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# Contemporary Anterior Cruciate Ligament Outcomes: Does Technique Really Matter?

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**Significant advances have been made in anterior cruciate ligament reconstruction surgical technique. Further progress is being made to improve our ability to replicate anatomy with minimally invasive techniques. Presently, wide intersurgeon variation exists regarding several crucial aspects of the procedure, suggesting that the optimal technique continues to evolve. After reviewing the history of anterior cruciate ligament reconstruction surgical technique and the surgical anatomy, this manuscript outlines the various debated topics in the literature surrounding the method for drilling the femoral tunnel (outside-in vs transtibial vs anteromedial), graft selection and method of fixation as it applies to surgical technique, number of bundles reconstructed (single vs double), and surgical approach (incision vs all-inside). For each, the best available clinical evidence is reviewed to determine advantages and disadvantages. Patient factors that may indicate the use of a certain technique and special considerations such as reconstruction in the skeletally immature are discussed.**
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**KEYWORDS** anterior cruciate ligament reconstruction, anteromedial, double bundle, surgical technique, transtibial

Anterior cruciate ligament (ACL) tears are among the most common knee injuries, occurring in up to 5% of females by age 50.[1] Surgical reconstruction is among the most commonly performed orthopedic procedures with estimates of >100,000 ACL reconstructions performed annually.[2] Wide variation exists within surgical techniques.[3] These variations have contributed to a renewed interest in biomechanical replication of the ligament's function through anatomic reconstruction.[4-9] These developments have been clinically driven by several series associating clinical failure with intraoperative technical errors.[9-13] Surgeons have lessened surgical trauma through increasingly minimally invasive approaches.[3,14,15]

This manuscript discusses the various reconstruction techniques through interpretation of their anatomical and biomechanical bases as validated by clinical outcomes, seeking to discern which advances provide additional benefit over previous techniques. Heterogeneity within method of tunnel drilling (transtibial [TT] vs anteromedial [AM] vs outside-in),[16-21] graft selection (autograft vs allograft and patellar tendon vs hamstring tendon),[2,22,23] method of fixation (suspensory vs aperture),[24-27] number of bundles reconstructed (single vs double),[28-31] and approach (incision vs "all-inside"),[14,15] will be addressed using the best available evidence. Much has been written about ACL surgical technical modifications; however, little high-quality evidence exists. A recent systematic review of all studies that specified that they had used an "anatomic" reconstruction identified 74 manuscripts—but 83% of these were level III or less.[31]

## Historical Perspective

Historically, initial attempts were made at primary ligamentous repair.[32-34] The majority of efforts after the late 1970s were directed toward reconstruction.[35] Early attempts reconstructed the constraint provided by the ACL to internal tibial rotation[36] through extra-articular tenodesis.[32,37-39] Some examples included the "Slocum pes plasty," which involves a 180 degree superior rotational "flip" of the pes anserine tendons,[40] the "Macintosh" in which the iliotibial band (ITB) was passed beneath the lateral collateral ligament and intermuscular septum and transfixed back on itself (Macintosh I) or placed "over the top" and intra-articularly (Macintosh II),[3]

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the “Losee” in which the ITB was also passed beneath the lateral gastrocnemius tendon and through an extra-articular tunnel,[41] and the “Andrews mini-reconstruction” in which the ITB was divided into 2 strips that were tenodesed to the lateral femoral condyle such that 1 strip tightened in flexion and 1 in extension.[42]

