Review Article

Anterior Cruciate Ligament Revision Reconstruction

Mark D. Miller, MD
Michelle E. Kew, MD
Courtney A. Quinn, MD

ABSTRACT

Revision anterior cruciate ligament (ACL) reconstruction is used in patients with recurrent instability after primary ACL reconstruction. Identifying the etiology of graft failure is critical to the success of revision reconstruction. The most common etiologies include technical errors, trauma, failure to recognize concomitant injuries, young age, incomplete rehabilitation, and hardware failure. Patients should undergo a complete history and physical examination with a specific focus on previous injury mechanism and surgical procedures. A revision ACL reconstruction is a technically demanding procedure, and the surgeon should be prepared to address bone tunnel osteolysis, concurrent meniscal, ligamentous, or cartilage lesions, and limb malalignment. Surgical techniques described in this article include both single-stage and two-stage reconstruction procedures. Rates of return to sport after a revision reconstruction are lower than after primary reconstruction. Future research should be focused on improving both single-stage and two-stage revision techniques, as well as concomitant procedures to address limb malalignment and associated injuries.

Anterior cruciate ligament (ACL) reconstructions are done at a rate of 74.6 per 100,000 in the United States[1] and have a satisfactory outcome in 75% to 97% of patients.[2] However, graft rupture can be a devastating complication and is seen at a higher rate in patients younger than 20 years old.[3] These patients typically undergo revision reconstruction because studies have shown that ACL deficiency leads to increased meniscal damage and development of degenerative changes and arthritis.[4] This article will discuss the etiologies of graft failure and the preoperative workup before revision reconstruction and briefly discuss ACL revision reconstruction surgical techniques.

Etiology of Graft Failure

Identifying the etiology of graft failure is key to a successful revision ACL procedure. The multicenter ACL revision study (MARS) group detailed the

From the Department of Orthopaedics, University of Virginia, Charlottesville, VA (Miller and Kew), and INOVA Sports Medicine, INOVA Health System, Fairfax, VA (Quinn).

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causes of ACL graft failure and showed that multiple factors lead to the majority of retears (37%).[5] Traumatic reinjury was the leading single cause of revision in 32% of patients. Technical error was found to affect 24% of patients, and biological factors were the cause of graft rupture in 7% of patients.[5]

The reconstructed ACL should provide stability throughout range of motion and across a wide range of applied loads. Autografts have been shown to have good results and result in minimal donor site morbidity.[6,7] However, available autograft donor sites for a revision ACL reconstruction depend on the graft used for previous ligamentous reconstruction procedures. Allografts have been shown to result in a markedly higher risk of a revision procedure in the young and active population.[8]

Technical errors are the leading cause of ACL graft rupture.[5] The most common errors are inappropriate tunnel placement, incorrect hardware placement or hardware failure, and unrecognized or unaddressed limb malalignment. A malpositioned graft sees nonphysiologic strain, and if stressed beyond its yield point, the graft will fail.[9] The most common tunnel malpositioning is an anteriorly placed femoral tunnel.[5] This position leads to decreased knee flexion because of increased graft tension, or if physiologic knee flexion is achieved, the graft will attenuate and/or fail. Vertical femoral tunnel placement leads to adequate anterior-posterior restraint; however, the rotatory stability of the knee is compromised. Malpositioning of the tibial tunnel also affects the graft. Anterior placement of the tibial tunnel leads to graft impingement on the notch during extension. Posterior placement leads to graft laxity in flexion and posterior cruciate ligament impingement.

Graft fixation is critical to maintain appropriate graft placement and tension, especially at approximately 2 weeks postoperatively when the graft is at its weakest point.[10] Bone-tendon-bone grafts can fail at the bone-bone interface or with pull-out failure of the interference screw fixation. Soft-tissue graft fixation failure typically occurs because of improper placement of the endoscopic fastener or tension failure of the suspension fixation.

