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REVIEW

Surgical reasons for failure of anterior cruciate ligament reconstruction: an update

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ABSTRACT

Anterior cruciate ligament reconstruction (ACLR) is a reliable method to restore knee stability and function in professional and recreational athletes. Reasons for failure of ACLR include re-rupture, suboptimal surgical technique, issues with graft incorporation, timing and efficacy of rehabilitation programs, time of return to sport, and unrecognized concomitant pathology such as malalignment, meniscal or ligamentous injuries. Surgical technique continues to play a pivotal role in the success or failure of ACLR. The purpose of the current review is to provide an update on modifiable surgical risk factors for failure of ACLR and potential pitfalls to avoid in order to optimize postoperative outcomes and patient satisfaction.

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Key words: Anterior cruciate ligament reconstruction - Treatment failure - Reconstructive surgical procedures.

Anterior cruciate ligament ruptures (ACLR) are common injuries with an incidence ranging from 37 to 84 per 100,000 persons.[1-3] The number of ACL reconstructions (ACLRs) performed in the USA greatly increased from 50,000 per year in 1995 to nearly 200,000 in 2012. Overall, reported long-term failure rates range from 1.8-27%.[4, 5] When necessary, the outcomes following revision ACL reconstruction have been steadily improving, however they remain inferior when compared with that seen following primary ACLR.[6-9]

ACL reconstruction failure is defined as painful stiffness, a flexion contracture greater than 10 degrees, or recurrent laxity in the context of activities of daily living (ADLs) or sports.[10] Recurrent laxity, or patholaxity, remains the primary indication for revision ACLR.[11] Greis *et al.* proposed three etiologies for ACLR failure: 1) errors in surgical technique; 2) failure of graft incorporation; and 3) trauma.[12] Graft failure from technical errors or failure of incorporation is often cited as the single most common cause for ACLR failure, with incidence estimates ranging from 0.7% to 8%.[13-16]

Technical errors including tunnel placement, graft selection, graft fixation and tensioning are implicated in anywhere from 21-79% of all ACL reconstruction failures.[17-22] Tunnel placement has been shown to be the most common technical error leading to failure of ACLR.[17-19] A review of common surgical reasons for failure of ACL reconstructions was previously published by the senior author (E.J.S.).[23] The purpose of the current review is to provide an update on some of the more recent advances in ACLR surgery and how to mitigate technical errors which may contribute to failure.

Operative indications and timing

The initial evaluation of a patient with a suspected ACL rupture includes a thorough history and physical examination. Patients may report a pivoting mechanism of injury with or without associated contact. Typically, the affected knee will swell within a short period of time due to disruption of the blood supply along the ACL and the development of a hemarthrosis.[24] Clinicians should have a high index of suspicion for concomitant meniscal or articular cartilage injuries. Physical examination findings for ACL ruptures or insufficiency include a Lachman, pivot shift, and anterior drawer test. Of these special tests, the Lachman test is the most sensitive for a complete rupture on an awake patient with a recent meta-analysis demonstrating a sensitivity of 96% compared with gold standard MRI or diagnostic arthroscopy.[25]

The acute phase of injury is characterized by inflammation, pain, and decreased range of motion. Shelbourne *et al.* demonstrated that ACL reconstruction performed prior to 7 days after injury led to an increased rate of arthrofibrosis compared with those reconstructions performed after 21 days.[26] However, more recent meta-analyses have shown that ACL reconstructions performed in the acute phase of injury do not have a higher risk of postoperative arthrofibrosis as long as swelling has reduced and full range of motion has been achieved.[27, 28] Thus the status of the knee with respect to the acute inflammatory phase of injury is more important than the duration of time since injury.

In addition, early ACLR, defined as reconstruction before 10 weeks following injury, has been shown to be cost-effective compared to rehabilitation and delayed reconstruction with no difference in clinical outcomes.[29, 30] Although it is presumably more cost effective to perform ACLR as acutely as possible, our preference is to allow for pain and swelling to resolve and for the patient to recover full range of motion and quadriceps strength prior to surgery.

