The role of anatomic ACL reconstruction in ACL revision surgery

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Abstract: Revision anterior cruciate ligament (ACL) reconstruction is a technically demanding procedure with more challenges than primary ACL reconstruction. The etiology of primary ACL reconstruction failure is most commonly due to technical error. Determining the cause of ACL failure is the primary objective, and careful preoperative planning is of the utmost importance. It is imperative to incorporate anatomic revision ACL reconstruction principles to restore rotatory stability. This article reviews anatomic revision ACL reconstruction, including preoperative evaluation, surgical technique, pitfalls, and outcomes.

Keywords: Revision anterior cruciate ligament reconstruction (Revision ACL reconstruction); anatomic anterior cruciate ligament reconstruction; revision anterior cruciate ligament

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Introduction

Anterior cruciate ligament (ACL) reconstruction has largely been considered a successful operation, but failure, particularly in young, competitive athletes, remains a difficult problem. Revision ACL surgery has been shown to be less successful than primary ACL reconstruction, with a failure rate 3 to 4 times that of primary reconstruction (1). Graft failure occurs in 6–25% of revision surgeries (2-6). Revision ACL reconstruction patients also have lower IKDC scores and lower return to sport rates than primary ACL reconstruction patients (2). Hence, there is a need to improve revision ACL reconstruction treatment. Anatomic revision ACL reconstruction can provide a biomechanically superior reconstruction (7) but requires thoughtful preoperative planning and sound intraoperative techniques as discussed in this review.

Revision ACL reconstruction

Early recurrence of instability has been shown to be related to poor surgical technique, biological failure of the graft, premature return to high-level sports, and improper rehabilitation (8). Late failure, occurring more than one year after ACL reconstruction, is hypothesized to be related to new isolated trauma or repetitive microtrauma on the graft (9,10). An independent third-party investigation of the Multicenter ACL Revision Study (MARS) data found that 60% of revision reconstruction cases were due to "technical cause of failure," with improper positioning of the femoral tunnel being cited most often (11).

The increased complexity and inferior clinical outcomes of revision ACL reconstruction, as compared to primary ACL reconstruction, indicates a need to establish sound indications for revision surgery. The criteria for revision ACL surgery are continued symptomatic and functional instability in activities of daily living or sport with or without complete failure of the graft (12). Revision surgery can be appropriate in patients without overt graft rupture, but with a poorly positioned graft and recurrent symptomatic instability. A vertically oriented graft may lead to persistent rotatory instability that may limit an athlete's ability to return to the previous level of competition (3). Malpositioned tunnels can affect the range of motion of the knee. Femoral tunnels placed too anteriorly or tibial tunnels placed too posteriorly can lead to loss of flexion and tibial tunnels placed too anteriorly may lead to graft impingement and loss of extension (13). The anatomic footprint of the native ACL has been well described with the posterior border 4mm from the articular cartilage, anterior border at the lateral intercondylar ridge, and approximate width between 10 and 18 mm depending on the patient (14,15). Radiographically, the center of the femoral insertion is located 24.8% of the long axis and 28.5% of the short axis as described in the widely used quadrant method (16). Prior femoral tunnel malposition is defined as tunnel placement partially or completely outside of the native femoral insertion.

Subjective patient factors are a large aspect of the criteria for revision surgery, therefore it is important to obtain a thorough history, as well as objective measures. Patients often present with pain, loss of motion, recurrent episodes of "giving out", and decreased level of activity compared to their pre-injury state (12). The subjective symptoms can be corroborated on the physical examination, with a positive pivot shift, Lachman, or anterior drawer test, or more quantitatively using a KT-1000 arthrometer (12). Contraindications to revision surgery include active infection, lack of significant symptoms, unacceptable anesthesia or medical risks, and lack of functional deficits.

Anatomic reconstruction

Anatomic repair or reconstruction is a guiding principle in orthopedic surgery, and studies have demonstrated the benefits of anatomical reconstruction for multiple joints. Patients with displaced acetabular fractures who undergo anatomic reconstruction report higher postoperative Harris hip scores (17). In athletes, when anatomic reconstruction of the anterior talofibular ligament was not possible due to insufficient normal ligament, a hybrid anatomic procedure produced higher Foot and Ankle Outcome Scores than a non-anatomic repair (18). There is a growing body of evidence within the ACL literature to support the benefits of anatomic reconstruction (7,19-21). Anatomic reconstruction may be thought of as "the functional restoration of the ACL to its native dimensions, collagen orientation, and insertion sites" (22).

