

[Orthopaedic Surgery]

Revision Anterior Cruciate Ligament Reconstruction

Jeffrey Wilde, MD,[†] Asheesh Bedi, MD,^{*†} and David W. Altchek, MD[‡]

Context: Reconstruction of the anterior cruciate ligament (ACL) is one of the most common surgical procedures, with more than 200,000 ACL tears occurring annually. Although primary ACL reconstruction is a successful operation, success rates still range from 75% to 97%. Consequently, several thousand revision ACL reconstructions are performed annually and are unfortunately associated with inferior clinical outcomes when compared with primary reconstructions.

Evidence Acquisition: Data were obtained from peer-reviewed literature through a search of the PubMed database (1988-2013) as well as from textbook chapters and surgical technique papers.

Study Design: Clinical review.

Level of Evidence: Level 4.

Results: The clinical outcomes after revision ACL reconstruction are largely based on level IV case series. Much of the existing literature is heterogenous with regard to patient populations, primary and revision surgical techniques, concomitant ligamentous injuries, and additional procedures performed at the time of the revision, which limits generalizability. Nevertheless, there is a general consensus that the outcomes for revision ACL reconstruction are inferior to primary reconstruction.

Conclusion: Excellent results can be achieved with regard to graft stability, return to play, and functional knee instability but are generally inferior to primary ACL reconstruction. A staged approach with autograft reconstruction is recommended in any circumstance in which a single-stage approach results in suboptimal graft selection, tunnel position, graft fixation, or biological milieu for tendon-bone healing.

Strength-of-Recommendation Taxonomy (SORT): Good results may still be achieved with regard to graft stability, return to play, and functional knee instability, but results are generally inferior to primary ACL reconstruction: Level B.

Keywords: knee; anterior cruciate ligament; reconstruction; revision surgery; arthroscopy; grafts

Reconstruction of the anterior cruciate ligament (ACL) is one of the most common surgical procedures, with more than 200,000 ACL tears occurring annually.^{32,37,55} Indications for primary ACL reconstruction include symptomatic anterior instability in athletes who wish to return to sports requiring frequent cutting or pivoting. Although primary ACL reconstructions have been considered a successful operation, the range of success is still only 75% to 97%.^{7,9,17,18,60} Failures include graft rupture and structural failure as well as functional failure with residual instability and pivoting in the setting of an intact graft. Consequently, several thousand revision ACL reconstructions are performed annually and are unfortunately associated with inferior clinical outcomes. In this regard, patients should be appropriately counseled on expectations, goals, and a more gradual, prolonged rehabilitation following revision surgery.

A rigorous and meticulous approach should be utilized for patients after failed ACL reconstruction surgery. Even under the best of circumstances, revision ACL surgery is associated with significantly inferior clinical outcomes relative to primary ACL reconstruction.^{11,12,31,33,42,52-54,63} There should be no compromise of preoperative evaluation, technical approach, and postoperative rehabilitation to avoid a catastrophic recurrent failure. Acceptance of suboptimal tunnel position or approaches that allow for a single-stage reconstruction at the expense of the graft position, fixation, and biological incorporation are not favored. The potential advantage of an expedited return to play is far outweighed by the increased risks of nonanatomic graft configuration, fixation failure, or incomplete healing in this setting. A staged approach with autograft reconstruction is recommended when a single-stage approach may result in

From [†]Department of Orthopaedic Surgery, University of Michigan, Ann Arbor, Michigan, and [‡]Hospital for Special Surgery, New York, New York

*Address correspondence to Asheesh Bedi, MD, Assistant Professor, MedSport, University of Michigan, 24 Frank Lloyd Wright Drive, Lobby A, Ann Arbor, MI 48106 (e-mail: abedi@umich.edu).

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Table 1. Causes of failure of primary anterior cruciate ligament reconstruction

Technical error
Unrecognized additional ligamentous injuries (posterolateral corner, medial collateral ligament)
Lower extremity malalignment
Biological failure of graft incorporation
Recurrent or acute trauma

suboptimal graft selection, tunnel position, graft fixation, or biological milieu for tendon-bone healing.

INDICATIONS

Generally, patient dissatisfaction following primary ACL reconstruction is divided into 3 categories: recurrent instability (structural or functional graft failure), postoperative complications (infection, loss of motion, development of arthritis), and preexisting occult comorbidities (lower extremity malalignment, meniscal tears).

Graft failure occurs when the reconstructed ligament does not restore stability to the knee with pivoting activities. This is demonstrated as symptomatic recurrent laxity, defined by episodes in which the knee “gives out” with or without associated pain. The causes of graft failure in primary ACL reconstructions are multifactorial (Table 1). Early failures are typically associated with (1) technical error, (2) unrecognized associated ligamentous injuries (posterolateral corner, medial collateral ligament), (3) malalignment of the lower extremity, or (4) biological failure of graft incorporation. Early failure is typically associated with compromised strength at one of the fixation points because graft incorporation is incomplete, while late failure often occurs with noncontact trauma, which is the most common source of rerupture.²⁰ A significant portion of “late failures” represents suboptimal reconstructions that are identified after they are subjected to the *in vivo* forces associated with return to sport.

Errors in surgical technique account for the majority of primary ACL reconstruction failures.⁶⁹ The most common technical error is improper tunnel placement outside the native femoral and tibial ACL footprints. An anterior femoral tunnel placement results in excessive graft tension during flexion, causing loss of knee flexion or stretching of the graft.⁴³ A posteriorly placed femoral tunnel results in excessive graft tension while the knee is in full extension with laxity in flexion.¹⁹ If the femoral tunnel results in a vertical graft configuration, the reconstruction may provide stability in the sagittal plane but less-than-adequate rotational stability.⁴

Improper tibial tunnel placement may also have detrimental effects on the graft’s longevity and function.³¹ The tibial tunnel should capture a portion of the anteromedial (AM) bundle footprint to optimize graft obliquity. However, an anteriorly placed tibial tunnel that extends outside the footprint may impinge at the notch in extension and cause a loss of terminal extension. Similarly, a tibial tunnel too posterior may impinge on the posterior cruciate ligament with associated loss of flexion.² Medial or lateral misplacement of the tibial tunnel can also result in notch impingement and iatrogenic injury to the chondral surfaces of the medial or lateral tibial plateau cartilage.⁴⁹

For years, the transtibial technique was the gold standard for ACL reconstruction. However, transtibial endoscopic ACL reconstruction techniques often result in vertical graft orientation because of inherent technical limitations in reaming an anatomic femoral tunnel.^{16,21} A nonanatomically positioned femoral tunnel is one of the most common causes of clinical failure after ACL reconstruction; 15% to 31% of athletes complain of pain, persistent instability, or an inability to return to the previous level of competition.^{5,6,10,28} Despite technical modifications, significant concerns persist regarding the ability to restore ACL anatomy using a transtibial technique.³⁸ This technique predisposes to a “mismatch” graft position from the posterolateral tibial footprint to the AM femoral footprint (Figure 1).³⁸ Conventional referencing of the ridge between the medial and lateral intercondylar tubercles at the base of the tibial eminence or 7 mm anterior to the posterior cruciate ligament places the tibial tunnel aperture at the posterior margin of the tibial footprint.⁵⁶ A transtibial technique can capture the native tibial and femoral footprints only if a tibial starting point is prohibitively close to the joint line.³⁶ Eccentric posterolateral positioning of the guide wire in the tibial tunnel can result in iatrogenic rereaming of the tibial tunnel and significant inadvertent tibial aperture expansion with femoral tunnel preparation (Figure 1).³⁶ For this reason, independent drilling of the tibial and femoral tunnels is recommended to minimize the risk for nonanatomic socket position outside the native ligament footprints.

