23

SURGICAL TREATMENT OF THE FAILED ACL WITH OPTIMAL TUNNEL TREATMENT

Mark A. Slabaugh, MD; Nicole A. Friel, BS; Brian J. Cole, MD, MBA; and Bernard R. Bach, Jr, MD

Nearly 300 000 anterior cruciate ligament (ACL) reconstructions are performed annually in the United States alone.[6] Despite improved results and attention to surgical detail and postoperative rehabilitation, the percentage of clinical failures has been thought to be as high as 8%.[32,46] Multiple reasons exist for clinical failure of a primary ACL reconstruction, including pain, recurrent instability, painful hardware, recurrent trauma, or inability to return to the patient's preinjury level of activity. Intraoperative surgical complications and unrecognized concurrent ligamentous patholaxity can also lead to a poor outcome following ACL reconstruction.[13] Prior meniscal deficiency, degenerative joint disease, and loss of motion secondary to scar tissue can also contribute to a failed surgical result.[2] The purpose of this chapter, however, is to discuss surgical treatment in the failed ACL patient who has optimal tunnel placement.

CLASSIFICATION OF FAILURE

The main focus in the literature regarding failed ACL reconstruction deals with recurrent instability.[3,12,13,33,35] Failure may be traumatic or atraumatic. The etiology of traumatic instability is either early (<6-9 months) or late (>9 months). Early causes of failure include premature return to pivoting sports either before biologic fixation of the graft to bone[28] or premature return to sports before the extremity has regained neuromuscular control.[19]

In the late postoperative period when the patient has completely regained full function and strength, a single traumatic event can result in graft failure.[5] In patients who have returned to their preinjury levels of activity or sport, the incidence of traumatic failure is thought to be around 5% to 10%.[24] The mechanisms, specific sports participated in, and the signs and symptoms of these patients with late traumatic instability after reconstruction are similar to those who present with primary instability.[24]

An ACL reconstruction may also fail atraumatically. Included in atraumatic causes are technical or diagnostic errors and failure of graft incorporation. The most commonly cited cause of failure in ACL reconstruction is surgeon technical errors.[14,25,43,45] Within this category the most common surgical error is improper femoral tunnel placement.[17] With the evolution of arthroscopic ACL reconstruction from 2 to single incision, tunnel errors evolved from anteriorized femoral and tibial tunnels with the 2-incision technique to vertically oriented femoral and posterior tibial tunnels with the endoscopic or single-incision technique. Often the cause of failure cannot be attributed to just one cause and frequently is due to a combination of the above causes. This chapter discusses the preoperative evaluation, preoperative planning, and surgical technique that can be utilized for revision ACL reconstructions with proper tunnel placement.

PREOPERATIVE EVALUATION

HISTORY

A thorough history should be performed to adequately assess the need for revision surgery. The history should begin with the mechanism of primary injury, symptoms before reconstruction, assessment of function following initial reconstruction, rehabilitation program, and history of re-injury after the reconstruction. Symptoms including pain, swelling, giving way, locking, stiffness, or limping should also be elicited. The patient's activity level is an

Bach Jr, B, Provencher M.
ACL Surgery: How to Get It Right the First Time and What to Do If It Fails.

important treatment consideration. Finally, the patient's functional goals should be ascertained.

A surgical history should not only include the details regarding the previous ACL procedure but also the history of concomitant procedures such as meniscal and/or articular cartilage treatments. Operative reports should be reviewed (if possible) to note the type and size of graft used and the types of fixation on both the tibia and femur. Knowing the exact hardware (manufacture and size) used in previous graft fixation is paramount should removal be necessary.

In the revision setting a patient's expectation from the surgery should be determined. Patients should be counseled that the outcomes for revision ACL reconstruction are not as successful as a primary reconstruction (see Table 23-1).[9,10,12,18,38,44] Patients should have a full understanding of the risks and benefits of a revision reconstruction. Rehabilitation after a revision is usually slower than after primary surgical reconstruction and patients need to understand that their postoperative rehabilitations will be more conservative. Often expectations for this type of surgery need to be discussed at length and frequently some changes in lifestyle or activities might be warranted if there are injuries to other structures in the knee.

PEARL: It is important to emphasize to the patient that revision ACL reconstruction results do not approach those of primary reconstructions. Due to prior meniscal loss and/or articular cartilage abnormalities, revision ACL surgery should be considered a salvage procedure.