Biomechanical studies show that non-anatomic transtibial single-bundle reconstruction does not fully restore rotatory stability of the knee (23). The degree of rotational stability at 30 degrees of flexion is comparable between the anatomically reconstructed ACL and a native ACL, while a non-anatomically reconstructed ligament shows increased rotatory instability (7,24,25). Similarly, the non-anatomically reconstructed ACL also experiences increased AP laxity at 30 degrees flexion when an internal rotatory force is applied (26). Validated computer models have compared graft forces and stability of anatomic to non-anatomic transtibial reconstructions and showed that anatomic reconstruction provides improved AP stability (27). This increased instability may contribute to the lack of athletic confidence after ACL reconstruction that prevents some athletes from return to sport (28). A biomechanical analysis of *in situ* forces on cadaveric knees showed that anterior tibial translation of anatomic double-bundle ACL reconstructions was significantly closer to that of the intact knee than single bundle reconstruction (7). Furthermore, the *in situ* force on the anatomically reconstructed ACL normalized to the intact ACL (97%±9% of the intact ACL), while the single bundle reconstruction only restored 89%±13% of the *in situ* force (7). This difference is accentuated when the knees were placed in 30 degrees of flexion with a rotatory load. Anatomic reconstructions restored 91%±35% of the forces the intact ACL experienced, while the single bundle reconstruction only restored 60%±40% of intact ACL forces (7). Forces not felt by the ACL graft may be absorbed by the surrounding tissues, including the menisci and articular cartilage, and disruptions of normal knee kinematics may consequently contribute to an increased risk of knee osteoarthritis (OA) seen long term (29).

There is a large body of clinical evidence which supports anatomic reconstruction over non-anatomic reconstruction for improved patient outcomes, objective knee stability, and reduced risk for graft failure and revision surgery (30,31). In a randomized controlled trial comparing non-anatomic ACL reconstruction to anatomic single- and double-bundle reconstruction, anatomic reconstruction showed significant improvement in Lysholm scores, IKDC scores, objective knee anterior stability, and rotatory instability compared to non-anatomic reconstruction (32). Anatomic ACL reconstruction best restores rotatory stability to the native ACL and represents the optimal biomechanical option in revision ACL reconstruction.

One-stage versus two-stage reconstruction

Thorough preoperative planning for revision ACL reconstruction with clinical examination and imaging,

Figure 1 X-ray and 3D-CT reconstruction of a 21-year-old female with prior ACL reconstruction and recurrent instability showing anterior placement of the femoral tunnel. For revision surgery, an entirely new femoral tunnel can be drilled posterior to the old tunnel.

including X-ray, magnetic resonance imaging (MRI), and computed tomography (CT), is essential for successful surgery. Preoperative planning is greatly facilitated by three-dimensional CT (3D-CT) modeling, from which tunnel position, tunnel widening, and hardware position can be most accurately determined (*Figure 1*). In particular, surgical technique is dictated by the location of the tunnels relative to the anatomic insertion site of the native ACL. The tunnel location is broadly divided into three categories: (I) non-anatomic—tunnels completely outside of the anatomic footprints, (II) anatomic—tunnels completely within the anatomic footprints, or (III) semi-anatomic—tunnels partially overlapping the anatomic footprints (33).

With non-anatomic tunnels, which are seen most commonly (11), the technique of primary anatomic ACL reconstruction can be employed without modification, while ensuring adequate bony bridge between tunnels. When tunnels are anatomic, evidence of tunnel widening must be considered. In the absence of widening, anatomical tunnels may be reused in the revision reconstruction. Graft debridement, tunnel re-drilling, and dilation are first completed to remove soft tissues, which may interfere with graft-bone healing, and create solid bony walls for the new tunnel. If significant widening or osteolysis exists (>16 mm for a single-bundle tunnel), bone loss may be addressed in a two-stage technique using allograft or autograft bone to promote ingrowth (34). Traditionally, staged revision ACL reconstruction has been performed 4–6 months following bone grafting of tunnels.