In addition to poor tunnel placement, excessive or inadequate tensioning of the graft may contribute to graft failure. While the optimal graft tension and knee position for tensioning remain controversial, overtensioning in nonanatomic positions or in flexion that does not allow extension may constrain motion and increase contact pressures on the chondral surfaces. Inadequate tensioning may manifest as residual laxity and subjective instability following the primary reconstruction.

Other causes of technical failure include fixation failure before graft incorporation resulting in graft laxity and recurrent instability. Fixation device failure, host bone osteopenia, increased interference screw-tunnel divergence angle, and inadequate socket length and tendon-bone interface for healing are all factors that may affect the strength of the graft-bone fixation construct and are sources of graft compromise.

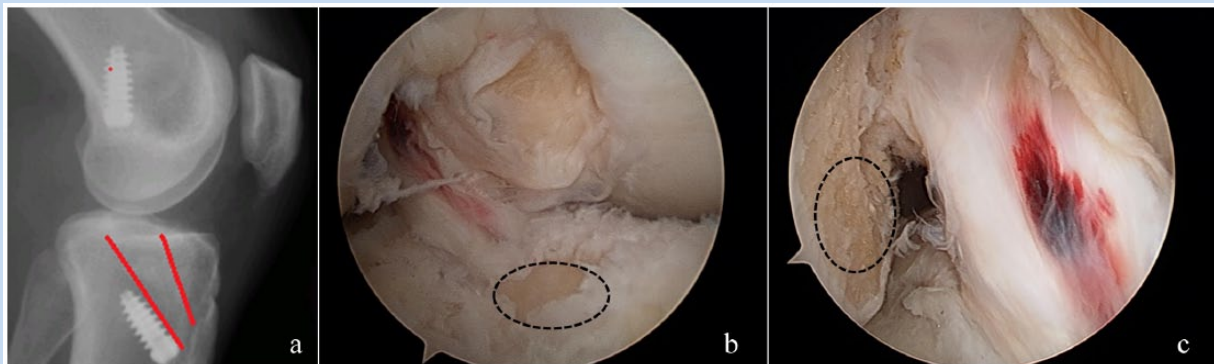


Figure 1. (a) The transtibial technique can result in iatrogenic rereaming of the tibial tunnel during femoral tunnel preparation; this results in time-zero tunnel expansion and further exacerbation of a posterolateral tibial tunnel position. The arthroscopic transtibial technique predisposes to a “mismatch” graft position from the posterolateral tibial footprint to the anteromedial femoral footprint. (b) Note that the anteromedial tibial footprint (dotted circle) has not been captured with this transtibial reconstruction. (c) The nonanatomic femoral graft position has not captured any of the native anatomic femoral footprint position on the lateral femoral condyle, which would allow for independent drilling of a new femoral tunnel with a revision procedure.

Secondary instability as a result of occult ligamentous injury at the time of the primary ACL reconstruction is another cause of graft failure and need for revision ACL reconstruction.³⁰ Concurrent injuries to the lateral ligamentous complex and the posterolateral corner are the most common, with occurrences in 10% to 15% of chronically ACL-deficient knees.¹³ These deficiencies are associated with hyperextension and varus stresses across the knee, resulting in supraphysiologic forces in the ACL graft.³⁰ Similarly, medial collateral ligament deficiencies may also result in an excessive strain on the graft with valgus forces on the knee. The posterior horn of the medial meniscus acts as a secondary stabilizer against anterior translation of the tibia.³⁵ Untreated tears in the posterior horn of the medial meniscus can create excessive pressure on the graft due to loss of the secondary stabilizer and can predispose to premature graft failure.³⁵

Lower extremity malalignment, particularly varus deformity, can elevate stress on the ACL graft.⁵⁰ Consequently, it is important to obtain preoperative hip-to-ankle weightbearing radiographs (Figure 2). If a significant varus deformity with medial compartment narrowing is present, a concurrent or staged proximal tibial osteotomy may be warranted to prevent increased strain and premature failure of the graft.⁵⁰ The varus deformity may be more severe with medial compartment arthrosis and posterolateral corner insufficiency—factors that must be addressed with a revision ACL reconstruction.

Late laxity is usually associated with acute traumatic rupture of the ACL graft, which can manifest as a premature return to competitive sports with inadequate return of strength, balance, and proprioception.⁵⁹

HISTORY AND PHYSICAL EXAMINATION

A thorough history, as well as a complete previous surgical history, is critical to determine the cause of injury, any other associated ligamentous/meniscal injuries, and type of graft used. It is important to assess the postoperative course from primary surgery, including rehabilitation techniques, length of rehabilitation, and time to return to competitive play. Failure to return to a level of performance as in the preinjury state may indicate a technical failure in the primary surgery or inadequate postoperative rehabilitation. These data are essential to diagnose the likely mechanism of injury and determine if revision surgery will benefit the patient.