PHYSICAL EXAMINATION

Examination should evaluate prior skin incisions, swelling, pain location (if any), crepitus, and range of motion. Although uncommon, signs of joint sepsis should be identified, because this may be a cause of pain. Any suspicion of a septic joint requires aspiration to rule out infection. Competency of the ACL is tested with the Lachman exam and pivot shift tests as well as a quantitative measurement with the KT-1000 (MEDmetric, San Diego, CA). In addition to anterior stability testing, posterior, medial, and lateral instability should be ruled out in addition to evaluation of the posterolateral structures. Some authors feel that a major cause of failure of a primary ACL reconstruction is an unrecognized posterolateral corner injury.[15,20] Gait evaluation is particularly important in revision settings because ACL insufficiency may exhibit abnormal rotational or varus/valgus thrusts with ambulation.[13]

IMAGING

Radiologic assessment must be obtained to determine tunnel orientation, enlargement, hardware type, and other concomitant pathology. In addition to the standard knee views, imaging should include a lateral view in maximal extension or hyperextension. This specific lateral view allows for evaluation of tunnel placement within the tibia to ascertain that it is not impinging in extension.. A weight-bearing posteroanterior (PA) radiograph should be taken at 45 degrees of knee flexion.[36] This view helps in evaluation of tunnel placement but also evaluates degenerative changes and intercondylar notch configuration. Examples of correct tunnel placement are shown in Figures 23-1 and 23-2.

In addition to radiographs, computed tomography (CT) and magnetic resonance imaging (MRI) can be used to further assess the knee radiographically. CT is more useful to assess tunnel expansion. MRI helps in assessing competency of the previous reconstruction as well as chondral or meniscal damage (Figure 23-3). If any varus is appreciated on clinical exam, long-leg alignment films should be obtained to assess for malalignment.

PEARL: In patients who have malalignment, staged, or concurrent osteotomy may be required.[1]

INDICATIONS AND CONTRAINDICATIONS

The success of any surgical procedure depends upon careful selection of appropriate surgical candidates (Table 23-2). This is especially true in the revision ACL reconstruction setting. An ideal patient would be one who has only true instability as his or her main complaint after primary ACL reconstruction. Weakness from inappropriate rehabilitation causing quadriceps inhibition needs to be ruled out as a cause of instability. Usually these patients will have instability complaints with linear or straight ahead activities (eg, walking) or a sense of buckling while standing. If the patient's main complaint is pain, other sources of failure need to be identified. If the patient complains of pain and instability, often concurrent pathology will exist in addition to the primary ACL reconstruction failure. If the patient only complains of pain despite evidence of a failed ACL reconstruction, revision is less likely to benefit the patient in contrast to the failed ACL associated with instability-only complaints.[29] Table 23-2 outlines the indications and contraindications of revision ACL reconstruction.

Key Points of Preoperative Evaluation

- Appropriate patient selection is critical.
- Instability should be the primary complaint.
- It is necessary to rule out other structural damage if pain is main complaint.
- Operative reports and type of fixation are crucial to help determine cause of failure and plan the revision procedure.
- Appropriate radiographs are necessary to assess tunnel positioning and malalignment.

Table 23-1

Outcomes of Revision ACL Surgery

Author	*Follow-Up*	*Graft Type*	*Outcomes*
Denti et al (2008)	41.9 months (24 to 72 months)	Doubled semitendinosus and gracilis tendon graft: 37 Patellar tendon: 27 Achilles tendon: 2	Lysholm scores • 57% excellent • 13% good IKDC • 36% excellent (class A) • 46% good (class B) Lachman • Negative: 68% • Positive test with hard end point: 20% • Positive results: 12% KT-1000 arthrometer maximal side-to-side difference • <3 mm: 56% • >6: 10%
Weiler et al[44]	2.5 ± 1.8 years	Hamstring autograft	Revision graft failure: 6.5% KT-1000 arthrometer maximal side-to-side difference: 2.1 ± 1.6 mm
Salmon et al[38]	89 months (60-109 months)	Hamstring tendon autograft	10% had objective failure of the RACLR Subjective IKDC: 73% normal or nearly normal Overall IKDC grade: 56% normal or nearly normal KT-1000 arthrometer maximal side-to-side difference: 2.5 mm (range, –1 to 4 mm)
Garofalo et al[12]	4.2 years (3.3 to 5.6 years).	Quad tendon-patellar bone autograft	No patients required further revision IKDC score: 93% normal or nearly normal Lachman • Negative: 17/28 • Grade 1 Lachman with firm endpoint: 11/28 KT-1000 arthrometer maximal side-to-side difference • <3 mm: 65% • >5 mm: 3%
Grossman et al[18]	67 months	Bone-patellar tendon-bone allograft: 22 Bone-patellar tendon-bone autograft: 6 Achilles allograft: 1	All patients available for follow-up reported that they would have the surgery again Objective IKDC: • 15 patients had an A score; 8 had a B score; 4 had a C score KT-1000 arthrometer maximal side-to-side difference: 2.78 mm; Allograft (3.21 mm) vs autograft (1.33 mm)
Fox et al[10]	4.8 years (2.1 to 12.1 years)	Nonirradiated patellar tendon allograft	87% of patients indicated that they were completely or mostly satisfied with the surgical outcome. Lachman: • Normal: 56%; grade 1: 31%; grade 2: 13% Pivot shift: • Negative: 71%; grade 1: 25%; grade 2: 3% KT-1000 arthrometer maximal side-to-side difference • <3 mm: 84% • >5 mm: 6%