Unrecognized bony malalignment and missed concomitant injuries have been shown to affect the risk of ACL graft rupture. Posterior tibial slope and varus malalignment place increased stress on the graft, and posterior tibial slope >12° was shown to be the strongest predictor of repeat ACL injury by Salmon et al.[11] Untreated injuries to the posterolateral or posteromedial structures and the medial meniscus at the time of the initial ACL reconstruction can also lead to an increased risk of graft failure.[2]

Traumatic ACL graft failure can be divided into those that occur before graft incorporation and those that occur after the patient returns to regular activities of daily living or athletic activity. Early physical therapy is advocated for initiation of range of motion and gentle strengthening. However, aggressive early strengthening (<2 weeks postoperatively) can put a new graft at risk because an animal study showed that the ACL graft has 30% of the strength of the native ACL during the first postoperative year.[12] Acute trauma to the surgical knee can occur at any point during the rehabilitation timeline, and graft rupture is most commonly attributed to a singular event. However, high-level sports with increased cutting movements have been shown to cause microtrauma to the graft, which can eventually lead to graft attenuation and failure.[13] Risk factors for rupture after return to full activity include age <25 years and return to pivoting, jumping, or contact sports.[13] Decreased quadriceps/hamstring strength and poor performance with single-leg hop/jump testing postoperatively have also been shown to correlate with a higher risk of reinjury.[14]

Evaluation

The clinician should begin by obtaining a thorough history of presenting symptoms and functional limitations. Previous surgical notes and reports should be obtained to allow for the evaluation of the previous injury mechanism, concomitant injuries, graft type, fixation methods, and postoperative rehabilitation protocol. Previous arthroscopic images, radiographs, and advanced imaging should be reviewed. Return to sports (RTSs) and functional limitations after the initial reconstruction should also be noted. Patients should be questioned and counseled regarding future plans for athletic activity or desired functional abilities to ensure that the patient's expectations match the outcomes of a revision procedure. Finally, the clinician should determine the etiology for the patient's graft failure to ensure a successful revision procedure.

The physical examination should begin with inspection of the affected knee to identify effusions, signs of infection, and previous surgical incisions. Standing alignment and gait are evaluated to identify potential limb malalignment. Varus or valgus thrust while walking should be further evaluated with specific maneuvers for the evaluation of the posterolateral or posteromedial corners. Range of motion should be compared with the noninjured side and should be done both prone and supine to identify deficits that would require preoperative rehabilitation. The ligamentous examination should begin with the evaluation of the ACL with the Lachman test to assess anterior-posterior restraint and the pivot shift test to assess for rotatory instability. Medial and lateral collateral ligaments should be tested at 0 and 30° of flexion with valgus or varus stress, respectively. The posterior cruciate ligament (PCL) is tested with the posterior drawer test by noting posterior sag of the tibia relative to the femoral condyles. The Dial test can also be used to test for isolated posterolateral corner injuries or those with an associated PCL injury. A KT-1000 arthrometer (Medmetric) can be used to obtain more precise measurements of anterior tibial translation, and a >3-mm difference between the injured and unaffected leg signifies an ACL tear.[15]

Imaging

All patients presenting with recurrent knee instability should initially undergo radiographs of the affected knee. Anterior-posterior and lateral images can be evaluated for tibial and femoral tunnel placement. Harner et al[16] described that the tibial tunnel should cross the articular surface at the midpoint of the tibial plateau on the anterior-posterior radiograph and at the anterior third on lateral radiograph. The femoral tunnel should be located in the posterior quadrant of Blumensaat's line.[2] ACL tunnels will be in an accurate location without need for redirection, in an inaccurate location requiring redirection through native bone, or in an inaccurate location requiring redirection through a preexisting tunnel. The latter group may require bone grafting of existing tunnels before revision tunnel placement. Critical analysis of tunnel placement is imperative for a successful revision procedure. Patient should also receive weight-bearing knee radiographs and standing alignment radiographs. These images are evaluated for degenerative changes or limb malalignment, including varus, valgus, and excessive posterior tibial slope. Tibial slope can be measured on radiographic images. LaPrade et al described a commonly used technique for measuring tibial slope on a lateral knee radiograph.[17]

Advanced imaging should be obtained in all patients with a history of ACL reconstruction and recurrent laxity. MRI can be primarily used to evaluate the status of the graft and for any associated injuries, including chondral damage, meniscal tearing, or other ligamentous pathology. MRI can be used to estimate tunnel widths; however, in cases where notable tunnel widening is suspected, CT imaging has been shown to be the most reliable imaging modality.[18] CT imaging provides a detailed evaluation of bony pathology and tunnel size[18] (Figure 1). Tibial and femoral tunnel size should be measured on the preoperative CT scan to plan for bone grafting during the revision procedure. Tunnel diameter should be measured at the widest visualized diameter on the axial, coronal, and sagittal planes. Measurements >15 mm are consistent with notable tunnel osteolysis and literature supports proceeding with a bone grafting procedure before revision ACL reconstruction.[2]