A thorough examination of the knee should begin with an evaluation of gait and stance, varus/hyperextension thrust, or varus deformities that may place increased strain on the graft. The initial observation should include quadriceps circumference for any evidence of residual muscle atrophy. Additionally, palpation for neuroma formation around prior surgical incisions is required, as these can be a frequent source of pain. Passive and active motion of the knee should be assessed to evaluate any limitations in flexion/extension and to assess for an extensor lag. Motion loss may necessitate aggressive preoperative physical therapy or a staged procedure with lysis of adhesions before the revision ACL reconstruction. A knee stability examination should be performed on the involved and contralateral lower extremity and must include Lachman, anterior and posterior drawer, pivot-shift, and varus and valgus stress tests, as well as dial examination at 30° and 90° of flexion. Tibial motion with dial examination

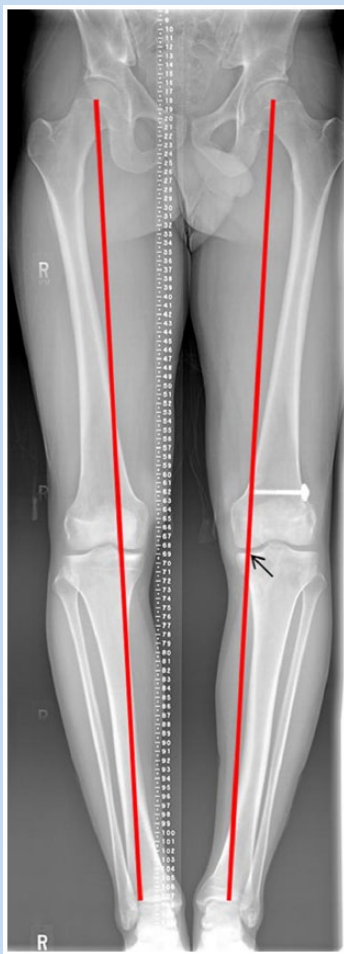


Figure 2. Long leg weightbearing radiographs should be obtained if concern for varus/valgus malalignment is present on examination. Significant varus alignment of the left lower extremity (arrow) in this case should be addressed with proximal tibial osteotomy before a revision ACL reconstruction. ACL, anterior cruciate ligament.

must be carefully assessed to distinguish posterolateral and posteromedial insufficiency. Asymmetry in examination relative to the contralateral limb is invaluable to identify subtle differences in stability, motion, and strength.

PREOPERATIVE IMAGING STUDIES

All patients should have standard knee radiographs, with views including full weightbearing anteroposterior, 45° of flexion weightbearing, lateral, full extension lateral, notch, and tangential (merchant). Although small errors in the previous tunnel position may be difficult to visualize, gross tunnel malposition can easily be identified (Figure 1). The lateral view in full extension can be utilized to evaluate the sagittal alignment of the tibial tunnel. The appropriate position of the tunnel is parallel and slightly posterior to the Blumensaat line.⁴³

Graft obliquity of the tibial and femoral tunnels is an essential component to restoring the rotational stability of the knee after an ACL reconstruction.

Visualizing tunnel position is vital to the preoperative planning of a revision ACL reconstruction. Tunnel position should be labeled *ideal and usable*, *slightly misplaced but usable*, *slightly misplaced and unusable*, or *completely misplaced*. If tunnel position and integrity cannot be adequately assessed on plain radiographs, a 3-dimensional imaging study should be obtained. Computed tomography (CT) is favored and reliably allows for characterization of tunnel position, expansion, and the integrity of the bone stock (Figure 3). If there is a substantial bone loss or tunnel widening, then a staged procedure with bone grafting before ACL reconstruction may be warranted (Figure 3). Magnetic resonance imaging (MRI) may be a useful adjunct to assess the tunnel position (Figure 4). Unfortunately, the utility of the MRI is often compromised because of artifacts from existing metal hardware in the knee.

SURGICAL ANATOMY

As with all surgical techniques, definition of the native ligamentous anatomy is critical to the preoperative planning and success of the procedure. The nomenclature of the bundles was developed in reference to the insertion location on the tibia and the functional tensioning pattern seen at the 2 bundles during knee flexion/extension. The classic concept of AM bundle tensioning describes the AM bundle as moderately loose when the knee is in extension, whereas the posterolateral bundle is under tension.¹³ As the knee is ranged from full extension to full flexion, the AM bundle transitions from a relatively loose tensioning pattern to significant tension as the fibers become more horizontally oriented.¹³ This is not the case when loading is applied to anterior translation as well as anterior translation in combination with internal rotation. Under these conditions, the AM and posterolateral bundles are both under tension, with the AM bundle maintaining that level of tension throughout knee flexion. The insertion sites on the femur and tibia are more than 3 times larger in comparison to the midsubstance ligament, making tunnel placement more challenging because of the limited size of the graft options.¹³

PORTALS/EXPOSURES

Old incisions should be used only if they were properly placed. It is critical to recognize that the tibial footprint extends as far anterior as the intermeniscal ligament and that the target of any commercial ACL tibial guide should be positioned centrally within the footprint in the anteroposterior and mediolateral dimensions. Another viable option for direct visualization of the medial aspect of the lateral femoral condyle is a central patellar tendon-splitting portal. This can provide a great panoramic view during drilling of the femoral tunnel through the AM portal. If a patellar autograft is used, the arthroscope can be inserted into the tendon defect for the creation of this portal.

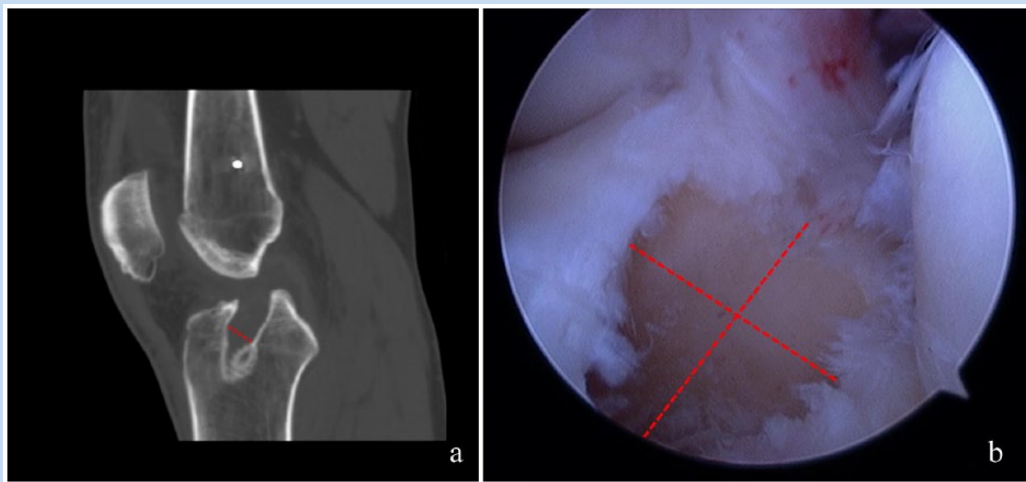


Figure 3. (a) CT reliably allows for characterization of tunnel position, expansion, and the integrity of the bone stock before surgery. This sagittal image demonstrates posterior tibial tunnel position and significant expansion (dotted red line). (b) This arthroscopic image depicts a substantial amount of bone loss and tibial tunnel widening, which may favor a staged procedure with bone grafting before ACL reconstruction. ACL, anterior cruciate ligament.



Figure 4. MRI may be a useful adjunct to assess the tunnel position as well as the status of the chondral surfaces, meniscal tears (arrow), and other ligamentous structures of the knee before surgery. MRI, magnetic resonance imaging.

