUS/GRACILIS TENDON AND BONE-PATELLAR TENDON-BONE AUTOGRAFTS

The bone-patellar tendon-bone (BPTB) autograft technique, first introduced by Jones in 1963, involves harvesting the middle third of the patellar tendon along with bone blocks from the patella and tibia.[5] These bone blocks are then positioned within hollowed femoral and tibial tunnels to achieve secure fixation at the anatomical insertion sites of the native ACL.

Initially considered the gold standard, the BPTB autograft was later challenged by the introduction of the quadruple semitendinosus/gracilis tendon (QSGT) autograft, developed by Marcacci et al., which demonstrated favourable patient outcomes.[6] This technique involves doubling both the semitendinosus and gracilis tendons to create a four-strand construct.

At present, both the BPTB and QSGT autografts remain the most commonly utilised grafts among surgeons. While each exceeds the tensile strength of the native ACL (2160 N), other factors, such as stiffness and cross-sectional area, also influence graft performance.[7] QSGT offers superior tensile strength (4090 N) and a larger cross-sectional area (53.0 mm^2) compared to BPTB (2977 N and 35.0 mm^2, respectively), which may help reduce micromotion within bone tunnels and enhance graft fixation and durability.[7] Although BPTB's smaller diameter can increase this risk, it is often mitigated with supplementary fixation techniques.[7]

Beyond mechanical properties, differences in biological healing also influence graft success. Bone-to-bone healing, as seen with BPTB grafts, is superior in speed and integration compared to tendon-to-bone healing in QSGT grafts. In rabbit models, Park et al. reported that bone healing was four weeks faster.[8] West and Harner suggest this accelerated healing may contribute to the lower re-rupture rate seen in BPTB grafts.[9]

From a clinical perspective, donor site morbidity is common with BPTB grafts, particularly anterior knee pain. Although complications such as knee laxity and hamstring weakness can occur with QSGT autografts, they are reported less frequently compared to other graft types.[10] Leys et al. reported anterior knee pain in 42*%* of BPTB recipients versus 24*%* of QSGT recipients.[11] Similarly, Sadeghpour et al. found lower pain scores and shorter rehabilitation periods in patients receiving QSGT autografts.[12]

In a meta-analysis of 25 studies, Samuelsen et al. concluded that BPTB autografts provide greater knee stability but are associated with higher rates of postoperative pain.[13] As each graft presents distinct advantages and drawbacks, graft selection should be tailored to the individual patient's clinical profile and rehabilitation objectives.

ALL-INSIDE QUADRUPLED SEMITENDINOSUS AUTOGRAFT

The all-inside quadrupled semitendinosus (AIST) autograft, introduced by Lubowitz et al., is structurally similar to the QSGT autograft but preserves the gracilis tendon.[14] This preservation is thought to enhance knee stability and reduce donor site morbidity by maintaining dynamic stabilisers.[15] The AIST technique facilitates a large graft cross-sectional area and uses shorter bone tunnels, which may reduce micromotion and improve graft fixation.[14]

Monaco et al. reported superior flexion strength in patients receiving AIST grafts compared to those treated with QSGT grafts.[15] In a two-year follow-up study using KT-1000 arthrometry, Smith et al. found that functional outcomes with AIST were comparable to those achieved with BPTB grafts.[16]

One limitation of the AIST technique is the requirement for a minimum tendon length, as only the semitendinosus is harvested. Nevertheless, Nuelle et al. reported successful graft harvest in all 60 patients in their study.[17] Moreover, the all-inside approach demands less graft length overall due to the use of shorter tunnels.[18]

Although AIST shows promise, more comparative studies are needed to validate its long-term clinical benefits.

FREE QUADRICEPS TENDON AND QUADRICEPS-TENDON PATELLAR-BONE AUTOGRAFTS

The free quadriceps tendon (FQT) autograft is utilised in approximately 10% of ACLR procedures.[19] In systematic reviews by Slone et al. and Hurley et al., six out of 14 and all 15 included studies, respectively, directly compared FQT to BPTB grafts.[20,21] Both reviews concluded that FQT grafts were associated with significantly lower donor site morbidity while providing comparable functional outcomes.