Semi-anatomic tunnels represent a unique challenge. The surgeon must decide whether a one-stage or two-stage reconstruction is the best approach for the patient. One-stage techniques include eccentric drilling of the previous tunnel, diverging tunnel creation, using larger bone blocks, or an over-the-top (OTT) technique. The OTT ACL reconstruction technique, in which the graft is routed through the notch, around the posterosuperior lateral femoral condyle, and directly contacts the lateral wall, permits one-stage revision regardless of tunnel location. This technique is especially helpful in the case of semi-anatomic tunnels where obtaining adequate residual bone stock may not be possible. In a recent systematic review of primary ACL reconstruction, the OTT technique was found to yield comparable outcomes to traditional all-inside, transtibial, and anteromedial portal drilling techniques (35). While this trend was also seen for revision ACL reconstruction, only three case series of revision OTT ACL reconstruction (comprised of 60 total patients), have been reported (35). No studies directly comparing OTT against alternative techniques for revision ACL reconstruction have been performed. Instead of the OTT technique, divergent tunnel creation can be used to provide a cone of adequate bone for graft incorporation in order to avoid tunnel convergence and minimize the risk of graft pullout (36). Utilization of grafts with large bone blocks, or the inclusion of impacted bone graft adjacent to the graft in the tunnel, may permit one-stage procedures in the context of mild to moderate osteolysis (37,38). Alternatively, the use of a rectangular tunnel technique may permit placement of the graft within the anatomic footprint despite an overlapping primary tunnel, as the rectangular bone block is smaller in area than the traditional oval-shaped bone block (39). Additionally, in the revision of double bundle ACL reconstructions, it may be possible to drill a new tunnel corresponding to one bundle while preserving the other tunnel for the second bundle (33,40).

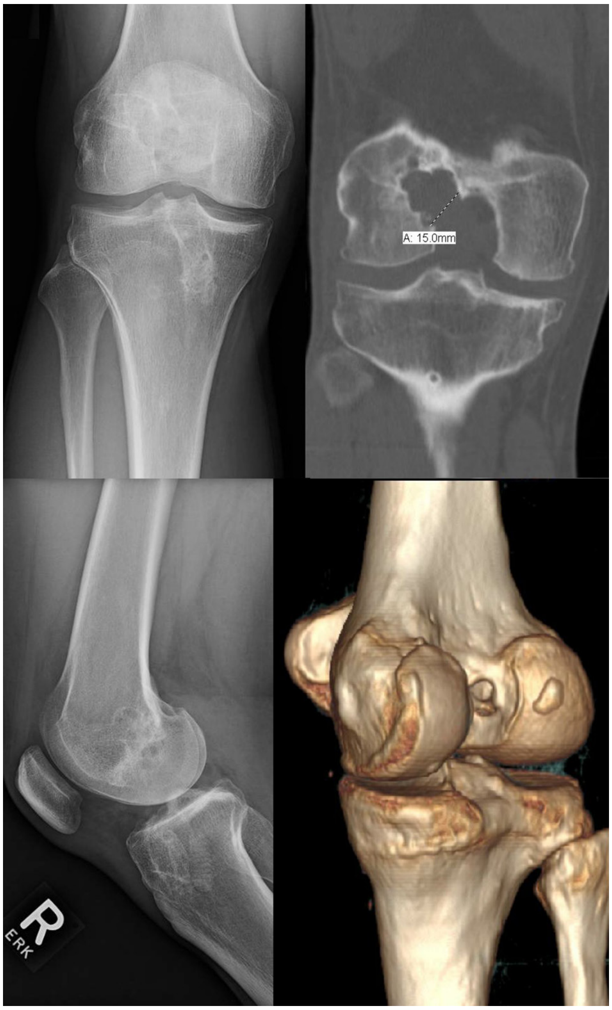

Figure 2 A 43-year-old male with two prior failed ACL reconstructions who presented with recurrent instability, and femoral and tibial tunnel widening. Revision surgery requires an OTT technique, use of a large bone block, or two-stage procedure with bone grafting.