Medial portal placement is also critical, particularly when a medial portal-independent drilling technique is utilized. Under direct visualization, the spinal needle is inserted directly above the anterior horn of the medial meniscus (Figure 5).

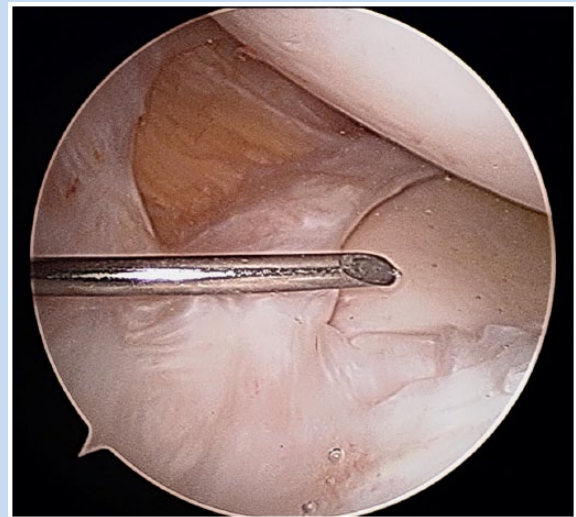


Figure 5. Medial portal placement can be performed under direct visualization, with the spinal needle being inserted directly above the anterior horn of the medial meniscus. Care should be taken to ensure a trajectory that can approximate the center of the ACL femoral footprint while affording safe clearance of the medial femoral condyle with reamer passage. ACL, anterior cruciate ligament.

IMPORTANCE OF MENISCUS REPAIR

Our understanding of the role of the meniscus has advanced substantially over the past 30 years. Initially thought to be

a structure that should be removed at the slightest sign of injury,⁴⁸ it is now highly regarded for its critical role in shock absorption,⁶⁶ load transmission,^{44,67} and knee stability.^{3,45,46} Because of these important roles in knee function, much research has shown the clear association between meniscal injury/loss (eg, partial/complete meniscectomy) and the development of degenerative changes and osteoarthritis of the knee. Consequently, attempts should be made to salvage the remaining meniscus by repairing red/red and red/white tears. This information has recently been summarized in a systematic review by Salata et al.⁵⁷ As this understanding has increased, surgeons and scientists have been continually trying to develop better ways to repair torn menisci to achieve healing and preservation of its function. The evolution of meniscal repair techniques has followed advancements in arthroscopy that have allowed direct visualization and repair of the injured meniscus while minimizing operative morbidity.

GRAFT CHOICE

There is no perfect graft choice for primary or revision ACL reconstruction. Both allograft and autograft options are reasonable, but each is associated with unique risks and benefits. Allografts eliminate concerns of donor site morbidity and may be particularly useful in the setting of multiligament knee reconstructive surgery. Furthermore, grafts such as the Achilles tendon offer a large cross-sectional area and may be useful to fill large but well-positioned tunnels in a single-stage revision ACL reconstruction. However, there is a small risk of disease transmission with allografts that is not present with autografts. Allografts tend to incorporate more slowly than autografts, which can prolong the rehabilitation process.^{39,40} Also, the sterilization process and irradiation may contribute to the weakening of the mechanical properties of the allograft.^{26,41,47,64,65}

Allografts are frequently used in revision ACL reconstruction, especially if autograft options are limited or compromised by the initial procedure. The Multicenter ACL Revision Study demonstrated that 54% of surgeons used an allograft at the time of revision reconstruction, compared with only 27% who utilized an allograft at the time of the initial reconstruction.⁷² Within this study's cohort, 50% of the allografts were bone-patellar tendon-bone, followed by tibialis anterior (23%), Achilles tendon (12%), and tibialis posterior (11%).⁷² Other available options include the quadriceps tendon, hamstring tendons, peroneus longus tendon, and fascia lata. The increased utilization can likely be attributed to a number of factors, including more effective sterilization techniques, better organization and distribution of the tissues, and increased confidence in the strength and stability of the grafts.^{8,15,62} Of note, the recent literature has suggested that allografts may have a greater rate of failure in young athletic and active patients, with failure rates as high as 15 times more likely in the allograft group compared with the autograft cohort.²⁴

Many surgeons favor autograft because of these additional risks. Patellar tendon or hamstring autograft options may not

be viable in revision surgery. In these settings, quadriceps autograft may be favorable due to its large cross-sectional area. The patient should have a full understanding of the risks and benefits inherent with both graft types before surgery. In cases of substantial tunnel expansion and partial tunnel malposition, a staged approach may be required independent of graft selection.

BONE GRAFTING

Previous tunnels must be evaluated for enlargement with bone loss that may render them unusable for the revision procedure. If the tunnels have become significantly expanded, it becomes difficult to achieve rigid fixation because of the size of the bony defect.⁴³ Expanded but completely malpositioned tunnels may allow for independent tunnels to be drilled in a single stage (Figures 1 and 6). However, expanded but partially malpositioned tunnels present a greater technical challenge for a single-stage procedure, and grafting may be favorable to allow for staged preparation of an anatomically correct tunnel position after osseous consolidation and healing (See Figure 3). Tunnel grafting using press-fit plugs has produced excellent tunnel fill and osseous integration (Figure 7).¹³ Once the interference screw is removed from the primary ACL reconstruction, the bony defects should be measured. The bone plug should be 1 mm in diameter greater than the debrided tunnel to accommodate a press fit for the graft within the tunnel (Figure 7). Multiple harvest plugs may be necessary if there is a substantial bony defect.

Bone grafting with crushed, cancellous allograft chips can be difficult, particularly in the femoral tunnel, where gravity and fluid flow frequently cause the graft to fall back into the joint. A few techniques and tools can be used to help facilitate the bone graft transfer into the tunnels. First, a 10- to 11-mm chest tube, filled with bone graft, can be used to assist in the impaction of the graft material in the tunnel. The chest tube should be inserted through the AM portal and into the femoral tunnel; then, a metal trocar of a slightly smaller diameter than the tube can be used to express the graft and impact it into the tunnel (Figure 7). Autograft or allograft plugs can then be impacted into the tunnel, using the arthroscope to directly visualize graft fill flush with the intra-articular socket aperture. A confirmatory CT scan can be obtained at 3 to 6 months postoperatively to confirm excellent incorporation and safe staging of the ACL reconstruction, though the CT scan may be deferred in straightforward cases to avoid further exposure to radiation (Figure 7).