continued

Table 23-1 continued

OUTCOMES OF REVISION ACL SURGERY

Author	*Follow-Up*	*Graft Type*	*Outcomes*
Noyes et al (2001)	33 months (24 to 74 months)	Bone-patellar tendon-bone autograft	Significant improvements (postop versus preop): • Overall rating of the knee (*p* < 0.0001) • Pain (*p* < 0.0001) • Activities of daily living (*p* <0.01) • Sports participation (*p* < 0.001) • Patient satisfaction (*p* < 0.0001)
Eberhardt et al[9]	41.2 months	Patellar tendon autograft	75% of knees were noted normal or near normal IKDC: 75.0% rated normal or nearly normal (grades A and B) Lachman: 79.5% negative or slightly positive Pivot shift: 84.0% negative KT-1000 arthrometer maximal side-to-side difference: 3.5 mm

Key: IKDC=International Knee Documentation Committee

FIGURE 23-1. Anteroposterior (AP) x-ray in patient who failed primary reconstruction with correct positioning of tunnels. Notice low lateral wall placement of femoral tunnel and oblique placement of tibial tunnel.

PREOPERATIVE PLANNING

In the revision setting, it is crucial to determine the likely cause of failure prior to determining treatment options. In the scenario described in this chapter, it is assumed that the tunnels were placed correctly, and therefore other causes of failure need to be carefully entertained. Occasionally, the exact cause of failure cannot be ascertained from the patient's history, exam, and radiographic images. In this case, extreme diligence needs to be used intraoperatively to ensure that a cause can be identified and corrected to give the patient the best chance of a successful outcome.

In our experience in most patients who have correct tunnel placement, we feel that the most common cause of failure is macrotraumatic. The exception might be in patients who have loss of fixation despite properly created tunnels. Common technical errors in ACL reconstruction include inadequate graft (auto or allograft), graft impingement, improper graft tensioning, or improper graft fixation.

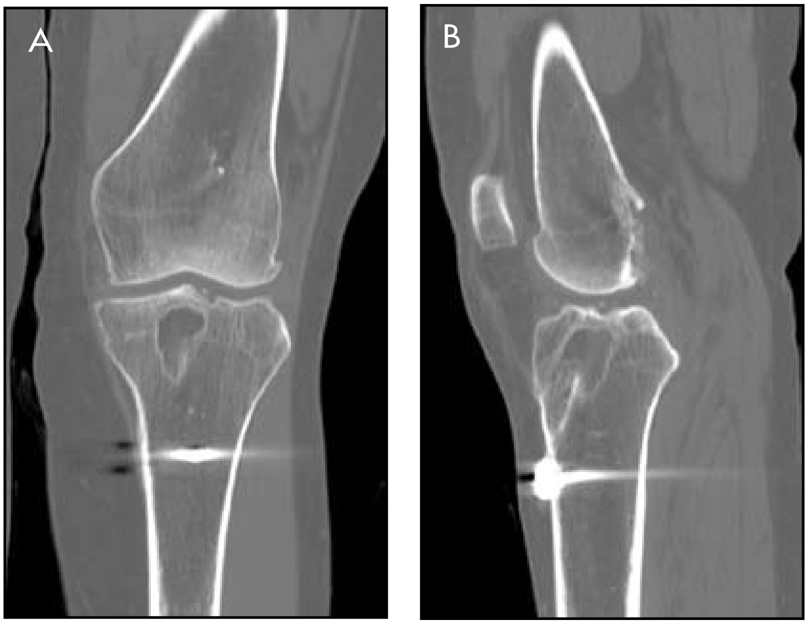

Figure 23-2. Lateral radiograph in patient with proper positioning of graft tunnels. Notice posterior placement of femoral tunnel.