Preoperative Considerations

When planning a revision ACL reconstruction, the surgeon should determine whether concomitant or staged procedures are necessary. As noted above, patients with limb malalignment may need correction to prevent recurrent graft laxity or injury. Procedures to correct limb malalignment are typically done at the same time as the revision ACL reconstruction but can also be done in a staged fashion. Anterior closing wedge tibial osteotomy for excessive posterior tibial slope has been validated to decrease anterior tibial translation and force exerted on the ACL (Figure 2). In patients with varus malalignment, high tibial osteotomy is advocated with good results for RTS.[19] Patients with valgus malalignment can undergo either a varus-producing lateral opening wedge distal femoral osteotomy or medial closing wedge distal femoral osteotomy. Recent literature shows a successful return to athletics after concomitant varus-producing distal femoral osteotomy and ACL revision reconstruction.[20]

When deciding between a single-stage or two-stage ACL revision reconstruction, the surgeon should critically evaluate the amount of bone tunnel osteolysis and need for bone grafting. Patients who have appropriately placed tunnels without excessive tunnel osteolysis (<15 mm) or previous tunnels outside the trajectory for revision tunnels can be considered for a single-stage revision. In addition, concomitant osteotomies or correction of associated chondral or meniscal pathology can be done as a single-stage procedure with thoughtful placement of hardware. Two-stage procedures are done if tunnel osteolysis >15 mm is present or if previous tunnel position will affect placement of new tunnels. Patients should also undergo a two-stage revision in the setting of decreased knee range of motion, specifically >20° loss of terminal flexion or >5° loss of extension,[21] or in the setting of active or chronic infection. Correcting range of motion, with physical therapy or

Figure 1

CT scans of failed anterior cruciate ligament reconstruction showing bone tunnels with osteolysis.

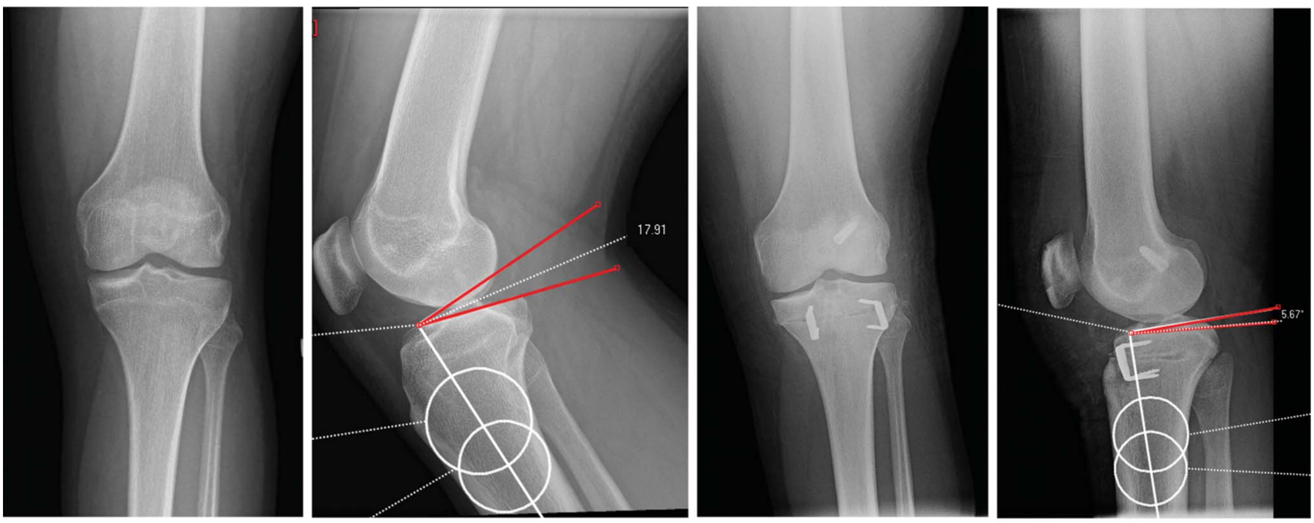
surgical intervention, to physiologic ranges is recommended before a revision procedure. Patients with a history of infection should be counseled about the risks associated with a revision procedure. Complete resolution of the infection should be confirmed before proceeding with the revision reconstruction.