As understanding of the importance of the ACL as a restraint to anterior tibial translation developed,[43] as well as the development of the ability to test anterior translation with the Lachman test,[44] surgeons began to migrate toward intra-articular repairs, which better constrained sagittal plane laxity by centering the reconstruction in the coronal plane. Intra-articular reconstruction was first paired with extra-articular augmentation, and then used as a sole technique as growing evidence suggested that the nonphysiologic kinematics of extra-articular reconstruction combined with the extent of surgical dissection necessary could contribute to the progression of degenerative joint disease.[3,45] These repairs migrated toward the use of free grafts (usually the patellar tendon[46] and the hamstrings tendons)[47] passed through tibial and femoral tunnels with an intervening intra-articular segment.[3] This platform provides the basis for all modern reconstructions. However, prior techniques have aimed for the 1 o’clock (or 11 o’clock) position in search of a more “isometric” point on the femur.[48] Recent literature on the anatomy of the ACL and the biomechanical function of vertically oriented grafts compared with anatomic grafts has altered this thinking.[8,49-52]

## Anatomy

Increasing attention has been directed toward reconstruction of patient anatomy, specifically because nonanatomic repairs have been linked to graft attenuation, graft impingement, failure to reconstitute rotational stability, and failure to reconstitute sagittal plane stability.[9-13] Anatomic reconstruction whereby the Lachman and pivot shift tests are eliminated should be the operative goal of ACL surgery.[53] The surgeon must develop a full understanding of the anatomy of the native ACL (Fig. 1). A full review is provided elsewhere within this issue. Of note, significant variation exists between patients with regard to the location of these footprints. By definition, anatomic reconstruction is predicated on replication of each patient’s anatomy, and thus for reconstruction to be “anatomic,” it must be individualized.[31]

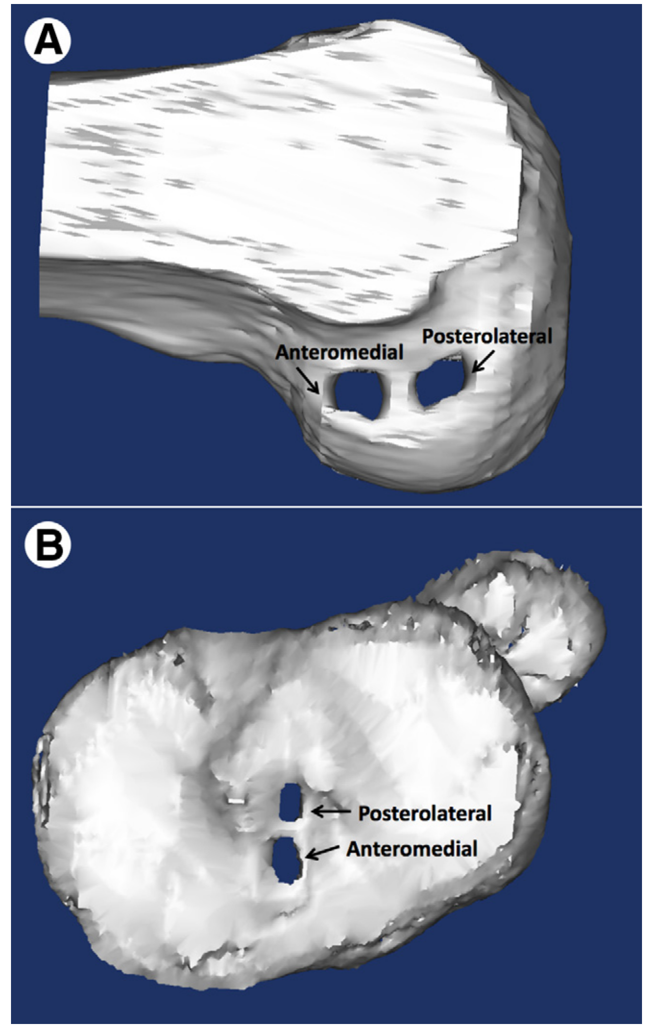


**Figure 1** (A) Femoral and (B) tibial footprints for the anteromedial and posterolateral bundles of the anterior cruciate ligament.