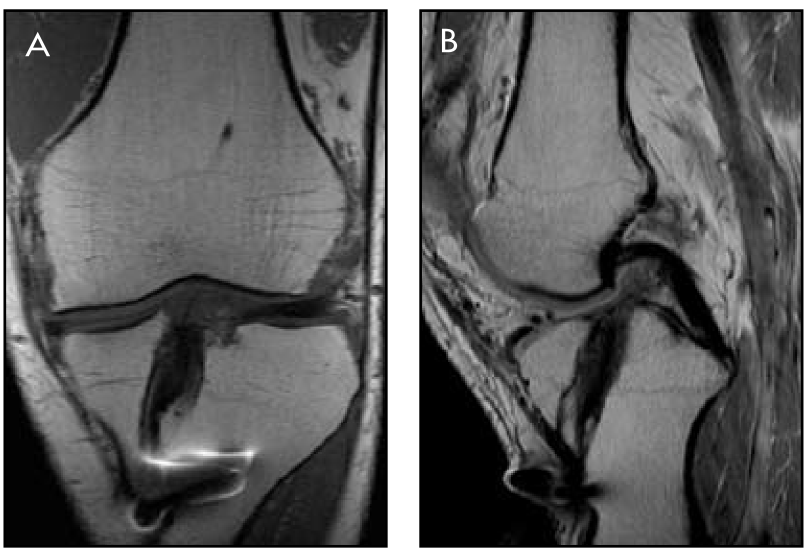

Figure 23-3. Sagittal magnetic resonance imaging (MRI) of knee with good tunnel position in both tibial and femoral tunnels with midsubstance rupture of the anterior cruciate ligament (ACL) reconstruction after a traumatic injury.

Table 23-2

Indications and Contraindications for Revision ACL Reconstruction

Indications	*Contraindications*
• Instability from ACL deficiency	• Inadequate rehabilitation
• Failed nonoperative treatment	• Uncorrected malalignment
• Normal mechanical alignment	• Diffuse osteoarthritis
• Correctable concurrent meniscal or cartilage damage	• Inflammatory arthritis
	• Joint infection

Figure 23-4. Intraoperative picture of a patient who had failure of a primary anterior cruciate ligament (ACL) reconstruction with adequately placed tunnels. Findings showed lateral wall restenosis and notch overgrowth, causing impingement of the graft in extension.

Inadequate graft size is an infrequent cause of failure in ACL reconstruction. When using allograft or patellar-bone tendon-bone autograft, the surgeon can more easily control the size of the graft if proper harvesting techniques are used. However, hamstring autograft size is completely patient dependent. Even though there is no clinical data to determine which size of quadruple-looped hamstring graft would lead to an increased risk of failure, most surgeons believe that a graft at least 7 mm in diameter is needed to control stability in the knee.[42] This arbitrary number fails to take into consideration the age of the patient, size of the patient, and other anatomical concerns such as intercondylar notch width.

Causes of graft impingement can be multifactorial, such as tunnel malposition, inadequate notchplasty, and/or inadequate lateral wall removal (Figure 23-4). In these instances, the ACL will either partially tear or stretch, leading to an incompetent graft. An anteriorly placed tibial tunnel will have graft impingement at the intercondylar notch in full extension resulting in a cyclops lesion or loss of extension on clinical exam. A posteriorly placed graft will have impingement over the lateral portion of the posterior cruciate ligament (PCL). The lateral wall must be removed sufficiently to prevent impingement on the wall itself to create enough room in tight intercondylar notches in order to prevent PCL impingement.[30]

Graft tensioning is an important consideration during ACL reconstruction. If done improperly (either too tight or too loose), it can lead to primary reconstruction failure. The ideal amount of tension applied and the flexion angle of the knee remains debatable and depends upon the type of ACL graft tissue used. Undertensioned grafts will result in immediate graft laxity and failure. Overtensioned grafts will lead to poor revascularization due to high tensile forces and will fail due to inadequate ligamentization.[23,46] A generally accepted concept is that high tension can be employed when securing the graft in extension (or hyperextension), whereas low tension should be used if the graft is secured in 20 to 30 degrees of flexion. We have generally advocated graft fixation in extension; high-tension graft fixation in flexion may "capture" and overconstrain the knee.

Biomechanical graft fixation is the most important contributor to early ACL graft stabilization reconstruction to avoid failure before graft host bone healing has occurred. There are 2 major considerations concerning graft fixation: strength and stiffness. With the myriad of fixation devices available to surgeons today, the discussion of which fixation device is optimal for the femur and tibia is beyond the scope of this chapter. Surgeons should be aware of several considerations when choosing an implant. First, the ultimate strength of the planned reconstructive tissue needs to be considered. An intact ACL tendon has an ultimate strength of 2160 N.[47] The strength of the tissue used should exceed this number.[4] Cooper et al have reported that the strength of a central one-third patellar tendon (10 mm) is 2977N and a quadrupled semitendinosus/gracilis graft is 3879 N.[7] Noyes et al have postulated that the amount of force the ACL experiences with daily activities is approximately 445 N. Therefore, the initial fixation strength should exceed 445 N in order to withstand the postoperative rehabilitation.[34] Most fixation devices for either bone-tendon-bone or soft tissue constructs exceed this number.[26,27]

Surgical Technique

Surgical technique and graft selection should be planned preoperatively, considering all factors, including patient age, activity level, details of the previous ACL reconstruction, and preoperative examination and radiographic findings. The plan must allow for flexibility should unanticipated findings occur intraoperatively. As a generalization, allograft tissue is used in approximately 90% of our revisions, particularly when the index procedure involved an ipsilateral patellar tendon autograft. If the index procedure used a hamstring graft, we would consider use of a patellar tendon autograft. If a contralateral patellar tendon graft had been used for the index procedure, we would recommend use of the ipsilateral patellar tendon. We have had minimal experience using quadriceps tendon grafts for ACL primary or revision surgery. In our patient population discussion of the contralateral patellar tendon for revision surgery is not readily received.