On the other hand, a staged approach with bone grafting remains a viable strategy (*Figure 2*). Staged procedures have been reported to restore knee laxity measurements similar to that achieved with primary ACL reconstruction, but are associated with worse subjective outcomes. This is likely due in part to secondary meniscal and/or chondral lesions acquired in the interim between bone grafting and revision ACL reconstruction (41,42). However, a recent cohort study comparing one-stage versus two-stage revision ACL reconstruction found no differences between groups in objective and subjective outcomes at 2-year follow-up (43). Nevertheless, presumed equivalence between treatment strategies may be questioned as the one-stage revision group was comprised of patients with bone tunnels completely outside of the native insertion sites, while the two-stage revision group underwent bone grafting as they had enlarged bone tunnels (>16 mm) or those that would critically overlap with anatomic tunnels (43).

The Pittsburgh approach to anatomic revision ACL reconstruction

Preoperative evaluation

In our experience, the key for successful anatomic revision ACL reconstruction is a thorough preoperative workup. When presenting with clinical signs of ACL reconstruction failure, the patient undergoes radiographic evaluation with a series of knee radiographs, a hip-to-ankle long cassette, CT including 3D reconstruction, and MRI to evaluate multiple anatomic factors for preoperative planning (*Figure 3*). Knee radiographs and the hip-to-ankle long cassette are used to assess mechanical varus/valgus alignment of the knee, tibial slope, and signs of OA. The tibial slope is an important and sometimes overlooked factor. Increased lateral tibial posterior slope is associated with risk of ACL reconstruction graft rupture (44,45). Posterior slope is measured in all revision cases as part of the routine preoperative planning, and preparations are made for correction if necessary. MRI allows for evaluation of graft integrity and concurrent cartilage, meniscal, and ligamentous injuries, which may require repair. 3D-CT helps to define prior tunnel position and evaluate the amount of tunnel osteolysis or widening. We have also used 3D printed models of the knee, which provide even further detail in defining the previous tunnels and intercondylar notch size.

Operative considerations

Review of prior operative reports allows for identification of the previously used graft and hardware, which may require removal intra-operatively. Fluoroscopy and a variety of screwdrivers may be necessary for previous hardware removal and should always be available the day of revision surgery.

Revision ACL reconstruction is complicated by the previous tunnel position, with or without signs of tunnel widening or osteolysis. Previous anatomic tunnels require hardware removal, drilling of the tunnels to remove soft