## Method of Tunnel Drilling

Although the 2-incision “outside-in” technique evolved in the mid 1980s and was used initially for arthroscopic ACL reconstructions, a transition in this technique evolved around 1990 to a 1-incision technique in which the femoral tunnel was drilled by passing the drill through the tibial tunnel, that is, the TT technique. Excellent outcomes have been reported using both techniques.[54-57] However, the TT approach constrained placement of the femoral tunnel based on the location and orientation of the tibial tunnel, whereas the 2-incision technique allowed independently drilled femoral and tibial tunnels.[9,51,58] A reconstruction with this graft alignment provides stability in the sagittal plane, but these tunnels are nonanatomic and may not restore rotational stability. In this case, the pivot shift phenomenon will persist and the patient will be predisposed to poor functional outcomes and dissatisfaction with their surgical result.[8,49-52] A vertically oriented graft replicates the AM ACL bundle.

The technical errors related to the 2-incision technique were often related to anterior placement of the femoral and tibial tunnels. With the evolution of the single-incision technique, surgeons achieved more accurate placement of the femoral tunnel in the sagittal plane, at the expense of more superior placement of the femoral tunnel in the coronal plane. Additionally, particularly with hamstring grafts that used smaller tibial tunnels, the tendency was to place the tibial tunnel too posterior in the sagittal plane. In fairness to the early investigators of the TT technique, isometric plots of the ACL femoral footprint suggested that one should aim superiorly in the intercondylar notch.[48]

These concerns regarding the TT approach led to the development of the AM technique in which the femoral tunnel is drilled through an accessory medial arthroscopic portal

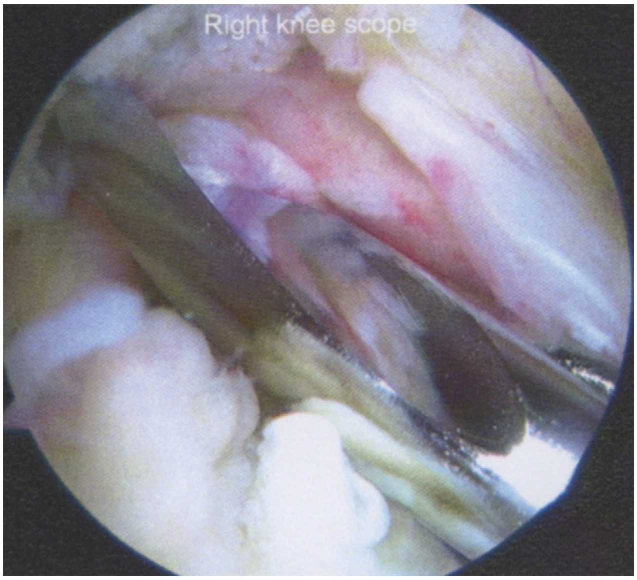


**Figure 2** Arthroscopic image of drilling of the femoral tunnel using the anteromedial portal.

with the knee in hyperflexion (Fig. 2).[9,51,58] The AM portal technique was initially popularized by O'Donnell in an attempt to reduce divergence of interference screw fixation on the femur.[59] This technique allows independent positioning of the femoral and tibial tunnels, theoretically improving the ability of the surgeon to achieve anatomic placement of the tunnels. However, the AM technique is technically demanding. Drilling is best performed in a difficult-to-maintain hyperflexed position. The reamer passes immediately adjacent to the medial femoral condyle and anterior horn of the medial meniscus and endangers both of these structures. Hyperflexion can obscure visualization, and the reamer can displace the fat pad into the arthroscopic view, further reducing the exposure.[60,61] The AM technique also leads to shorter femoral tunnels, possibly predisposing to fixation failure and graft tunnel mismatch.[62,63] Biomechanical studies have linked the AM technique to supraphysiologic graft tension, which may lead to increased articular contact pressures, graft breakdown, or tibial subluxation.[26,64-68] Several researchers have demonstrated that the centroid of the femoral footprint can be reached using a TT approach with appropriate modifications of surgical technique,[49,69-71] and thus be used to perform an anatomic reconstruction (Fig. 3), so some surgeons may be hesitant to switch femoral tunnel drilling methods. Others may believe the benefit of greater freedom in femoral tunnel location outweighs technical difficulties associated with the AM technique. It should be stressed that inadequate knee flexion will result in intratunnel posterior wall violation (ie, blowout) with this technique. However, recently, flexible reamers have been developed as an alternative to the TT technique of the extreme hyperflexion required with AM drilling.