SINGLE-STAGE PROCEDURE

If the femoral and tibial tunnels from the previous procedure are acceptable or the previous tunnels are grossly malpositioned such that they can be avoided completely when drilling new tunnels, then the revision ACL reconstruction can be done in a single operation (Figure 8). Completely inaccurate tunnel placement is commonly seen

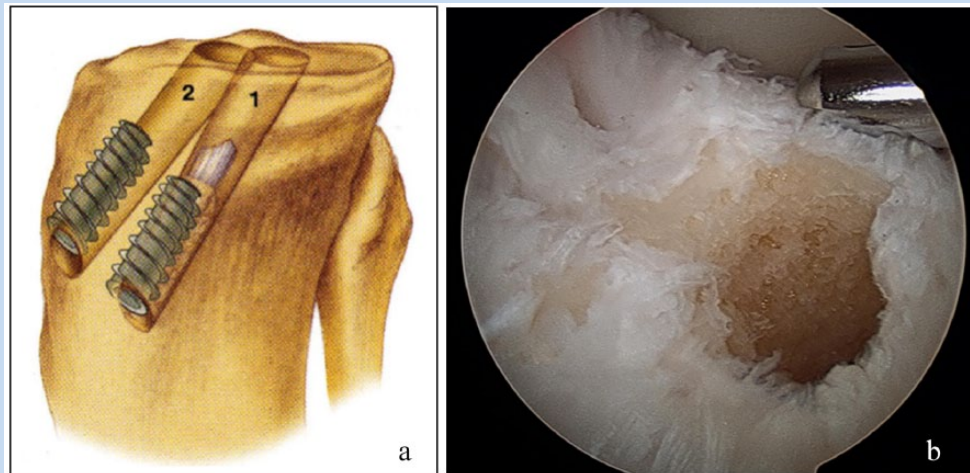


Figure 6. (a, b) A completely malpositioned tibial tunnel (1) may allow for preparation of a completely independent tunnel (2) to be drilled anatomically in a single stage.

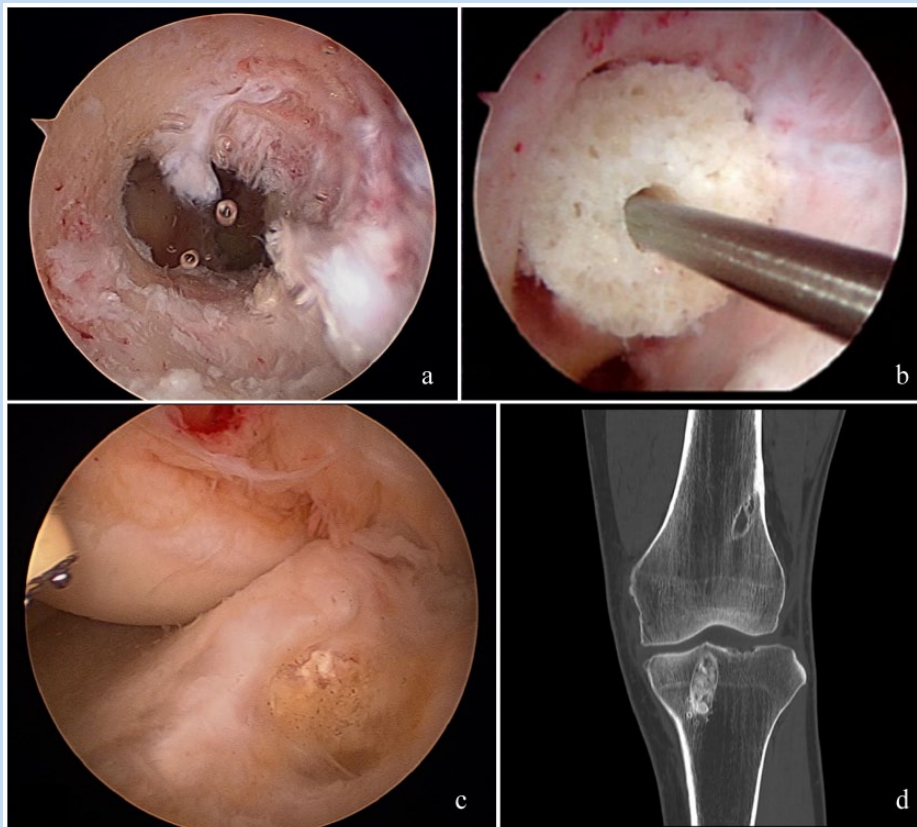


Figure 7. (a) Grafting of the tibial or femoral tunnel is typically straightforward, but care must be taken to remove all hardware and debride all soft tissue circumferentially along the tunnel to bleeding, cancellous bone. (b) The allograft plug should be 1 mm in diameter greater than the debrided tunnel to accommodate a press fit for the graft within the femoral tunnel. (c) Large tibial tunnel defect successfully healed and consolidated after staged grafting. (d) A confirmatory CT scan can be obtained at 3 to 6 months postoperatively to confirm excellent incorporation and consolidation of allograft in the tunnels before staged revision ACL reconstruction if there is concern, though the CT scan may be deferred in straightforward cases to avoid further exposure to radiation. ACL, anterior cruciate ligament; CT, computed tomography.

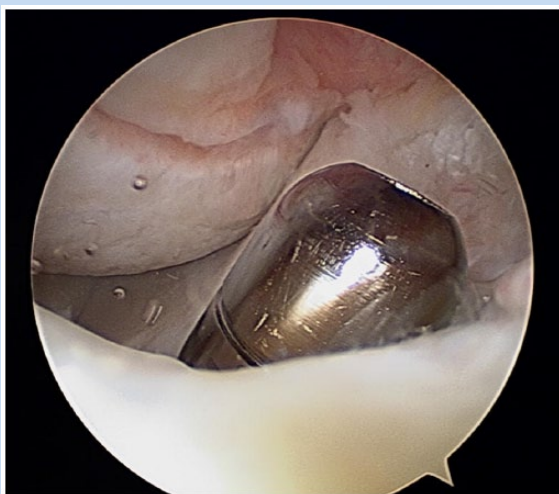


Figure 8. A well-positioned tibial tunnel can be utilized in a single-stage procedure. A well-positioned tibial tunnel is being cleared and dilated to accommodate a new graft for revision ACL reconstruction. ACL, anterior cruciate ligament.

in vertically malpositioned femoral tunnels prepared with a transtibial technique such that a new anatomic femoral socket can be drilled without risk of convergence with the old tunnel (Figure 9). If this is the case, the old graft can remain in situ, with the new graft offering additional sagittal and rotational stability to the knee. Partially overlapping tunnels are the most problematic and should be reassessed on a case-by-case basis to determine the need for a single versus staged approach. Posterior tibial tunnels with significant widening (see Figure 3) may be best treated with a staged approach rather than accepting significant malposition, whereas anterior but relatively anatomic tibial tunnels with expansion may be effectively managed by filling with a large graft in a single-stage setting.