Exam Under Anesthesia and Arthroscopy

A thorough exam under anesthesia (EUA) is essential to confirm the diagnosis and to rule out any other concurrent pathology. This examination should consist of assessment of the patient's range of motion, Lachman, posterior drawer, pivot and reverse pivot shift tests, as well as varus/valgus instability testing at 0 and 30 degrees, and assessment for asymmetric thigh-foot angles (eg, "dial test"). The contralateral knee should be examined as a baseline comparison. Following this examination, diagnostic arthroscopy is performed to exclude and/or treat any concomitant injuries.

The ACL graft should be probed to determine its integrity. If the graft is intact but lax (Figure 23-5), it is possible that the graft stretched out over time due to inadequate pretensioning, fixation, graft healing, or a previously medial meniscectomized state. More frequently, the graft is either fully torn or significantly frayed, indicating impingement, improper tunnel positioning, or recurrent trauma as the cause of failure. In the case of correct tunnel positioning, and lack of recurrent traumatic failure, sites of graft impingement should be closely evaluated. The knee should be taken through a full range of motion to determine the site of impingement or whether an inadequate roof or notchplasty was performed (see Figure 23-4). Occasionally these sites can also develop bony overgrowth.

Graft Preparation

Graft harvest techniques for autografts and allografts are well described in the chapters by Grumet and Bach. The reader is also referred to the chapters authored by Malogne on soft tissue techniques.

Tunnel Assessment

If the index tunnel placement is deemed appropriate radiographically, the quality of the tunnels should be assessed intraoperatively. Complete visualization of the old tunnels can be achieved after the former ACL graft is removed from the lateral wall to the tibial insertion. Arthroscopic electrocautery is used to carefully define the intra-articular sites of the former ACL graft. Intracondylar notch width should be examined if impingement is thought to be a contributing factor to graft failure. The necessity and extent of notchplasty are variable among surgeons, but it is generally indicated when the space within the intracondylar notch is inadequate for proper tunnel and graft placement for a given size of graft. As a generalization, we prefer to have 10 mm of space between the lateral aspect of the PCL and the lateral wall of the intercondylar notch.

Even in the case of proper tunnel positioning at the index surgery, tunnels may be enlarged. Tunnels with

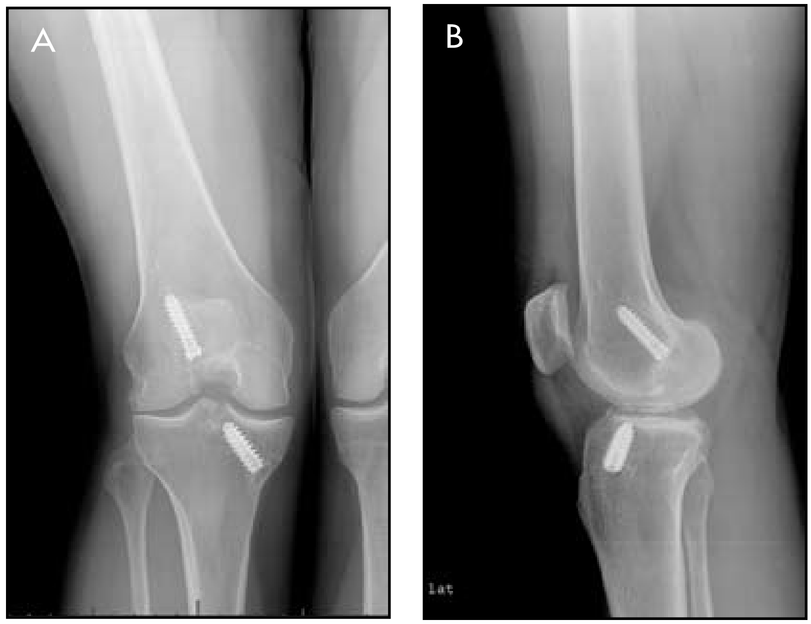

Figure 23-5. Intraoperative picture of patient who had failed primary anterior cruciate ligament (ACL) reconstruction and had properly placed tunnels. Probing of the graft revealed that the graft was lax. Causes could include biologic failure of graft incorporation from inadequate tensioning, early return to pivoting sports prior to incorporation, or inadequate fixation.

excessive widening may require a larger graft or an initial bone grafting and a subsequent staged procedure. In the revision setting where larger grafts are sometimes needed to fill an expanded tunnel, a larger wall or notchplasty will be needed to accommodate the larger graft.