Controversy persists within the orthopedic community about which of these techniques is preferable. A recent meta-analysis that specified that an "anatomic" reconstruction was used, noted roughly one-half of those articles specified that a TT approach was used and roughly one-half specified that an AM portal approach was used.[31] Only 2 directly comparative clinical studies exist, the findings of which directly conflict with one another.[17,72] The TT technique continues to be the method of choice for 70%-85% of the members of the American Orthopedic Society for Sports Medicine and the American Academy of Orthopedic Surgeons according to recent surveys.[16]

## Graft Selection

A variety of graft options exist in ACL reconstruction. The 2 most popular options are bone–patellar tendon–bone (BPTB) and 4-stranded gracilis/semi-tendinosis. Both grafts can be obtained in the majority of patients as autografts, and both grafts can be used as allografts. Debate exists within the literature regarding which of these options provides the best surgical outcome.[2,73] Only BPTB allows osseous fixation on the graft. Of the available grafts, BPTB is both the stiffest at time zero and the least viscoelastic, which theoretically could provide reduced laxity on examination.[74,75] Comparative studies, including numerous retrospective and prospective trials, some randomized, and 2 separate meta-analyses have been performed, with some concluding that BPTB provides reduced laxity, and others concluding that graft selection does not influence laxity.[2,23,53,73] Given the ambivalence of the evidence available to date, no strong recommendations can be made in favor of either graft. Graft selection remains a matter of surgeon and patient choice. However, the patient must be informed and the surgeon must be aware that certain surgical techniques (the double-bundle technique, the all-inside technique, etc.) rely on the use of soft tissue grafts, and thus if the surgeon or the patient is uncomfortable with this graft type, these techniques cannot be performed.[73] There are

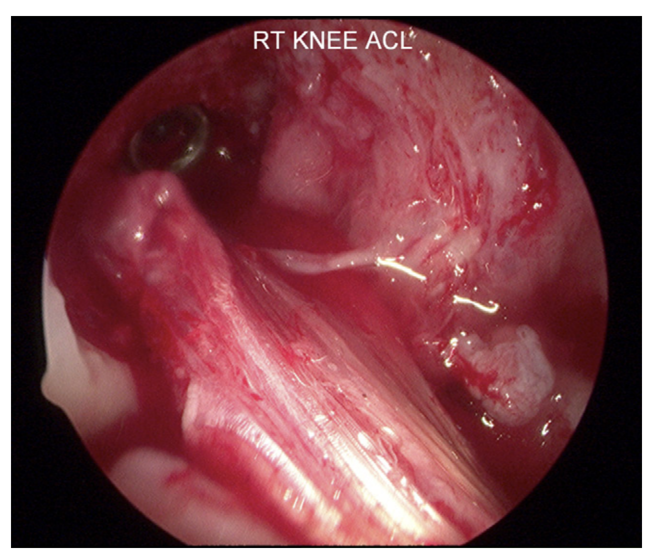


**Figure 3** Arthroscopic image of a completed anterior cruciate ligament reconstruction using a transtibial approach to drilling of the femoral tunnel demonstrating tunnel placement low on the wall at roughly the "10:30" position.