Step 1: Diagnostic Arthroscopy and Socket Characterization

A thorough examination of the knee under anesthesia should be performed before arthroscopy. The general principles of ACL reconstruction apply to a revision procedure as well. A thorough debridement is critical for visualization and to the success of the revision ACL reconstruction. Both fixation points of the previous graft should be visualized and debrided to clearly define their location and the fixation hardware. A cyclops lesion or any residual graft should be thoroughly resected before proceeding with the procedure. The notch should be well visualized, and any hypertrophic scar should be resected. An aggressive prior notchplasty may offer insight into socket malposition and the mechanism of graft failure. A revision notchplasty may be required, however, to afford sufficient visualization for anatomic socket preparation and in rare cases of a narrow or “A-frame” notch configuration, which

may pose a significant risk for notch-graft impingement despite anatomic graft obliquity.¹³

Step 2: Hardware Removal

Generally, all loose hardware should be removed regardless of its positioning. Determination of whether secure hardware needs to be removed is related to the position of the tunnels from the previous ACL surgery. If the tunnels from the previous surgery are significantly malpositioned and completely new tunnels can be drilled, we prefer to leave the previous hardware in place. Unnecessary extraction of these fixation devices can lead to bone voids that can be difficult to fill and may compromise the revision ACL fixation options and pullout strength. If the tunnels are only partially malpositioned or are in the correct position, the fixation devices may need to be removed. Often, bioabsorbable screws can be overdrilled, but nonbioabsorbable screws often must be removed. In most cases, the tibial tunnel is the most problematic tunnel, as these screws more commonly interfere with the revision tunnel and graft fixation. The femoral tunnel is often very poorly aligned in the vertical/anterior orientation that allows for preparation of an entirely new tunnel in an anatomic location. In both cases, suspensory fixation devices (EndoButton, Smith & Nephew, Memphis, Tennessee) or the screw and post can often be left in place.

Step 3: Tunnel Preparation

Femoral Tunnel Preparation

The medial aspect of the lateral femoral condyle can be accessed through the AM portal or via a 2-incision technique. The center of the new femoral tunnel can be localized to the center of the footprint if native ligament footprint margins have been preserved. If these have been obliterated from the previous surgery, referencing of the intercondylar and bifurcate ridges can help to facilitate localization of the native femoral footprint (Figure 10).¹⁴ With a medial portal technique, the knee should be hyperflexed to 120° before drilling the guide wire to allow for sufficient clearance from the medial femoral condyle and satisfactory graft obliquity. “Half-moon” low-profile or flexible reamers have been useful to avoid injuring the medial femoral condyle and may be passed in modest knee flexion to improve visualization with femoral socket preparation (Figure 11).

Another option for drilling the femoral tunnel is outside-in drilling using the 2-incision technique. This technique requires the creation of an accessory lateral incision. This technique provides the advantage of drilling tunnels in a more oblique or horizontal orientation and may offer great versatility in avoiding the tunnels from the primary surgery.

Alternatively, the over-the-top technique is a viable “nonanatomic” salvage option when the posterior wall of the previous femoral tunnel is insufficient and has compromised the ability to prepare an independent anatomic femoral tunnel.¹³ This technique utilizes the same incision and approach as the outside-in technique. Instead of drilling a

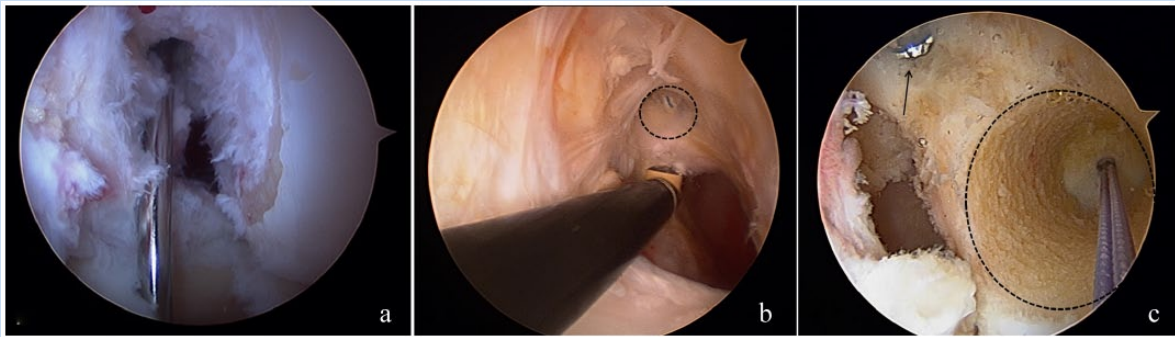


Figure 9. (a and b) A nonanatomic femoral tunnel outside the femoral footprint is frequently observed with an improper transtibial technique such that a new anatomic femoral socket can be independently drilled without risk of convergence with the old tunnel. (a) Note the native ACL femoral footprint on the condylar wall that has been entirely missed by the vertical femoral tunnel. (c) The relationship between the newly drilled anatomic femoral socket (circle) and the previously created vertically malpositioned femoral tunnel (interference screw fixation, arrow). ACL, anterior cruciate ligament.

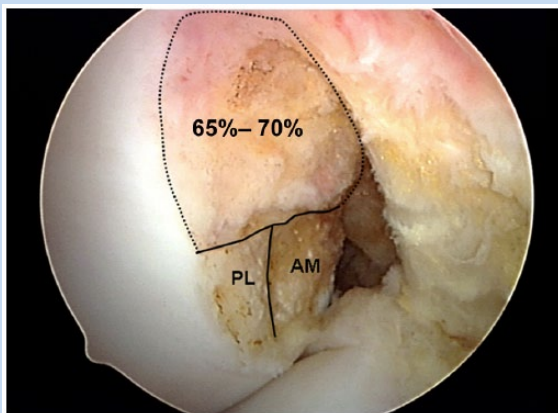


Figure 10. Referencing of the intercondylar and bifurcate ridges can help to facilitate localization of the native femoral footprint and delineate the anteromedial (AM) and posterolateral (PL) bundles. Image courtesy of Charles Brown, MD.



Figure 11. A flexible reamer system may be utilized to prepare an independent anatomic femoral tunnel with a divergent trajectory from the original femoral tunnel (arrow).

femoral tunnel, a small opening is created in the intermuscular septum, and a tract is bluntly dissected to the posterolateral aspect of the intercondylar notch. This area should be decorticated with a rasp to create a bleeding cancellous channel for the graft fixation. The graft should be passed into the groove through the septal hiatus with the assistance of a curved clamp or a tendon passer and fixed proximally with a soft tissue staple or screw-and-post suspensory fixation.