Femoral tunnel placement

The primary purpose of ACLR is to restore knee stability and function. The importance of bone tunnel placement cannot be understated. It is one of the most cited technical errors leading to ACLR failure in the form of recurrent laxity or outright graft failure. It is imperative that the surgeon have an understanding of the native anatomical footprints as well as potential pitfalls in order to ensure proper femoral and tibial bone tunnel placement.

The femoral bone tunnel has been implicated in up to 50% to 79% of ACL failures.[31] A keen understanding of the native anatomy of the ACL femoral footprint is required in order to optimize femoral bone tunnel placement. Arnoczky's anatomical description published in 1983 serves as a foundation for our understanding of the ACL.[32] He described two distinct anatomical and functional bundles, the anteromedial bundle (AMB) and posterolateral bundle (PLB). The femoral attachment is a semi-circle, wider in the cranio-caudal than ventral-dorsal dimension, and located approximately 8 mm posterior to the posterior femoral cortex and 4 mm anterior to the posterior condylar articular surface (Figure 1).[32, 33] The length of the ACL has been shown to range from 12-23 mm proximal-distal and the diameter from 7-13 mm anterior-posterior.[34-36] Another useful metric that has been elucidated is the relationship of the ACL footprint to the articular margin. Studies show that the superior margin of the ACL footprint is 1.8±1.3 mm inferior to the "over-the-top" position, the posterior-most aspect of the footprint is 2.5±1.1 mm anterior to the posterior articular surface, and the inferior-most portion of the footprint is 2.8±1.5 mm from the posterior articular surface.[34] The goal of femoral bone tunnel placement in ACLR is to maximize coverage of the anatomical footprint.

There are several challenges to femoral

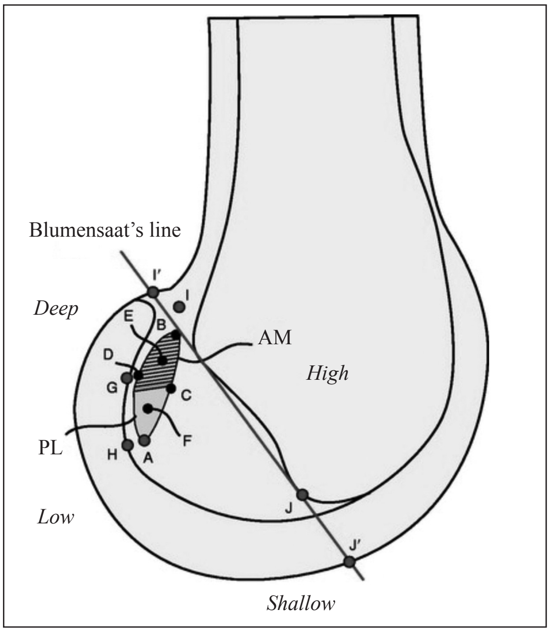

Figure 1.—Two distinct anatomical and functional bundles of the ACL exist, the anteromedial bundle (AMB) and posterolateral bundle (PLB). The femoral attachment of the ACL is a semi-circle, wider in the cranio-caudal than ventral-dorsal dimension, and located approximately 8 mm posterior to the posterior femoral cortex and 4 mm anterior to the posterior condylar articular surface.