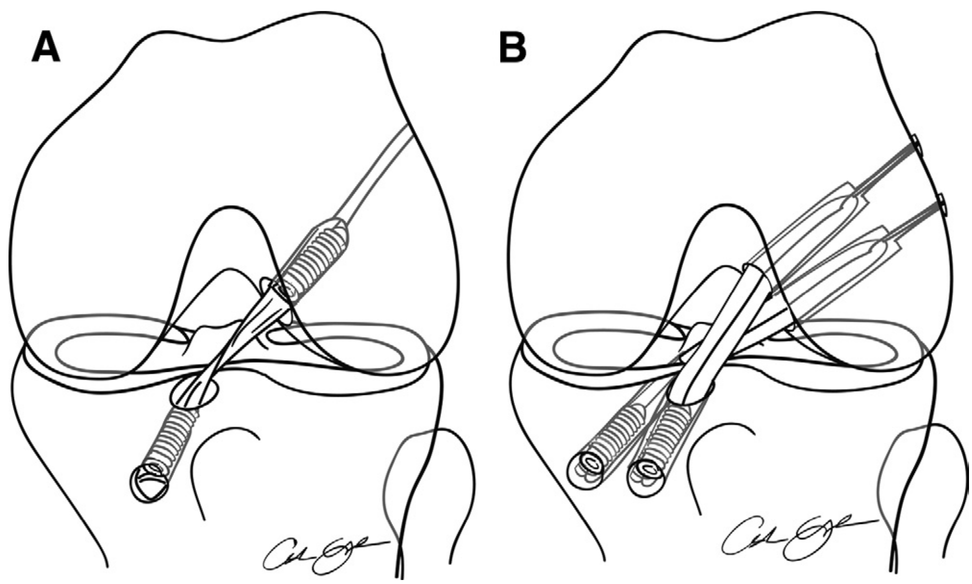


**Figure 4** Schematic images of (A) single- and (B) double-bundle anterior cruciate ligament reconstructions.

some data that indicate that the smaller tunnels used in hamstring reconstruction may preclude anatomic femoral location with a TT technique.[76]

## Method of Fixation

Several different methods exist for graft fixation. Generally, these techniques can be divided into "intratunnel" fixation in which the graft is fixated within the tunnel itself, such as with an interference screw, and "suspensory" fixation in which the graft is fixated at or beyond the extra-articular end of the tunnel, such as a staple or cortical button. Suspensory fixation may subject grafts to the "windshield wiper" or "bungee" effect in which graft micromotion occurs within the tunnel with knee flexion and extension. This may draw joint fluid within the tunnel, may contribute to tunnel widening, and may abrade the graft and lead to early failure, although no clinical evidence exists to support these theoretic concerns.[24] Fixation methods can vary in stiffness by an order of magnitude, with interference screws and Washerloc© (Biomet, Inc, Warsaw, IN) combinations having the greatest stiffness.

One concern using aperture fixation in the form of an interference screw is colinearity of the screw with the graft. Graft-screw divergence can reduce the fixation strength[24-27] or compromise the graft itself.[14,15,61] Some authors have recommended accessory portals for screw insertion. Several authors claim that this may be more difficult using the AM technique because of the hyperflexion required.[15,60]

## Single- Vs Double-Bundle Reconstruction

The link between nonanatomic tunnel placement and clinical failure,[8,49,52] likely owing to failure to provide physiological rotation laxity,[50,51] has lead to the concept of a reconstruction of both AM and posterolateral bundles of the ACL (Fig. 4).[28-31] Several technical variations already discussed are necessary for this type of reconstruction including the AM approach to drilling of the femoral tunnel, the use of hamstring or other entirely soft tissue grafts, and suspensory fixation (eg, Endobutton, Smith and Nephew, Andover, MA). Although variations exist, the technique generally involves (1) preservation of the tibial and femoral footprints for referencing intraoperatively, (2) minimal or no notchplasty, (3) drilling 2 tibial tunnels with the aimer set at 55 and 45 degrees for the AM and posterolateral tunnels, respectively, to provide tibial tunnel divergence,[30] (4) sizing the grafts specifically for the tunnels, (5) drilling the femoral tunnels either transtibially or through the AM portal, (6) graft passage, (7) tensioning of each bundle separately, and (8) suspensory fixation.[28] Generally, femoral tunnel divergence is provided by the use of the TT technique for drilling the AM femoral tunnel and the AM portal technique for drilling the posterolateral femoral tunnel.[28] A variety of soft tissue grafts have been used, including hamstring tendon (auto- or allograft), tibialis anterior allograft, quadriceps tendon (auto- or allograft), and Achilles tendon allograft.[28] Several contraindications exist to performing a double-bundle reconstruction, including insufficient footprint size (<14 mm) to allow the positioning of 2 tunnels with a 2-mm bone bridge between tunnels, a narrow intercondylar notch (<12 mm), and open physes.[30]