Surgical Technique

Positioning and Room Setup

Before surgery, a thorough evaluation of the previous surgical reports is imperative to understand which implants were used and how they were applied and to

Figure 2



A B C D

Radiographs showing patient with posterior tibial slope and ACL tear. Preoperative (**A** and **B**) and postoperative after closing wedge high tibial osteotomy and ACL reconstruction (**C** and **D**). ACL = anterior cruciate ligament ensure that the implant extraction devices are readily available. Either supine or hemilithotomy positioning can be used, although supine positioning has the advantage of access to the iliac crest for autograft, if desired. A radiolucent table and intraoperative fluoroscopy can be useful for hardware removal and confirmation of tunnel positioning. As is always done, a complete ligamentous and range of motion examination of both knees is conducted before draping.

Arthroscopic Evaluation

Before autograft harvest, an arthroscopic evaluation of the knee should be conducted to confirm that a single-stage revision procedure can be done effectively based on tunnel width and positioning. If the previously made portals are in suboptimal positions, new portals should be made while avoiding narrow skin bridges. Diagnostic arthroscopy is also done to evaluate for other intra-articular pathology, including chondral damage, meniscal tears, and loose bodies, which can be addressed concurrently. After débridement of the previous ACL stump, and exposure of tunnel apertures, a limited notchplasty can be done in patients with notch overgrowth, although the contribution of this step is debated.[22] Removal of hardware is only necessary if the hardware interferes with new tunnel placement. New tunnels require circumferential bony margins, so careful preoperative planning can elucidate the need for hardware removal.

Single-Stage Revision

If tunnel osteolysis is <15 mm, and the previous tunnels are either in the appropriate positions or out of range of the planned tunnels, then a single-stage revision can be done. Tunnel overlap is not a contraindication to single-stage revision but requires additional methods to ensure appropriate graft fixation. Some techniques for the management of tunnel overlap include filling the tunnel (with either bone graft or bone substitute)[23,24] and immediate redrilling, a divergent tunnel technique, and drilling through hardware, as demonstrated in Figure 3. Stacking interference screws should be avoided because of risk of graft compromise.[25] Whenever graft fixation is questionable, defaulting to a two-stage procedure is appropriate. When using the previous tunnels, the surgeon should ream until desired diameter for the new graft, or when circumferential bony margins are achieved.

Two-Stage Bone Grafting

The goal of a two-stage procedure is to fill all bony defects and provide a fresh landscape for new tunnels.

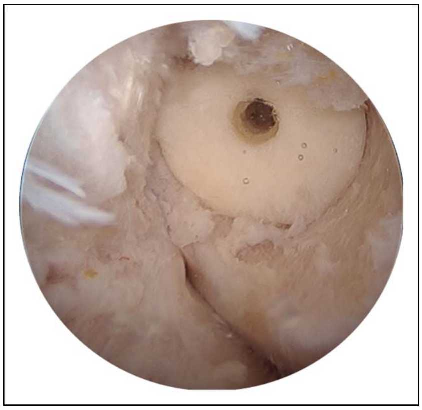
Figure 3

Clinical photograph showing drilling a new femoral tunnel adjacent to old hardware.

All hardware should be removed from the tunnel and immediately surrounding area. The tunnels are then reamed sequentially through the anteromedial portal to clear the fibrinous debris and residual ACL graft. Frequently, the ACL reamers are of insufficient diameter to clear the tunnels; in these circumstances, the intramedullary reamers from the intramedullary rod or total joint arthroplasty sets may be required. Large caliber reamers must be maneuvered around the medial femoral condyle with extreme care, always using a skid or other protective device along the cartilage to prevent abrasion. The use of flexible reamers through the medial portal can facilitate clearance of the femoral condyle.

Bone grafting of the tunnels can be accomplished in several ways, including allograft (chips or dowels), autograft, or bone substitutes. The authors prefer allograft dowels, which are cannulated cylinders that come commercially in a wide range of diameters and lengths, are easy to use, achieve reliable press-fit, and have been associated with dependable healing (Figure 4). These dowels have a bulleted end for ease of insertion. The dowel is rehydrated with sterile saline before being affected into the tunnel using a cannulated tamp. It is recommended to use a dowel of the same diameter as the largest reamer used on the tunnel because this obtains the best press-fit while decreasing risk of dowel fracture. Insertion of the dowel is to be done carefully because dowel fracture is possible and can lead to insufficient fixation and bony incorporation. After the initial procedure, the second stage can be performed after 3 to 6 months. Incorporation of the bone graft is confirmed with plain radiography or CT scan (Figure 5).

Figure 4



Photograph showing the bone plug placement in femoral tunnel.