PEARL: In the failed ACL with correct tunnel placement, tunnels can be expanded. Preoperative CT scan assessment is valuable to exclude excessive tunnel expansion.

HARDWARE REMOVAL

Removal of hardware should be carefully considered and only done if it is deemed absolutely necessary for correct placement of tunnels.

PEARL: In patients with poorly placed tunnels, hardware removal can be ignored. In the patient with properly placed tunnels, hardware removal is more likely.

However, in the setting of properly created tunnels, hardware removal will generally be required if metallic interference screws were used. In situations where a biologic or cortical fixation device was used (transfix, biointerference screw), formal removal may not be necessary. Depending upon the size of implant, hardware removal can leave bony defects, cause stress risers, and make subsequent fixation difficult. With properly placed prior tunnels, hardware removal occasionally is not needed and the tunnel can be drilled next to the hardware (Figure 23-6). In preparation for hardware removal, a complete set of interference screwdrivers or universal screw removal sets are useful, as are specialized instrumentation for removal of cannulated fixation screws. Intraoperative fluoroscopy may be needed to identify interference screws, especially within the tibia. Bone overgrowth and soft tissue should be debrided before attempting to remove screws, because this will decrease the chance of stripping the hardware (Figures 23-7 and 23-8). Stripping screws will make removal more difficult and can compromise the surrounding bone. If excessive bone must be removed to retrieve the screw even with well-placed tunnels, auxiliary fixation should be used (eg, staple, screw and post, button). Of note, bioabsorbable interference screws may be present even several years after the index surgery. Often sharp reamers can ream through these implants to obviate removal.

Figure 23-6. Intraoperative picture with the arthroscope in the tibial tunnel. Shows close approximation of the tunnel to the old metallic interference screw. Even in patients with properly placed tunnels, the angle can be changed slightly by increasing the tibial aiming device slightly to avoid the prior hardware.

TUNNEL PREPARATION AND FIXATION

In patients with well-placed tibial tunnels, the placement of the tibial tunnel is essentially the same as for a primary ACL. The inferomedial or a low medial portal can be used

Figure 23-7. Intraoperative picture of a retained metallic interference screw that was properly placed, necessitating removal. The bovie is used to clean off the screw head prior to removal. Additionally, a spinal needle can be used to remove tissue from the screw head to lessen the chance of stripping the screw.

Figure 23-8. Intraoperative picture showing screw removal in the same patient after some lateral wall had been removed and bone from around the screw head. Notice that the screwdriver tip is completely sunk into the head to ensure that stripping does not occur.

Figure 23-9. Schematic of knee showing how changing the coronal angle of the tibial tunnel can affect where the femoral tunnel can be placed. Placement of the tibial tunnel should be around 60 degrees off the tibial plateau in order to get to the 10 o'clock position for the femoral tunnel using a transtibial technique. (Reprinted with permission from Bach BR Jr, Fox J, Mazzocca AD, Rue J-PH. Revision ACL reconstruction. OKO online.)

Figure 23-10. Intraoperative picture of tibial pin placement in the center of the anterior cruciate ligament (ACL) footprint in line with the posterior border of the anterior horn of the lateral meniscus seen on the left of the image.

for the tibial guide. The angle is set at N + 10 (N is the length of the patellar tendon portion of the graft if patellar tendon graft is used). The pin is usually directed approximately 60 to 70 degrees from the coronal plane in order to create the proper trajectory for a transtibial femoral tunnel placement (Figure 23-9).[21] Additionally, the pin should exit the joint in the center of the ACL footprint, which typically is in line with the posterior border of the anterior horn of the lateral meniscus (Figure 23-10). However, the cannulated pin should be secured because it will reside within the former tibial tunnel. After determining proper position, it can be advanced into the lateral femoral wall to stabilize the pin while reaming. Additional stability can be achieved by securing the pin with a hemostat or Kocher clamp. Reaming is performed as in a primary ACL reconstruction. In failures that previously used a bone-tendon-bone (BTB) graft, the surgeon will experience more resistance as the reamer bypasses the former bone plug residing within the tibia. We recommend at least enlarging the diameter of the tibial tunnel by 1 mm to ensure that sclerotic bone is removed and good bleeding cancellous bone is demonstrated to allow for good graft incorporation. Sequentially sized reamers and/or tunnel expanders may be used if needed in patients with sclerotic bone. We typically remove the camera and place it retrograde within the tibial tunnel to visualize the bleeding cancellous bone and assess for adequacy of soft tissue debridement.

PEARL: When creating a new tunnel in patients who have had a previous patellar tendon autograft or allograft, anticipate increased resistance as drilling proceeds through the former bone plug.

Figure 23-11. Posterior wall blowout can vary on horizontal or vertical pin placement as well as amount of posterior placement. (Reprinted with permission from Bush-Joseph CA, Bach BR Jr, Bryan JM. Posterior cortical violation of the femoral tunnel during endoscopic anterior cruciate ligament reconstruction. *Am J Knee Surg.* 1995;8(4):130-133.)