Although this technique was developed in pursuit of anatomic reconstruction, both single- and double-bundle reconstructions can be performed anatomically and nonanatomically. Both techniques require careful attention to tunnel positioning; performing a "double-bundle" reconstruction does not in-itself guarantee an anatomic reconstruction. If the bundles are inappropriately placed or tensioned, this could result in a less kinematically normal knee than that obtained with a vertical single-bundle reconstruction owing to impingement between the grafts and abnormal graft tensions. Double-bundle failures can lead to a particularly complex revision procedures secondary to tunnel expansion and overlap often requiring a staged bone grafting and subsequent revision procedure.

One additional technique consideration with the double-bundle reconstruction is the tensioning protocol. Secondary to the anisometric position of their respective footprints, the AM bundle has greatest physiological tension at 60 degrees, whereas the posterolateral bundle has greatest physiological tension at 0-15 degrees.[77] Biomechanically, this provides the basis for tensioning the AM bundle at 45-60 degrees of flexion and the posterolateral bundle at full extension. A recent in vivo study compared tensioning of the AM bundle at either full extension or 20 degrees of flexion and tensioning of the posterolateral bundle at 20 or 45 degrees of flexion. Intraoperative computer-navigated laxity data and postoperative pivot shift and KT2000 testing suggested that tensioning both bundles at 20 degrees of flexion provides the most stable knee with respect to both rotation and translation.[78] Studies conducted in cadaver knees using similar methodologies have had similar conclusions.[79]

Clinical outcomes comparing single- and double-bundle reconstructions have been equivocal.[29,80] Although some authors have demonstrated superior rotational control[30] and reduced anterior translation with double-bundle reconstruction,[81] other large, well-conducted, adequately powered randomized clinical trials have failed to demonstrate any difference between these techniques.[82] Meta-analyses of these clinical trials have also failed to find any demonstrable difference in a variety of clinical outcome measures.[29,80] Several authors have suggested that more sensitive outcome measures are necessary to demonstrate any difference. It remains unclear whether such a difference would be clinically significant should one exist statistically.[28,30,31]

## The Minimally Invasive Approach

These techniques, combined with improved perioperative and postoperative pain and inflammation control regimens and alterations in patient expectations, have allowed outpatient ACL reconstruction.[54-56] Over time, ACL reconstruction has become progressively less invasive, with less surgical trauma.[3] Although initial reconstructions involved lengthy incisions for exposure of lateral structures for extra-articular tenodesis,[32,37,39] modern techniques using allograft often have no incision >3-4 cm.[3] Although providing improved patient comfort and satisfaction, it remains unclear whether more minimally invasive techniques affect long-term outcomes with respect to stability, range of motion, strength, and functional outcome measures.[83] For instance, a recent meta-analysis of 4 randomized clinical trials comparing the endoscopic technique to the outside-in technique for the creation of the femoral tunnel, which does involve lateral extra-articular dissection, was unable to demonstrate any additional benefit provided by the endoscopic technique, although power analyses are lacking and type II error is possible.[83] At our institution, when compared with the endoscopic technique, the dual-incision technique had longer postoperative hospitalization between 1986 and 1991, averaging 2.6 days, and led to increased postoperative pain, likely due to violation of the posterior capsule. Additionally, the dual-incision technique was associated with a higher rate of postoperative knee stiffness, perhaps related to posterior capsular perforation with the femoral rear entry aimer, more extensive dissection, and a protocol during that period that avoided immediate extension recovery.[55]