Graft and Fixation Choices

The use of autograft versus allograft in revision reconstruction is debated. Although some large systematic reviews suggest that the use of autograft is associated with decreased risk of failure and improved overall clinical outcomes,[26] others found that this difference may be minimal or clinically insignificant.[27] In general, the authors prefer autogenous grafts. If ipsilateral autograft options have been exhausted or are suboptimal, then contralateral harvest may be considered. Grafts should be at least 8 mm diameter to decrease the risk of graft failure.[28]

Loss of graft fixation is a common cause of early failure in revision ACL reconstruction.[2] If appropriate bone stock is available, interference screw fixation should be considered. Suspensory fixation is another option. Regardless of primary fixation method, liberal use of backup extracortical graft fixation should be exercised if there are any concerns for fixation integrity.[25] Options for supplementary fixation include a suture anchor, staples, and a screw and washer.

Extraarticular Supplementation

The anterolateral complex (ALC) of the knee is an important contributor to rotational stability[29] and can be injured or found deficient in patients with ACL tears. Several biomechanical studies have demonstrated that ACL reconstruction alone does not restore normal knee kinematics in the setting of ACL and ALC injury and that the addition of ALC augmentation in these circumstance reduces anterolateral rotatory laxity.[30,31] Therefore, reconstruction of the AL complex, either through lateral extraarticular tenodesis (LET) or anterolateral ligament reconstruction, in the setting of ALC injury has been suggested in both primary and revision ACL reconstruction settings. However, the exact indications for and clinical significance of ALC augmentation are being studied and debated.[32] Recently, Getgood et al[33] prospectively examined the outcomes of adding LET to primary ACL reconstruction and found that LET can decrease the risk of ACL reconstruction failure in young (<25 years old), active, ligamentously lax patients in the primary ACL reconstruction setting when hamstring autograft is used.

In revision procedures, this augmentation may be considered in any of the following scenarios: young patients, multiple revision situations, patients with high-grade pivot shifts (clunk or locking) preoperatively, patient intentions to return to high-risk cutting sports, increased posterior tibial slope not meeting criteria for

Figure 5

CT scan showing partial integration of femoral and complete integration of tibial bone dowels into respective bone tunnels.

slope correction osteotomy, and persistent rotational instability after ACL reconstruction. The authors' preferred technique is the anterolateral iliotibial band tenodesis (modified Lemaire) technique[34] (Figure 6). Alternatively, the anterolateral ligament complex can be reconstructed using an allograft tendon.[35]

One major concern regarding ALC augmentation is the possibility of overconstraining the knee, reducing the physiologic rotatory motion and, therefore, altering normal knee biomechanics. Although overconstraint has been demonstrated in biomechanical studies,[30,36] it has yet to be proven whether this constraint results in clinically significant changes in tibiofemoral contact pressures or results in worse long-term outcomes. Despite early data suggesting that adding ALC augmentation to ACL reconstruction results in increased risk of knee osteoarthritis,[37] this has not been found in more recent, highly powered studies with long-term follow-up.[38,39]

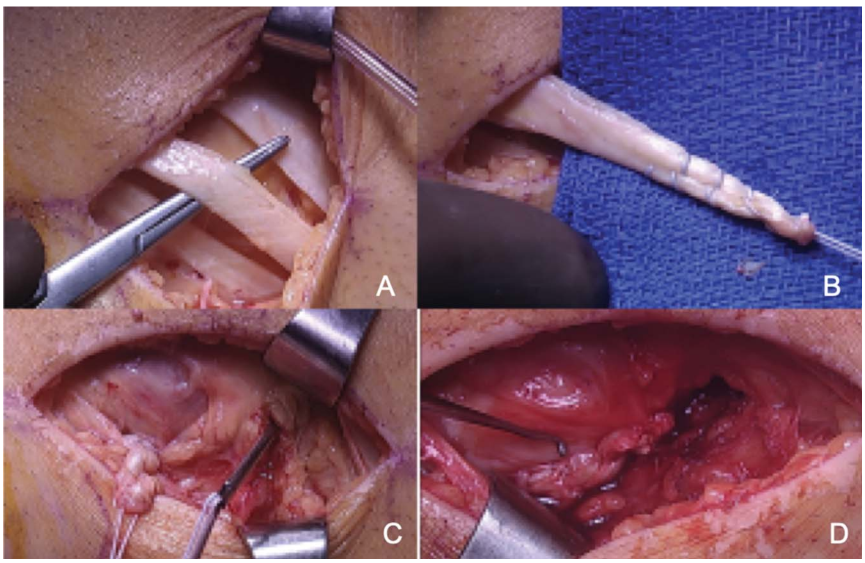
Postoperative Rehabilitation

Recommendations for postoperative rehabilitation can vary greatly depending on surgeon preference, but patients undergoing isolated revision ACL reconstruction can typically bear weight as tolerated immediately, with or without hinged brace with range of motion encouraged. If a concomitant osteotomy, meniscal repair, or cartilage restoration procedure is done, weight bearing should be limited at surgeon discretion to allow healing. Early rehabilitation includes heel slides, quadriceps sets, and motion exercises, as with a standard ACL rehabilitation protocol. Advancement to closed chain strengthening exercises generally occurs around 6 weeks postoperatively. Full RTS is expected around 9 to 12 months depending on patient strength and exercise tolerance.