PEARL: Place the arthroscope retrograde up the tibial tunnel and slowly rotate the arthroscope to assess for adequacy of soft tissue removal and to verify bleeding cancellous bone.

Once the tibial tunnel is created, attention is directed to creating the femoral tunnel. Frequently the femoral screw is not removed until the tibial tunnel is created. Any overlapping tissue or bone should be removed with a small curette. Tissue is frequently noted to fill the screw head recess and should be removed with a spinal needle. The screwdriver may be placed retrograde through the tibial tunnel and the knee flexed to allow orientation of the screwdriver so that it is less likely to result in stripping the screw. Once the screw has been removed, a femoral offset aimer can be introduced via the tibial tunnel. The over-the-top position should be confirmed and probed. If the probe slides off the edge, it needs to be further refined with a shaver or burr. We frequently will "walk" the aimer off of the intercondylar roof region until it slides off the over-the-top position.

PEARL: Make certain you can hook the over-the-top position with a probe to confirm that you are placing the aimer appropriately.

The aimer can then be rotated along the intercondylar wall to the appropriate position (10 o'clock for a right knee). The knee flexion angle should be verified. If the knee is inadequately flexed, proper entrance location could be initiated, yet the reamer could penetrate the posterior tunnel wall (Figure 23-11). The knee should be flexed a minimum of 70 degrees and preferably 80 degrees.

PEARL: Inadequate knee flexion during reaming may result in an initial anatomic placement but result in posterior intratunnel cortical perforation.

It is important to create an initial tunnel sufficient to confirm that the posterior edge of the femoral tunnel has not been violated. Once confirmed, final reaming can be performed. Although there has been considerable discussion regarding the ability to restore sagittal and rotational stability with a transtibial approach to femoral tunnel creation, Rue et al have demonstrated that significant portions of both the anteromedial and posterolateral bundles of the ACL can be reconstructed with this technique.[37]

After the tunnels are reamed, the graft tissue can be passed into the femoral socket using a standard Beath pin technique or "push-in" technique. The type of fixation depends on the type of graft, the quality of the bone, and surgeon preference. As with primary ACL reconstruction, there are multiple options for graft fixation.[8,11,39,40] An interference screw is used for patellar graft fixation by most surgeons. Kurosaka et al reported that metal interference screws had superior pullout strength compared with other fixation options.[28] The screw is ideally placed anterior to the graft on its cancellous surface. The cortical surface is oriented away from the screw to reduce the likelihood of soft tissue injury during screw placement. The important steps of femoral fixation include placing a flexible wire in the tunnel graft interval and hyperflexing the knee to at least 95 degrees prior to placement of an interference screw. The nitinol pin should be advanced until it "bottoms out" within the depth of the femoral socket. As a generalization, a 7 mm × 25 mm interference screw is used. If the bone was determined to be slightly expanded or osteopenic, a 9-mm-diameter screw could be used, but this might increase the chance of graft soft tissue injury. If the pin is not appropriately advanced, the wire-screw construct can rotate and twist the graft, leading to graft laceration. Alternatively, the screw may be more likely to diverge and possibly penetrate the posterior cortex. Inadequate flexion may result in graft soft tissue injury.

PEARL: During the course of femoral graft fixation, if the graft starts to rotate, be prepared to stop, remove the screw, and assess the graft for laceration.

Under normal fixation conditions the flexible wire should be removed after the screw is inserted approximately 50%; otherwise, it may be difficult to remove. Once secured, place tension on the graft to confirm that the graft is rigidly fixed. If inadequate fixation is observed, the surgeon may consider placement of an additional 7-mm-diameter interference screw to provide improved fixation.

Tibial fixation is also achieved with the use of an interference screw. Usually a 9-mm-diameter screw is used. The length of the screw is determined by the length of the bone plug and whether there is appropriate construct match. If the tibial plug is recessed within the tibial tunnel, a longer screw is used so that it is not buried intra-osseously. The graft is generally rotated so that the cortical surface is oriented anteriorly. The screw is placed on the cortical surface anteriorly. Graft fixation is performed in extension with the knee axially loaded. High tension is used. If graft–tunnel mismatch occurs, the graft can be rotated up to 540 degrees; this will shorten the graft approximately 8 mm. Alternatively, a trough can be made at the tibial tunnel entrance and the autograft bone plug can be inset into this trough and secured with 2 small to medium-sized barbed staples. Because tibial fixation is less optimal than femoral fixation, the graft can be reinforced with some form of cortical fixation.[27] Some authors[31] advocate double fixation in all revision cases. For example, both the tibial and femoral sutures can be tied over a post and washer. Alternatively, an additional metallic or bioabsorbable screw (stacked screws) can be placed adjacent to the bone plug for additional fixation.