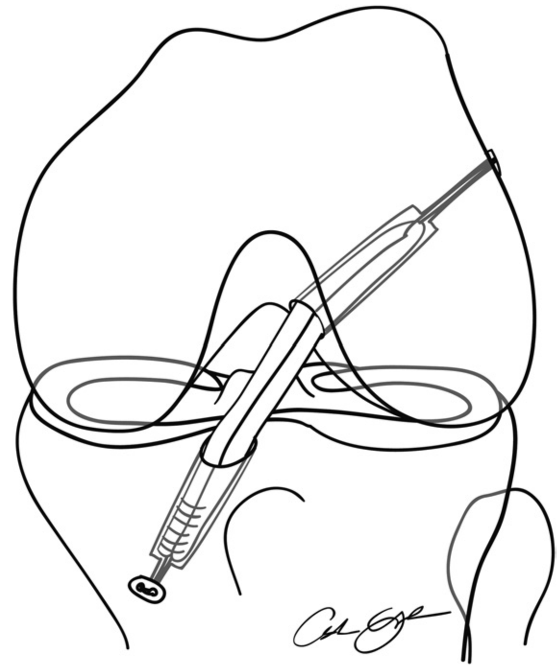

**Figure 5** Schematic image of an "all-inside" anterior cruciate ligament reconstruction.

Recently there has been interest in further decreasing the surgical trauma of ACL reconstruction through "all-inside" techniques (Fig. 5).[84] These techniques allow ACL reconstruction through 4 "stab" incisions and specialized instrumentation. A specialized guidepin must be used that can be converted into a retrograde drill (ie, retroreamer technique) once the tip is intra-articular and then converted back into a guidepin once the drilling is complete. An "outside-in" technique can be used for the femur. In both cases, the drilling does not progress to the superficial cortex. Thus, sockets are created for the graft on both the femur and tibia, which leaves the innervated periosteum intact, theoretically decreasing postoperative pain and inflammation. The tunnels can be independently positioned, which avoids the potential limitations of the TT technique. Although thus far only soft tissue grafts have been used for this technique, a BPTB graft could theoretically be used, although such a procedure would be technically demanding. If suspensory fixation is placed, this technique allows the surgeon to use the buttress of the anterior tibial cortex to place suspensory fixation with an adjustable graft loop length. This allows progressive tightening after fixation. Theoretically, this mechanism may provide the ability to adjust the tightness of the graft if the surgeon is concerned with the laxity provided with initial fixation. The surgeon can supplement with specialized aperture fixation that has been developed to place retrograde tibial and femoral screws and, theoretically, improving graft tension because they are advanced in the direction of graft tension.

This technique introduces several unique technical complexities. For instance, owing to the fixed lengths of the sockets, the surgeon must use meticulous technique to avoid graft-construct mismatch, which could lead to "bottoming out" of the graft within the socket and loss of tension. In particular, the authors recommend the use of a specialized graft preparation station with a soft tissue graft wound around tines set at an intraoperatively determined length to avoid graft–construct mismatch.[15] In addition, passing suture, grafts, screws, and so forth through "stab" incisions can traumatize the soft tissues, and thus the use of a cannula, as used in hip and shoulder arthroscopy, is recommended with this technique.[15] Because of the limited incisions, the surgeon also has limited intra-articular access, and the authors who have described this technique note that if complications occur during graft passage, salvage can be complex and may even require an open arthrotomy.[15] Overall, the technical complexity of these technical modifications is high and thus it may not be appropriate for a low volume surgeon. Of note, to date no clinical outcomes have been published regarding the all-inside technique, and thus further research will be necessary to determine the clinical utility of this technique.