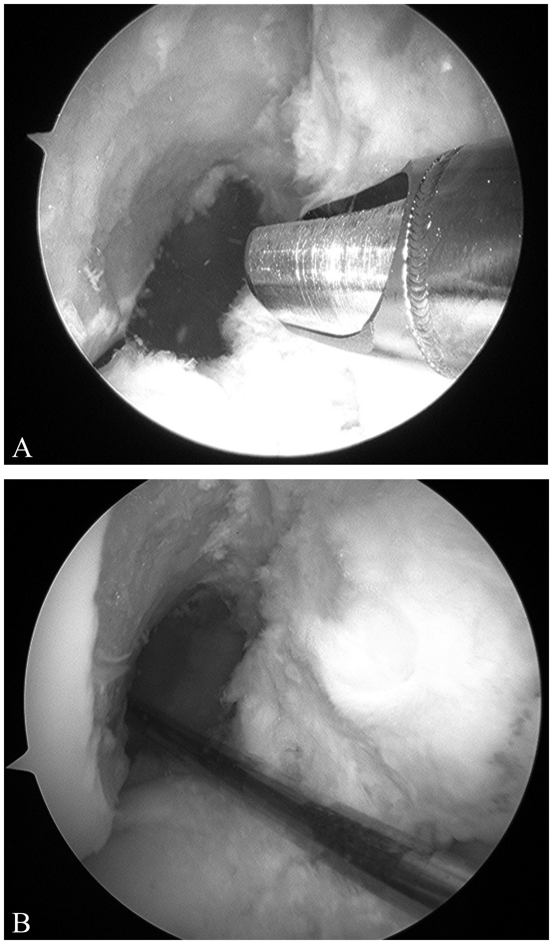

Figure 2.—A, B) Adequate notchplasty to the posterior aspect of the intercondylar notch with white periosteal tissue visible posteriorly.

bone tunnel placement including poor visualization, poor exposure of the posterior condylar wall, and poor access to the appropriate starting point. Adequate visualization of the lateral aspect of the intercondylar notch is of paramount importance. A low threshold to perform a notchplasty will optimize visualization and prevent improper placement of the femoral tunnel (Figure 2A). Additionally, the notchplasty should be carried out all the way posteriorly to visualize the most posterior aspect of the intercondylar notch. The notchplasty should not stop at the ridge, colloquially known as "resident's ridge," but rather continue posteriorly to the posterior condylar articular margin as noted by the presence of white periosteal fibers at the most posterior aspect of the notch (Figure 2B).

The most common malposition of the femoral tunnel is either too vertical or anterior, or a combination of both. A vertical tunnel placement will lead to rotational instability or impingement on the posterior cruciate ligament (PCL). A study by Lee *et al.*[37] showed greater rotational instability measured by a residual positive pivot-shift and worse Lysholm scores associated with increasingly vertical femoral tunnel placement.

Anterior malposition of the femoral tunnel will cause graft impingement on the anterior aspect of the intercondylar notch or increased tension in flexion leading to stretching and gradual increase in graft laxity. Maak *et al.*[38] found that tunnels placed in a more anteromedial position demonstrated the highest amount of impingement compared to tunnel placement centrally or posteriorly on the footprint. Anteriorly placed femoral tunnels have also demonstrated worse outcomes, with a higher rate of postoperative instability on instrumented testing and lower Lysholm scores.[39] Recent finite element analyses (FEA) have shown greater instability, higher cartilage contact pressure and meniscal stresses with anterior tunnel placement.[40] On the contrary, tunnels placed too posteriorly will increase the risk of violating the posterior cortex causing posterior wall blowout thereby compromising graft fixation or causing early graft failure.[41, 42] Additionally, FEA demonstrates increased peak stresses with posterior tunnel placement.[40]

When arthroscopically assisted ACLR gained widespread popularity, transtibial (TT) femoral drilling was the most common method with acceptable results. Studies demonstrated that this led to anterior and superior graft placement.[43] Anteromedial (AM) portal drilling, or the independent technique, became popularized as an alternative leading to more anatomic position of the femoral bone tunnel. Early studies such as the Danish registry suggested a higher rate of revision of AM technique compared with TT approach.[44] A cadaveric study by Giron *et al.*[45] demonstrated no significant difference in tunnel location between TT, double incision, or AM techniques. Other cadaveric studies have refuted Giron's findings suggesting that tunnel placement *via* TT approach leads to a more superior and posterior tunnel with less adequate graft-footprint overlap.[46-52] Several studies evaluating placement of the femoral tunnel using TT approach only evaluated radiographic parameters, not as evidenced by visualization or advanced imaging such as MRI.[53]