Tibial Tunnel Preparation

A relatively anatomic intra-articular aperture with modest tunnel widening may be utilized and filled with a graft with

a large cross-sectional area in a single-stage approach. A relatively posterior tibial tunnel, as frequently observed with a transtibial technique, may be more problematic (see Figure 3a). In the absence of significant tunnel expansion, this tunnel may be avoided by independent preparation of a new tunnel with divergent trajectory toward a more anterior anatomic position within the tibial ACL footprint. The ACL tibial footprint extends anteriorly to the intermeniscal ligament, which allows for a more anterior position of the new tibial tunnel. In the setting of significant tunnel expansion and slight posterior malposition, a staged approach may be required to avoid tunnel convergence or recurrent malposition (see Figure 3b).

Step 4: Graft Fixation

The fixation sites are the weakest component of the revision ACL reconstruction and are often the cause of early biomechanical failure.¹³ The graft fixation site should be assessed for quality of bone and relative size of the graft versus the tunnel diameter to achieve adequate fixation with interference devices. Appropriate fixation may be difficult to obtain if there is bone loss and poor bone stock at the fixation site. In the absence of significant tunnel expansion and good bone stock, interference screw fixation can be utilized in a manner analogous to primary ACL reconstruction. However, stacked screws or any fixation technique that may compromise graft fixation should not be used to facilitate a single-stage reconstruction at the expense of an increased risk of failure. As in primary ACL reconstructions, the screw divergence from the tunnel should not exceed 15° (Figure 12).¹³ If bone stock is compromised and the quality of interference fixation is modest, fixation should be augmented with a suspensory device such as a screw-post or ligament button. Combination fixation affords the biomechanical advantages of cortical fixation without the associated concerns of graft toggle in the tunnel (Figure 13).

POSTOPERATIVE COURSE

There is no standardized postoperative rehabilitation for revision ACL reconstruction surgery. There is significant variability that affects the course of the rehabilitation, including patient age, athletic demands and expectations, type of graft used, quality of bone stock, and cause of the original ACL reconstruction failure. Nevertheless, there are a few standard tenets to adhere

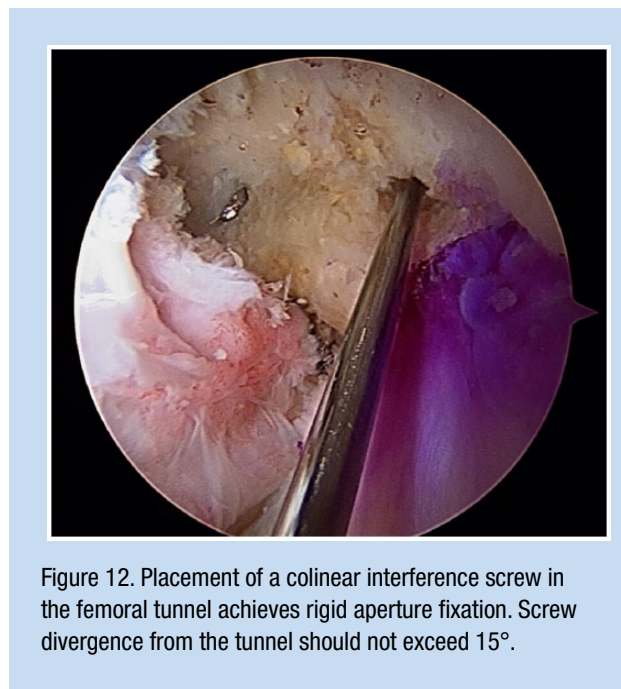


Figure 12. Placement of a colinear interference screw in the femoral tunnel achieves rigid aperture fixation. Screw divergence from the tunnel should not exceed 15°.

to despite these variables. The emphasis of the rehabilitation is early range of motion, preservation of quadriceps function, and progression of functional activities while not exceeding the limits of the involved tissue-healing properties. Weightbearing should be limited to toe touch, with slow advancement to weightbearing as tolerated with return of quadriceps strength and function.¹³ Knee braces can stabilize the knee until sufficient



Figure 13. (a) Postoperative anteroposterior and lateral radiographs of a single-stage revision ACL reconstruction using new, independent tibial and femoral tunnels. Note the anatomic femoral tunnel position and colinear aperture screw fixation. A new tibial tunnel could be prepared independently, as described in Figure 6, allowing for previous tibial fixation hardware to be avoided without complication. (b) Postoperative anteroposterior and lateral radiographs of a single-stage revision ACL reconstruction. A new, independent femoral tunnel was prepared using a medial portal technique without concern for convergence with the previous nonanatomic femoral tunnel. The previous tibial tunnel position was acceptable and utilized after careful debridement and dilation to accommodate the new graft. ACL, anterior cruciate ligament.

Table 2. Studies of clinical outcomes of revision anterior cruciate ligament reconstruction

Study	No. of Patients	Follow-Up, y	Time to Revision, y	Technical Failure	Cause, %			Technique, %		
					New Trauma	Multiligament, Malalignment	Two Incision	Anteromedial Portal	Trans tibial	
Noyes and Barber-Westin ⁵¹	21	4.1		61.9	42.9	24, 29	33	67	0	
O'Neill ⁵⁴	48	7.5	5	42	79	10.4, NA	29.2	70.8	0	
Denti et al ²²	60	3.5	4.4	52	33	Excluded				
Battaglia et al ¹¹	63	6.1	5			2, 1	96.8	3.2	0	
Ahn et al ¹	56	4	4.4	53.6			100	0	0	
Garofalo et al ²⁹	28	4.2	2.1	79	100		0	100	0	
Weiler et al ⁸⁸	62	2				Excluded	0	0	100	
Noyes and Barber-Westin ⁵³	55	5	2.8	64	80	31, 16	36	64	0	
Ferretti et al ²⁵	30	5	5	33.3	46.7		0	100	0	
Grossman et al ⁸⁴	29	5.6	4.7	34.5	48.3		89.7	10.3	0	
Salmon et al ⁵⁸	49	7.4	4	22	58		0	0	100	
Thomas et al ⁶¹	49	6.2					0	0	100	
Diamantopoulos et al ²³	107	6.2	5	63.5	24.3	2.8	0	0	100	
Fox et al ²⁷	32	4.8	4.1	79			75	25	0	

NA, not applicable.