## ACL Reconstruction in Skeletally Immature Patients

ACL reconstruction techniques used in the skeletally immature patient have continued to evolve. Extra-articular physeal sparing techniques were the mainstay of treatment 10-15 years ago, however, recent literature has shown that drilling across the physis results in a small area of physeal disruption.[85-87] This minimal physeal disruption likely is clinically insignificant in the majority of patients who sustain an ACL injury. Typically these patients may have few years of growth remaining. ACL tears do occur in the very young age groups, and in these patients an extraphyseal procedure may be indicated, however, there is no Level 1 literature to support this claim. In fact, biomechanical studies have shown that physeal sparing techniques cannot recreate the ACL intact state. Using the ITB as an alterative improves the anteroposterior stability but overconstrains the knee.[88]

Studies evaluating the amount of growth plate destruction have demonstrated that more vertical tunnels produce more cylindrical tunnels and less growth plate involvement by volume.[86,87] However, with the recent trend toward anatomic ACL reconstruction, the surgeon's dilemma is between providing the child the most stable knee or doing the least amount of damage to the physis at the risk of meniscal and chondral damage with recurrent injuries. The advent of new instrumentation has allowed all-physeal reconstructions that obviate this dilemma, yet introduce their own set of problems owing to extreme graft angles entering the bone that theoretically can lead to graft attenuation and failure. These techniques also yield small bone tunnels and difficulty filling these tunnels with graft using modern fixation techniques. A recent study of anatomic transphyseal drilling demonstrated that volumetrically only 2.4% of the distal femoral physis and 2.5% of the tibial physis were affected by drilling.[85]

Clinical studies have not shown any disruption of growth or malalignment after ACL reconstruction, despite using more modern techniques. Using a periosteum-central third of the patellar tendon–periosteum graft, Bonnard et al[89] found no growth disturbances at an average of 5.5 years in 56 patients with an average skeletal age of 11 years using a transphyseal drilling technique. In 10 different studies using the transphyseal method, only 2 of 310 (0.6%) patients had growth disturbance.[89-98] Extraphyseal techniques used in 70 patients across 4 studies[99-102] with only 1 patient suffering a growth disturbance, and 2 studies with a total of 20 patients using the transepiphyseal approach reported no growth disturbances.[89,103,104] With the risk of articular cartilage injury and meniscal damage, much greater in the revision setting, perhaps it is best to assure that pediatric ACL reconstructions are performed in an anatomic method rather than sacrifice stability for sparing of the physis. In fact, in a recent meta-analysis, the number of reruptures was almost double that of growth disturbances.[105]

## Future Directions

Several authors have attempted to apply computer-assisted navigation to improve outcomes in ACL reconstruction, either to perfectly replicate footprint placement or to measure laxity intraoperatively. These studies are preliminary and numerous technical, scientific, and logistical challenges exist before these techniques can be applied to general practice. Biological factors may also render these techniques irrelevant, as intraoperative laxity measurements may not accurately reflect laxity in the awake patient owing to neuromuscular control. For instance, Ohkawa et al[106] performed 125 ACL reconstructions using a computer-assisted intraoperative rotational and translational laxity measurement and were unable to find any correlation between intraoperative laxity and postoperative pivot and KT2000 findings, suggesting that intraoperative laxity may not be the main determinant to postoperative stability.

## Conclusions

Significant advances have been made in ACL reconstruction surgical technique. Surgeons must be careful not to embrace technique changes without evidence that these changes represent an improvement on present techniques, given the excellent outcomes with standard contemporary ACL reconstruction. Significant debate exists within the literature regarding the optimal method of tunnel drilling, graft selection, method of fixation, number of bundles reconstructed, surgical approach, and optimal technique in the skeletally immature patient. Further research will be necessary to determine which of the options within each of these variables provides the best patient outcomes.

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