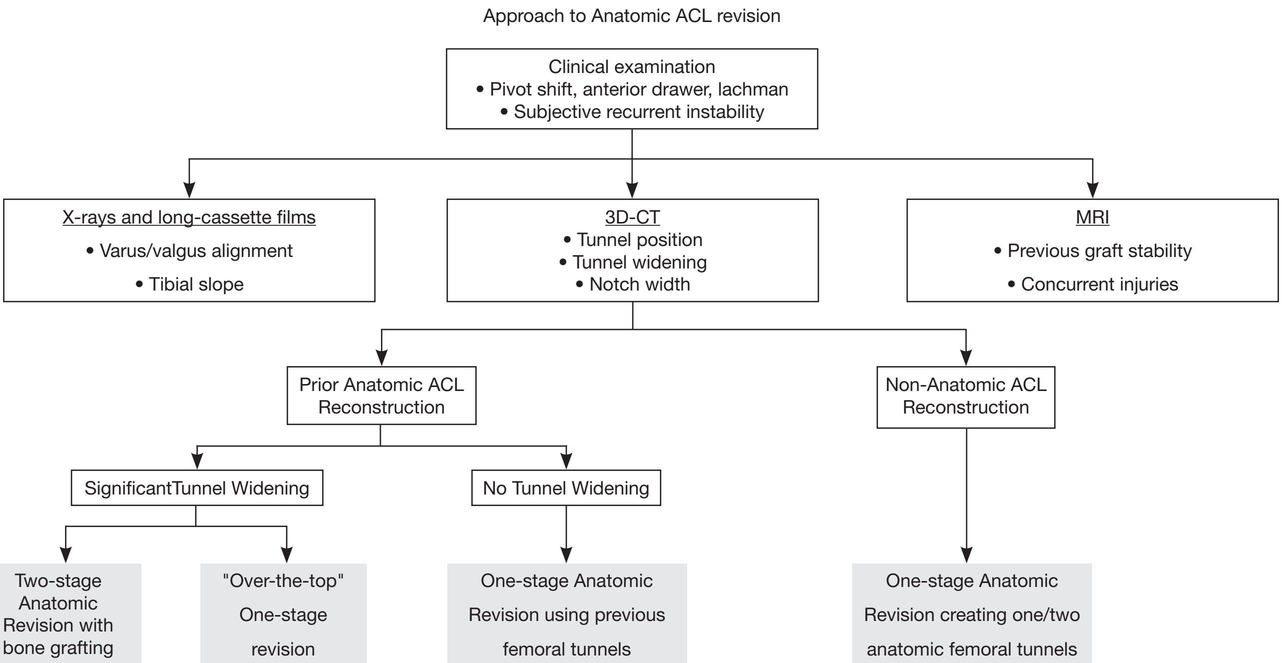

Figure 3 Algorithm for preoperative evaluation and operative technique for anatomic revision ACL reconstruction

Figure 4 A 41-year-old female with two prior failed ACL reconstructions presented with knee pain and recurrent instability. Initial radiographs (left) demonstrate posterior tibial slope of 17°. Patient underwent anterior tibial closing wedge osteotomy in conjunction with anatomic revision ACL reconstruction.

tissues, and placement of new fixation. In patients who present with significant tunnel widening and anatomically placed tunnels, the OTT reconstruction is preferred as discussed previously, but alternatively a two-stage procedure with bone grafting can be considered. Although the OTT technique is our preference in this case, there is no significant difference in patient satisfaction or clinical outcomes between one-stage and two-stage revision ACL reconstruction (43). If the prior reconstruction was non-anatomic with misplaced femoral tunnels and adequate bone stock is available for anatomic tunnels, the patient can undergo a one-stage revision ACL reconstruction with the creation of anatomic tunnels. In this situation, previous hardware can frequently be left in place. Inside-out drilling through an anteromedial portal is preferred for anatomic femoral tunnels. A narrow intercondylar notch may make this challenging, in which case an outside-in approach may facilitate the creation of the anatomic femoral tunnels.

Graft choice for revision ACL reconstruction is similar to primary ACL reconstruction with the exception that the prior ACL reconstruction(s) may have used one or more of the potential autograft options. Patellar tendon, quadriceps tendon, and hamstring tendon autografts have all been successfully implemented in revision procedures (46). Contralateral autograft harvest is an option in the setting of multiple revisions, although this is avoided when possible. Allograft does not have the morbidity associated with autograft harvest, but has an increased risk of graft failure in young, active patients (47,48). Achilles tendon allograft, with the ability to obtain a larger bone block, may be beneficial in cases of tunnel osteolysis (49). The calcaneus bone block can be rotated to match the osteolysis, and can be used for the OTT technique for femoral-sided fixation. Potential graft options should be discussed thoroughly with the patient during the preoperative visit.

Concurrent meniscal and ligamentous injuries must be carefully evaluated. Meniscus injuries occur more frequently in the setting of revision ACL reconstruction than in primary ACL reconstruction (50,51). Meniscus injuries should be repaired whenever possible in revision ACL reconstructions to aid in restoring rotatory stability (52,53). Missed posterolateral instability has been found to be a factor in failed ACL reconstructions and should be evaluated prior to revision (54). In the search for continued improvement in rotatory stability, the exact role for lateral extra-articular augmentation procedures is still being defined. We consider adding a modified Lemaire procedure (iliotibial band tenodesis) to anatomic revision ACL reconstruction in the settings of a large quantitative pivot shift, generalized ligamentous laxity, failed anatomic ACL reconstruction without identifiable cause, or a lateral femoral condyle bony morphology that we predict will be highly unstable (55,56).