In a separate study, Buescu et al. reported lower postoperative pain scores in patients receiving FQT grafts compared to those treated with QSGT grafts at two-year follow-up.[22] This may be attributed to the FQT's biomechanical similarity to the native ACL and its larger cross-sectional area, which exceeds that of both BPTB and QSGT grafts.[7]

To enhance integration, the quadriceps-tendon patellar-bone (QTPB) autograft incorporates a patellar bone block. However, this approach may increase donor site morbidity. Despite this, Crum et al. found no significant difference in graft rupture rates when comparing FQT and QTPB autografts.[23] Notably, QTPB grafts demonstrated greater postoperative rotational instability compared to FQT.

TENSOR FASCIA LATA AUTOGRAFTS

The tensor fascia lata (TFL) autograft, first described by Hey-Groves in 1917, remains infrequently used in ACLR.[24] The TFL, a component of the iliotibial band, contributes to hip abduction, internal rotation, and lateral knee stability. Notably, weakness of the TFL has been implicated in increased susceptibility to ACL injury.[25]

Several lateral extra-articular tenodesis techniques have been described for TFL fixation, including Zarins and Rowe's intramuscular method, the modified Lemaire procedure, and Micheli's extraphyseal technique. A systematic biomechanical review by Slette et al. confirmed that such procedures improve control of internal tibial rotation and anterior translation.[26] Micheli's physeal-sparing technique, in particular, avoids disruption of the growth plate, making it especially suitable for skeletally immature patients.[27] Willimon et al. demonstrated that this approach preserved skeletal development while providing adequate joint stability, with a reported revision rate of 14*%*.[28]

Clinically, Haillotte et al. reported near-normal knee function at six- and twelve-month follow-up following TFL reconstruction.[29] In a paediatric cohort, Sugimoto et al. found that TFL grafts preserved greater postoperative hamstring strength compared to QSGT autografts.[30] However, these findings were based on relatively small sample sizes of 53 and 93 patients, respectively.

Despite some promising outcomes, the TFL autograft remains limited in clinical use. This is largely due to the scarcity of high-quality comparative evidence, the relative complexity of graft harvesting, and ongoing concerns regarding donor site morbidity. Nonetheless, its anatomical advantages and physeal-sparing potential make it a valuable option in skeletally immature populations.

ACHILLES TENDON AUTOGRAFT

The Achilles tendon (AT) autograft remains infrequently used in clinical practice. This is largely due to concerns over donor site morbidity, the tendon's critical role in ankle function, and a scarcity of high-quality comparative data. While older studies have reported satisfactory outcomes in up to 85*%* of cases, these findings are based on a small cohort, and there is a notable lack of recent peer-reviewed literature evaluating AT autografts in ACLR.[31] As such, its use remains limited and is typically reserved for specific cases where conventional graft options are unsuitable.

ALLOGRAFTS

Allografts, derived from human donor tissue, continue to gain popularity. Harvest sites often mirror those used for autografts and include tendons such as BPTB, QSGT, AIST, FQT, and others like the tibialis anterior and peroneus longus.[7]

Key advantages of allografts include reduced operative time, smaller incisions, and the elimination of donor site morbidity, all of which lower the risk of intraoperative complications and postoperative pain.[32]

Donor tissue can be stored long-term; however, processing methods such as chemical treatment and irradiation may compromise graft integrity. This degradation is believed to contribute to the higher failure rates observed in allograft compared to autografts. Several studies have reported a three- to five-fold increase in failure rates when comparing BPTB allografts to BPTB autografts, although other findings challenge this view and suggest that irradiation can be a safe and effective method of sterilisation when properly controlled.[33-35]

Cryogenic storage at -80*°C* helps preserve graft histology by inhibiting collagenase activity and bacterial proliferation.[36] Nonetheless, cryopreservation does not achieve sterilisation, and additional processing such as irradiation or chemical treatment is often necessary.

The literature remains divided on clinical outcomes. While some studies report that allografts perform comparably to autografts, others have demonstrated inferior results, even when bone plugs are utilised.[37,38] Regardless of technique, allografts typically exhibit slower biological incorporation and, due to tissue heterogeneity, may provoke an immune response.[9,32,39]

As a result, autografts remain the preferred graft choice among surgeons for primary ACLR. Allografts, however, are commonly employed in specific situations, particularly in multiligamentous knee injuries and revision ACLR, where the need for multiple or larger grafts and the desire to avoid additional donor site morbidity make them a practical alternative.