More recent studies have shown that while the TT approach may allow for adequate tunnel placement, it may require a more oblique tibial bone tunnel with a more proximal starting point, leading to tibial tunnel shortening.[54] Tibial tunnel shortening may result in graft-tunnel mismatch jeopardizing graft fixation and/or incorporation.[54, 55] AM portal femoral tunnels have performed well in cadaveric studies, showing that 75-97% of the tunnel overlaps the native footprint.[50, 56] Other clinical studies evaluating tunnel placement with advanced imaging have corroborated a superiority of AM technique over TT approach in tunnel placement.[57-62] Schairer *et al.*[63] found similar rotational stability between AM-drilled tunnel ACLR and native controls, both superior to TT-drilled tunnels. A gait analysis conducted by Wang *et al.*[64] also found greater stability in AM-drilled tunnels, however also notably found a significant extension deficit in the late stance phase when compared with the TT approach.

Early clinical data is conflicting. A recent study by Arno *et al.*[65] compared tunnel placement using TT and AM techniques demonstrated that TT tunnels were placed more proximal in the footprint and therefore a more vertical graft compared with the intact ACL, however at mean follow-up of just over a year there was no difference in clinical outcomes. A prospective randomized trial by Zhang *et al.*[66] also found no difference in Lysholm scores or KT-1000 testing at a minimum of 12 months. Other short-term studies demonstrate higher outcome scores in patients treated with an AM technique, although there were no significant differences in objective physical examination testing.[67, 68]

Biomechanical studies also demonstrate an advantage to femoral tunnels drilled using the independent technique over the TT technique.[47, 51] Franceschi *et al.*,[69] in particular, demonstrated improvement in anterior-posterior stability as well as rotational stability with AM drilling. Part of the reason is that optimal placement of the femoral tunnel as previously discussed is in the center of the femoral anatomic footprint, which is easier to achieve with the AM technique.[70]

Though there is still a lack of mid-term and long-term outcome data on the AM technique, the overall trend has been away from TT tunnel drilling and towards an independent AM approach. A recent study showed the incidence of TT tunnel drilling decreased from 56.4% to 17.6%, while the incidence of anteromedial portal drilling increased from 41.3% to 65.1%.[71] A study by Duffee *et al.*[72] showed that TT drilling was a predictor of subsequent ipsilateral knee surgery, although no causality was

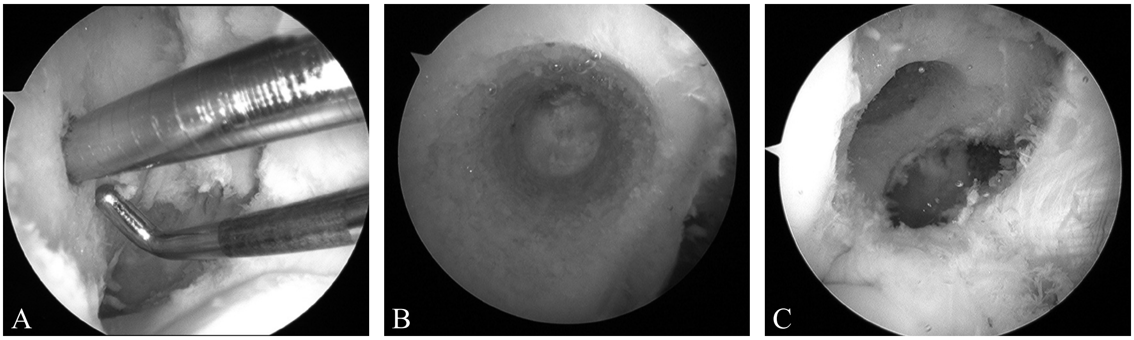

Figure 3.—Independent AM portal localization and drilling of the femoral tunnel allows for better recreation of the native anatomy. A) Distance to the back wall can be checked with the probe to avoid posterior wall blow-out. B) In-line viewing of the drilled tunnel can be achieved with the arthroscope placed in the AM portal confirming maintenance of the back wall throughout. C) AM drilled femoral tunnels better recreate the femoral origin than TT drilled tunnels.