Postoperative rehabilitation

Rehabilitation following anatomic revision ACL reconstruction follows our institutions standardized protocols for primary ACL reconstructions (57). The early postoperative period focuses on minimizing pain and swelling, restoring range of motion, and progressing to full weight bearing. Patients begin ankle pumps, isometric quadriceps contractions, and straight leg raises postoperative day one with frequent use of cryotherapy for the control of swelling and pain. Patients are restricted to crutches for 4 to 6 weeks but are allowed to unlock their brace for ambulation if no meniscal repair was performed. Active range of motion is progressively restored during the first 4 to 6 weeks, and focus is placed on regaining quadriceps strength with straight leg raises, isometric quadriceps contractions, and the use of adjunctive high-intensity electrical stimulation. High-intensity electrical quadriceps stimulation has been shown to improve patient outcomes and increase quadriceps strength following ACL reconstruction (58). Closed-chain weight bearing exercises and limited-arc (60–90°) open-chain exercises start as quadriceps strength improves. Aerobic low-impact training is added during the first three months postoperatively, including stationary bicycle or low-speed treadmill walking. As stability and balance improve, running is initiated four to six months postoperatively, usually first on a treadmill. Patients undergo slow progression if they do not develop new knee swelling or increased pain. Agility training and cutting drills can be started as soon as six months postoperatively if patients progress well through running training. Patients complete return to sport testing in conjunction with our physical therapy colleagues. Typical anatomic revision ACL reconstruction sees progression through rehabilitation and return to sport 9 to 12 months postoperatively.

Multiple revision ACL reconstruction

In the multiple revision patient, it is even more important to determine the reason for failure to ensure the same mistakes are not repeated. The surgeon must be prepared to expand the scope of possible interventions. For example, we present a case of a 41-year-old female with a history of a failed primary hamstring autograft ACL reconstruction, followed by a failed bone-patellar tendon-bone allograft revision ACL reconstruction (*Figure 4*). She presented with knee pain and recurrent instability. As part of her preoperative evaluation, posterior tibial slope was measured at 17°. Therefore, in addition to anatomic revision ACL reconstruction, an anterior tibial closing wedge osteotomy was performed to decrease the excessive posterior tibial slope and decrease the strain on the ACL (59). Multiple revision cases, such as this example, highlight the importance of a thorough preoperative plan and execution.

Outcomes and complications

The Multicenter ACL Revision Study (MARS) is a multicenter consortium collecting prospective data on revision ACL reconstruction. This study has provided the most significant data to the revision ACL reconstruction literature. Patient outcomes, including IKDC-Pain, -ADL, -Sports and -Symptoms, as well as MARX scores, have been shown to be significantly lower 2 years after revision ACL reconstruction as compared with primary ACL reconstruction (60). The use of autograft for revision ACL reconstruction was shown to have improved IKDC scores as compared to allograft (61). In addition, while IKDC and WOMAC scores are improved 2 years postoperatively from revision ACL reconstruction, Marx activity levels are significantly decreased (61).

In the MARS cohort, complications and the need for additional surgery following revision ACL reconstruction occurred in 11% of patients at 2-year follow-up (44). Arthrofibrosis requiring lysis of adhesions or synovectomy occurred in 1.4% of revision cases, while the need for meniscus surgery was the most frequent subsequent surgery in 4.1% of revision cases. Infection was reported in 0.35% of cases. Risk factors for subsequent surgery after revision ACL reconstruction included grade 4 cartilage damage at the time of revision, use of allograft, two-stage revision, and younger patient age (44). Bony cyst formation has been attributed to the use of bioabsorbable sutures (62). Overall, outcomes following revision ACL reconstruction are inferior to primary ACL reconstruction, but with adequate preoperative planning, establishing appropriate patient expectations, and high quality postoperative rehabilitation, complications can be minimized.

Conclusions

Anatomic revision ACL reconstruction is a complex procedure involving more comprehensive clinical examination, radiographic assessment, and preoperative testing than primary ACL reconstruction. Difficulties with revision ACL reconstruction include prior tunnel placement, tunnel widening and osteolysis, limb malalignment, concomitant injuries, and graft choice. Multiple techniques can be employed to allow for one-stage reconstruction including the use of the OTT technique, new anatomic tunnel placement, grafts with larger bone blocks, and divergent tunnel placement. While patient reported outcomes and return to sport following revision ACL reconstruction are lower than with primary ACL reconstruction, anatomic revision ACL reconstruction allows for restoration of knee stability and improved patient outcomes.

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