SYNTHETIC GRAFTS

Synthetic grafts, composed of polymers and other non-biological materials, were initially popularised in the 1970s but later fell out of favour due to poor clinical outcomes. First- and second-generation devices, such as the Ligament Augmentation Device (LAD) and the Leeds-Keio (LK) ligament, were associated with elongation, abrasion, and fraying, resulting in high rupture rates and limited durability.[40, 41] A meta-analysis by Jia et al. subsequently advised against their continued use.[42]

Synthetic grafts offer notable advantages, including the elimination of donor site morbidity and the absence of disease transmission risk. However, their use has been limited by inflammatory complications, including synovitis, and a potential to promote osteoarthritis through upregulation of pro-inflammatory mediators and metalloproteases.[40]

In recent years, third-generation synthetic grafts have renewed interest in this category. Devices such as the Ligament Advanced Reinforcement System (LARS) and Polyglycolic acid (PGA)-Dacron have been engineered to encourage host tissue intergration and reduce material fatigue.[43] LARS grafts offer a wide tensile strength range (2500–5600 *N*, depending on graft size) and have demonstrated low rupture (0.96%) and synovitis (0.24%) rates in a review of 35 studies by Parchi et al.[44] However, concerns remain: Tiefenboeck et al. and Iliadis et al. reported failure rates as high as 50% and 31%, respectively, raising questions about the long-term viability of LARS grafts.[45,46]

PGA-Dacron grafts, which combine degradable (PGA, a biocompatible polymer) and permanent (Dacron, a non-biodegradable polyester) components, aim to facilitate endogenous healing. In a 12-year follow-up study, Pritchett reported superior recovery outcomes, and no complications compared to BPTB autografts.[47] Nevertheless, the lack of large-scale, long-term comparative studies continues to limit widespread clinical adoption of synthetic grafts in primary ACLR. Similar to allografts, the use of synthetic grafts is generally limited to specific cases where graft or tissue availability is limited, or where additional structural reinforcement is required, such as in revision ACLR or multiligamentous knee injuries.

DISCUSSION

This review underscores the continued preference for QSGT and BPTB autografts as the gold standard in ACLR. Both graft types are associated with favourable clinical outcomes: BPTB grafts benefit from rapid bone-to-bone healing, while QSGT grafts offer improved biological incorporation due to their greater cross-sectional area and mechanical flexibility. In addition, autografts circumvent key limitations of allografts and synthetic grafts, including delayed integration, immunogenicity, and pro-inflammatory responses.

Recent developments in graft technology have introduced alternative options with encouraging early results. Autografts such as the AIST and the FQT graft demonstrate potential advantages in reducing donor site morbidity and accelerating postoperative recovery. Similarly, constructs such as the QTPB autograft and PGA-Dacron synthetic grafts have exhibited favourable biomechanical characteristics and short-term clinical outcomes. Nonetheless, the current evidence base for these alternatives remains limited, and high-quality, long-term comparative studies are required to establish their efficacy and safety.

It is important to acknowledge that graft selection is only one determinant of ACLR success. Surgical technique, fixation method, postoperative rehabilitation, and patient-specific factors, such as age, activity level, and comorbidities, also significantly influence clinical outcomes. Finally, this review is subject to several limitations, including variability in study design, small sample sizes within niche graft studies, and inconsistencies in outcome reporting. These factors must be considered when interpreting and generalising the available evidence.

CONCLUSION

This review synthesises the current evidence regarding graft selection in ACLR. BPTB and QSGT autografts remain the most extensively supported options, offering consistent clinical outcomes and favourable biomechanical properties. Emerging alternatives such as the AIST and FQT autografts may offer advantages in specific patient populations, particularly with respect to donor site morbidity and recovery profiles. While allografts and synthetic grafts continue to develop, concerns remain regarding their biological incorporation, immunogenic potential, and long-term durability. High-quality, comparative studies are needed to further evaluate the clinical utility of these evolving graft options.

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