established. There are no long term comparative studies evaluating these techniques. Inderhaug [73] in his 10-year prospective TT technique cohort had good Lysholm scores although 20% demonstrated a positive pivot-shift test postoperatively. Other long-term studies have shown a statistically significant greater incidence and severity of osteoarthritis, particularly in patients who had undergone meniscectomy and/or also had chondral lesions.[74, 75]

The AM method has shown promise in cadaveric, biomechanical, and early clinical studies. The ability to drill tunnels independently allows more flexibility to achieve optimal tunnel placement without compromising the tibial tunnel (Figure 3).

Tibial tunnel placement

Malpositioning of the tibial tunnel may not be as commonly implicated in revision ACLR as improper placement of the femoral tunnel, but it is equally as important to place this tunnel anatomically. Graft obliquity, impingement, decreased range of motion, and graft-tunnel mismatch can all occur with suboptimal tibial tunnel placement. Again, an understanding of the anatomical footprint is essential. Arnoczky described the tibial attachment of the ACL as anterior and lateral to the anterior tibial spine. He described anterior and posterior fibers that attach to the anterior and posterior horns of the lateral meniscus, respectively.[32] He showed the anterior edge inserts approximately 15 mm posterior to the anterior tibial plateau and an average insertion length of 30mm from anteromedial to posterolateral. Colombet *et al.*[34] showed mean footprint anteroposterior and mediolateral diameters of 17.6 mm and 12.7 mm, respectively.

Several studies have debated the optimal position of the tunnel in relationship to anatomical soft tissue or bony landmarks in the knee. Some soft tissue landmarks that have been advocated include the posterior aspect of the lateral meniscus or 7 mm anterior to the PCL (Figure 4). These landmarks, however, can be inconsistent and vary with the patient's anatomy. Feretti *et al.*[76] reported more reliability by measuring off the intermeniscal ligament in combination with the medial tibial eminence. McGuire *et al.*[77] advocated a bony landmark

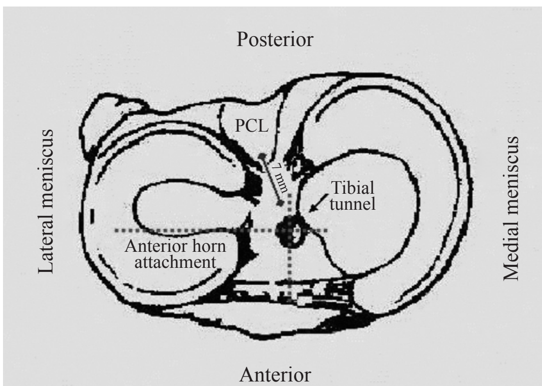

Figure 4.—Landmarks for tibial tunnel placement.

they called the "over-the-back ridge" (OTB), which was found to be a mean 6.2 mm posterior to the posterior edge of the ACL footprint. Edwards *et al.*[78] used the OTB and a point 5 mm lateral to the medial tibial eminence. Irrespective of the referencing method utilized, optimal tibial tunnel placement can significantly affect outcomes.

Improper tibial tunnel placement can cause graft impingement, usually due to excessive anterior placement leading to impingement on the roof of the intercondylar notch and higher failure rates.[79, 80] Essentially, the graft must be placed sufficiently posteriorly to allow full extension to occur without impingement.[81, 82] Tunnels placed too posteriorly exhibit greater instability. Tibial tunnel placement should not be taken lightly, as even anatomically-placed tunnels can have notch impingement. A larger tibial tunnel diameter and lower drill-guide angle have been shown to increase the risk of notch impingement.[83] Biomechanical studies have shown that drilling the tibial tunnel in the tibial footprint, or slightly anterior position within the footprint, yields optimal results (Figure 5).[84, 85]

Graft choice

Autograft remains the gold standard for ACLR despite the donor site morbidity associated with its harvest. Allograft use as an alternative gained popularity in previous decades, however carries its own risks of disease transmission, infection, higher incidence of graft failure in young patients, or potentially an immune reaction to the graft. Previous clinical data was compiled in a meta-analysis by Prodromos *et al.*[86] in 2007 which demonstrated a significantly higher rate of greater than 5 mm of laxity in allografts compared with autografts. At that time, ACLR was being performed with irradiated grafts, altering the biomechanical properties of the allografts. A study by van Eck *et al.*[87] showed an overall failure rate of 13% between 6 and 18 months with irradiated allografts, warning that graft incorporation may take longer than autograft.