Table 3. Studies of clinical outcomes of revision anterior cruciate ligament reconstruction

Study	Two Stage, %			Grafts, %			Laxity Measures			
	Two Stage, %	Hamstring	BTB	Quad	Allograft, %	Overall Failure, %	Mean KT, mm	KT > 5 mm, %	2+ Pivot, %	
Noyes and Barber-Westin ⁵¹				100	0	19	2	19	19	
O'Neill ⁵⁴		44	52		0	6		6		
Denti et al ²²	8.3	61.7	38.3		3.3	10		10		
Battaglia et al ¹¹		15.9	47.6	4.8	31.7	25	3.9	21		
Ahn et al ¹	5.4	37	36		26.8		1.5	3.6	0	
Garofalo et al ²⁹	0			100	0		3.1	3	0	
Weiler et al ⁶⁸	8	100			0	6	2.2	2.1	4.2	
Noyes and Barber-Westin ⁵³	0		100		0	24	2.2	22	22	
Ferretti et al ²⁵	13.3	100			0	10	2.5	7.1	7.1	
Grossman et al ³⁴	0		20.7		75, ^a 4 ^b		2.8	3.4	0	
Salmon et al ⁵⁸		100			0	10	2.5	8.2	6.1	
Thomas et al ⁶¹	100	69.4	30.6		0		1.36	5	2	
Diamantopoulos et al ²³	5.6	42.1	38.3	19.6	0		0.9	6.6	10.3	
Fox et al ²⁷	0				100 ^a	6	1.9	6	3	

BTB, bone–patellar tendon–bone; quad, quadriceps; KT, KT-1000 arthrometer measurement; 2+ pivot, grade 2+ on pivot-shift testing.

^aBone–patellar tendon–bone.^bAchilles.

Table 4. Studies of clinical outcomes of revision anterior cruciate ligament reconstruction

Study	Chondral Lesions, %	Lysholm or Cincinnati	Tegner	IKDC A-B, %	Return to Sports, %
Noyes and Barber-Westin ⁵¹		54 to >76		81	71.4
O'Neill ⁵⁴	16.7			84	75
Denti et al ²²	28.3	90.5	6.7	83.3	78
Battaglia et al ¹¹				71	59
Ahn et al ¹	21.4	63.4 to >84.6		73.2	
Garofalo et al ²⁹	46	93.6	6.1	93	93
Weiler et al ⁶⁸	20	65 to >90		91.7	
Noyes and Barber-Westin ⁵³	56	61 to >87			58
Ferretti et al ²⁵	10	65.4 to >90	6.2	92.9	
Grossman et al ³⁴	24, 24 ^a	86.6	5.2	79.3	80 ^b
Salmon et al ⁵⁸	53	85		56	70
Thomas et al ⁶¹	8, 10 ^a				
Diamantopoulos et al ²³	63.5	51 to >88.5	6.3	57.9	
Fox et al ²⁷	70	75	6.3	93	

IKDC A-B, International Knee Documentation Committee (grade A or B).

^aMedial, lateral.

^bDivision I athletes.

quadriceps strength has returned and can allow for earlier weightbearing when locked in extension.⁴ Activities that should be started immediately postoperative to maximize quadriceps strength include heel slides, straight-leg raises, ankle pumps, and muscle stimulation.^{4,13} Full range of motion should be achieved by 6 weeks, and closed chained kinetic exercises should be initiated. At this point the patient should be full weightbearing, and the graft should be strong enough to progress to closed chained kinetic exercises. Running and more aggressive activities that include cutting and pivoting should be delayed for a minimum of 6 months depending on the quality of bone stock and the cause of previous failure.^{4,13} Full return to aggressive sports should not be initiated until objective measures of leg strength as well as a return of balance and proprioception have returned to preinjury baseline postoperatively. Return to competitive play earlier than 9 to 12 months postoperatively is not recommended.

EXPECTED OUTCOMES

The clinical outcomes after revision ACL reconstruction are largely based on level IV case series (Tables 2-4).^{1,11,22,23,25,27,29,34,51,53,54,58,61,68} Much of the existing literature is heterogenous with regard to patient populations, primary

and revision surgical techniques, concomitant ligamentous injuries, and additional procedures performed at the time of the revision, limiting the generalizability of the reported results. Nevertheless, there appear to be 2 distinct groups within this body of literature. The first group does not have a concomitant ligament injury with intact meniscus and articular cartilage; these cases have a high success rate with regard to stability and return to functional activities. A second group has associated partial to complete meniscectomy, articular cartilage damage, or additional operative procedures. These cases are more complicated and often result in poorer outcomes. Regardless, there is a general consensus that the outcomes for revision ACL reconstruction are inferior to the outcomes in primary reconstruction.

O'Neill⁵⁴ reported that 92% of patients had normal International Knee Documentation Committee scores after primary reconstruction and 84% had normal scores after revision reconstruction. Seven additional studies reported lower rates of normal scores, ranging from 56.0% to 83.3% in subsets, compared with 4 studies that demonstrated greater than 90% of normal scores in their revision patients (Table 4).

Overall graft failure rate in revision ACL reconstructions ranged from 6.0% to 25.0%, with 5 studies demonstrating a

failure rate of 6% to 10% and 3 studies having a failure rate of 19.0% to 25.0% (Table 3).

Battaglia et al¹¹ reported only 59% of patients returning to the same degree of activity as their preinjury state. Seven other studies reported a range of 58.0% to 93.0% returning to sports at a high level. Of these 7 studies, only 1 reported greater than 90% return to play (Table 4).

A recent systematic review of 21 studies with a minimum of 2 years of follow-up by Wright et al⁷¹ demonstrated a 13.7% failure rate in revision ACL reconstruction, compared with 3.67% reported by Spindler et al.⁶⁰ Additionally, the failure rate in primary reconstructions was 2.9% after 2 years in the MOON cohort⁷⁰ and 5.8% by Wright et al⁷³ in another systematic review. These findings demonstrate a 3 to 4 times higher failure rate in revision ACL reconstructions compared with primary ACL reconstructions.⁷¹

CONCLUSION

Revision ACL reconstruction is a complex and challenging clinical problem for the knee surgeon and rehabilitation specialists. A favorable clinical outcome depends on the recognition and treatment of all predisposing factors for graft failure as well as the ability to successfully achieve an anatomic, biologically incorporated ACL graft. Technical challenges include previous hardware, limited graft options, malpositioned tunnels, tunnel expansion, and associated meniscal and ligamentous injury.

Generally, good results can be achieved with regard to graft stability, return to play, and functional knee instability, but results are generally inferior to those of primary ACL reconstruction. In this regard, there can be no compromise of preoperative evaluation, technical approach, and postoperative rehabilitation to avoid a catastrophic recurrent failure. Acceptance of suboptimal tunnel position or approaches that allow for a single-stage reconstruction at the expense of the graft position, fixation, and biological incorporation are not acceptable. The very small potential advantage of an expedited return to play is far outweighed by the increased risks of nonanatomic graft configuration, fixation failure, or incomplete healing in this setting. A staged approach with autograft reconstruction is favored in any circumstance in which a single-stage approach results in suboptimal graft selection, tunnel position, graft fixation, or biological milieu for tendon-bone healing.

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