Outcomes

Managing expectations of patients undergoing revision ACL surgery is important. Outcomes vary in the literature, largely due to there being a wide variety of concomitant pathology associated with ACL revision and due to the heterogeneity of the patient population regarding their symptoms and activity demands. Several large studies have demonstrated inferior clinical outcomes after revision ACL reconstruction compared with primary ACL reconstruction. Grassi et al[40] published a meta-analysis of eight studies comparing revision and primary ACL reconstructions. In this study, revision surgery was associated with inferior Lycholm Knee Scoring Scale scores (mean difference: 7.8 points) and a fourtime increased risk of residual pivot shift postoperatively, without any difference in AP laxity. Patients who underwent revision reconstruction were half as likely to describe their knee as "normal" with objective IKDC scoring. More recently, a systematic review by Mohan et al[27] found an objective failure rate (defined as graft rupture, repeat revision, pivot shift grade $\geq$2+, or side-to-side difference of >5 mm with KT-1000/2000) of only 6% for revision

Figure 6



Clinical photograph depicting the modified Lemaire technique for anterolateral complex reconstruction. **A**, Iliotibial band graft harvest, with surgical instrument highlighting the graft. **B**, Iliotibial tract graft preparation after distal release from the Gerdy tubercle. **C**, Passage of the graft under the lateral collateral ligament. **D**, Final graft fixation to the lateral femoral condyle.

ACL reconstruction after analyzing eight studies and 3,021 patients with an average follow-up of 57 months.

In a prospective study with the 2-year follow-up after revision ACL reconstruction, positive predictors of patient-reported outcomes (PROs) include higher baseline PRO scores, longer time from most recent ACL reconstruction, and male sex. Negative predictors of PROs at 2 years include grade 3 to 4 chondrosis noted at the time of revision surgery and previous lateral meniscectomy.[41] Assessing return to activities and sports is challenging because the definition of “return to sport” is inconsistent in the literature. However, most authors agree that returning to baseline activity and sport participation level after revision ACL reconstruction is lower than that after primary reconstruction.[42] After revision ACL reconstruction, current literature supports a rate of return to any level of sport to be 87%, with full RTS at the preinjury level to be 49%.[42] In a study by the MARS group on RTS and PROs, higher levels of RTS were associated with improved PROs.[43]

Future Considerations

Future directions of revision ACL surgery include expediting—or negating entirely—the waiting period between first and second stage surgeries with improved management of tunnel osteolysis and bone voids using fast-setting bone substitutes.[24,44,45] The role of lateral extraarticular tenodesis as a combined procedure with revision ACL reconstruction is gaining additional clinical evidence and support.[33,46] In addition, the contribution of excessive posterior slope in recurrent ACL injury is also garnering interest in the literature.[47] Current and future studies aimed at validating the role of proximal tibia anterior closing wedge osteotomy to correct tibial slope will greatly assist surgeons who treat primary and recurrent ACL injuries. Finally, as our understanding of patient-reported outcome measures from revision ACL surgery continues to be enhanced by large, multicenter cohort studies,[41] surgeons will be better poised to provide improved preoperative counseling for surgical candidacy and for postoperative expectations.

Summary

Failure of a previous ACL reconstruction is a challenging problem, both clinically and technically. With increased youth participation in sports, ACL rupture and rerupture will be seen more frequently in orthopaedic clinics. Revision ACL reconstruction is done to restore stability to the knee to allow return to functional and sporting activities and to decrease the risk of injury to cartilage and the menisci. ACL revision can typically be done in one procedure but may need to be staged if there is excessive tunnel osteolysis or poor previous tunnel positioning. Preoperative planning is imperative, as is having a wide armamentarium of techniques for malalignment correction, tunnel widening, and graft fixation. Setting appropriate patient expectations for the postoperative course is also important because functional and subjective outcomes after revision ACL surgery tend to be less favorable than with primary reconstruction.

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