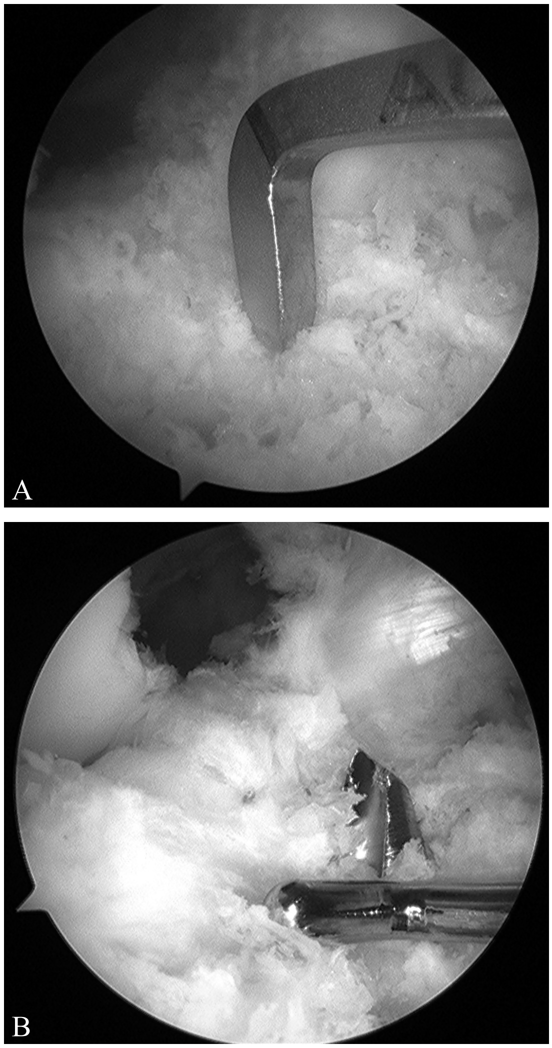

Figure 5.—A, B) Localization of the tibial tunnel within the native footprint utilizing the posterior aspect of the anterior horn of the lateral meniscus as a soft tissue landmark.

A more recent meta-analysis by Mariscalco *et al.*[88] in 2014 showed no significant difference in failure rates, graft laxity, or patient-reported outcomes comparing non-irradiated allograft ACLR and autograft ACLR. Crawford *et al.*[5] showed a higher infection rate and higher postoperative morbidity risk with non-irradiated allografts compared with autograft (7% *vs*. 2.8%, respectively). Most studies have suggested that non-irradiated grafts outperform low-dose (<2.5 Mrad) irradiated grafts.[89] However, mid-term results published by Tian

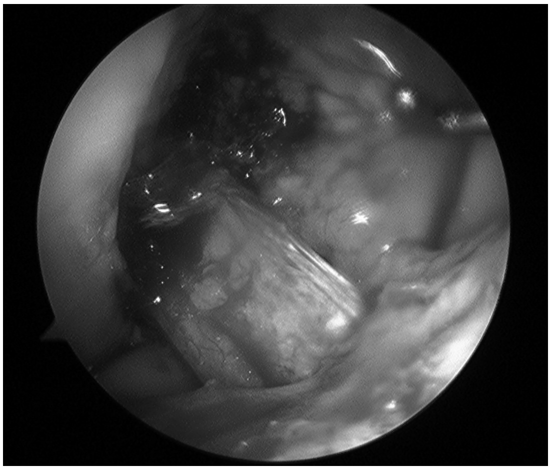

Figure 6.—Bone-patellar tendon-bone autograft ACL reconstruction.

et al.[90] showed no difference in functional outcomes comparing low-dose irradiated grafts and autografts. A recent meta-analysis by DiBartola *et al.*[91] showed a dose-dependent negative effect of gamma irradiation on tendon allograft strength. For all these reasons, autograft remains the gold standard (Figure 6). In cases where autograft is not a good option, however, non-irradiated allograft has been shown to have good results.

Another contested debate in graft selection is bone-patellar tendon-bone (BTB) *versus* hamstring autograft. Some argue that BTB grafts incorporate better secondary to bony healing, decreased graft stretch, and consistent graft size. Others highlight postoperative anterior knee pain, higher incidence of extension loss, and higher rates of postoperative complications with BTB autograft. Graft size is more variable for hamstring ACLR and smaller graft sizes have been shown to have a higher failure rate. Park *et al.*[92] showed that hamstring autografts less than 8 mm in diameter had a significantly higher failure rate. Furthermore, Spragg *et al.*[93] showed a lower likelihood of failure with every incremental increase in graft diameter. A long-term follow-up study by Bourke *et al.*[94] and meta-analysis by Gabler *et al.*[95] demonstrated equivalent graft survival comparing BTB and hamstring. Li *et al.*[96] published a meta-analysis showing that while survival rates are comparable, BTB grafts outperform hamstring on objective stability testing. Shakked *et al.*[97] found that young active females had improved objective measures of stability and significantly fewer failures using BTB autografts compared with hamstring grafts.

Graft fixation and tensioning

There is a multitude of a graft fixation options in ACLR including interference screws, cortical-based tension devices, staples, cross-pins, and press-fit. The variety of options and interchangeable nature of graft fixation represents the parity in techniques. Nonetheless, interference screws are one of the most common forms of both femoral and tibial fixation. They can be metal or bioabsorbable/biocomposite. Meta-analyses show no significant differences between bioabsorbable and metal interference screws with respect to objective outcome measures including stability testing and graft failure.[98, 99] The concern with bioabsorbable screws is their propensity for postoperative host reactions and screw breakage. Konan *et al.*[100] found a 1-10% intraoperative screw breakage rate. Several studies have also shown a higher rate of knee effusions with bioabsorbable screws with no noted clinical significance.[99] Irrespective of material, interference screws perform better when placed in parallel as divergent screws have been shown to cause graft failure.[101, 102] Additionally, eccentric screw placement displaces the graft and alters the reconstruction kinematics and must be taken into consideration.[103]

The main concern with suspensory fixation including cortical-based tension devices, is loosening of the suspensory mechanism and subsequent graft laxity. Biomechanical studies have shown that these devices have sufficient ultimate failure strength required for ACLR.[104] Additionally, adjustable-loop suspension constructs have been shown to have higher amounts of loosening compared with fixed-loop constructs and interference screws.[105-107] Furthermore, a meta-analysis by Colvin *et al.*[108] suggested a trend toward decreased surgical failures with interference screw fixation compared with suspensory fixation. Oh *et al.*[109] showed the combining interference screw and suspensory fixation increased the ultimate tensile strength and stiffness while decreasing graft slippage compared to either method alone. A systematic review by Balazs *et al.*[110] also demonstrated stronger initial fixation with less laxity, however no difference in patient-reported outcomes at minimum 1-year follow-up. Smith *et al.*[111] in an animal model showed suspensory fixation was associated with superior tendon-to-bone healing compared with interference screw fixation. With varying existing data, methods for graft fixation remain surgeon preference.

Conclusions

When performed using sound techniques, ACLR can restore stability and function in a large number of active patients. The strides made in understanding ACL anatomy and function combined with the advancements in surgical technique will continue to improve our ability to achieve better outcomes. A growing body of literature and collective experience is at our disposal. Armed with a fundamental understanding of anatomy, tunnel placement, graft and fixation options, we can mitigate surgical errors responsible for a large percentage of ACLR failures.

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