KEY POINTS FOR SURGICAL TECHNIQUE

1. A thorough EUA is important to confirm and quantitate instability.
2. Diagnostic arthroscopy should be used to rule associated chondral, meniscal, or ligamentous pathology.
3. Examination of the intercondylar notch and ACL remnant is important to rule out impingement as a cause of failure.
4. Adequate notchplasty is important in revision situations to ensure room for the graft.
5. Hardware removal should be carefully performed because it is generally required in revision where previous tunnels were appropriately created.
6. Graft selection should be determined preoperatively.
7. Consider double fixation, especially in the tibia in revision ACL surgery.
8. Don’t leave the operating room with inadequate fixation.

REHABILITATION

Rehabilitation for revision ACL reconstruction has to be tailored to each individual patient. The graft choice, mode of initial failure, patient size, patient’s expectations, concomitant procedures performed, and surgeon’s confidence in graft fixation will all guide the postoperative rehabilitation. Generally, the rehabilitation for an ACL revision will be slower than for a primary reconstruction, often due to the choice of allograft for the revision reconstruction.[41] Allografts take longer for bone-to-graft healing and vascularization of the graft.[22] Additionally, the sterilization process for allografts can cause delayed graft incorporation.[16]

Concurrent procedures will often dictate the postoperative weight-bearing status. Cartilage restoration procedures will dictate weight bearing in extension only and, depending upon their location, will also dictate the range of motion limits. Meniscal repairs will also necessitate a period of non-weight-bearing with restricted range of motion (0-90 degrees) for the first 4 weeks. In the absence of any other procedures, the rehabilitation for a revision is similar in regards to range of motion and strengthening. The principles of postoperative rehabilitation are detailed in the chapters by Tokish and Wilk. A hinged knee brace is used for a longer period of time as well; we will typically have the patient wear the brace for one month. We will allow patients to begin biking at 6 weeks, running on a flat surface at 4 months, return to pivoting exercises at 9 months, and a return to sports at 1 year.

At each visit the patient is reminded that the expectations for this revision procedure need to be different than for his or her primary reconstruction.[39] Patients will often assume that the rehabilitation and milestones during this process will be the same as for their primary surgery. However, the surgeon needs to temper their activities to ensure that proper graft healing and rehabilitation occur.

KEY POINTS FOR REHABILITATION

1. Weight-bearing status is dictated by other concomitant procedures.
2. Brace wear is extended.
3. Range of motion and strengthening rehabilitation are similar to a primary ACL.
4. Graft incorporation and ligamentization are delayed compared with primary ACL.
5. Return to sport is avoided until 1 year postop.
6. Reassure the patient regarding limitations and expectations.
7. Go slower!

REFERENCES

1. Aggarwal A, Panarella L, Amendola A. Considerations for osteotomy in the ACL deficient knee. *Sports Med Arthrosc Rev.* 2005; 13:109.
2. Alford W, Cole BJ. Failed ACL reconstruction and meniscus deficiency. Background, indications and techniques for revision ACL reconstruction with allograft meniscus transplantation. *Sports Med Arthrosc Rev.* 2005;13:93.
3. Brophy RH, Selby RM, Altchek DW. Anterior cruciate ligament revision: double-bundle augmentation of primary vertical graft. *Arthroscopy.* 2006;22:683.e1-683.e5.
4. Brown HR, Steiner ME. Anterior cruciate ligament injuries. In: Siliski JM, ed. *Traumatic Disorders of the Knee.* New York, NY: Springer-Verlag; 1994:193-284.

5. Carson EW, Simonian PT, Wickiewicz TL, et al. Revision anterior cruciate ligament reconstruction. *Instr Course Lect.* 1998; 47:361-368.
6. Cohen SB, Sekiya JK. Allograft safety in anterior cruciate ligament reconstruction. *Clin Sports Med.* 2007;26:597-605.
7. Cooper DE, Deng XH, Burstein AL, et al. The strength of the central third patellar tendon graft. A biomechanical study. *Am J Sports Med.* 1993;21:818-823; discussion 823-824.
8. Creighton RA, Bach BR, Jr. Revision anterior cruciate ligament reconstruction with patellar tendon allograft. Surgical technique. *Sports Med Arthrosc Rev.* 2005;13:38.
9. Eberhardt C, Kurth AH, Hailer N, et al. Revision ACL reconstruction using autogenous patellar tendon graft. *Knee Surg Sports Traumatol Arthrosc.* 2000;8:290-295.
10. Fox JA, Pierce M, Bojchuk J, et al. Revision anterior cruciate ligament reconstruction with nonirradiated fresh-frozen patellar tendon allograft. *Arthroscopy.* 2004;20:787-794.
11. Gallagher JA, Fowler PJ. Graft selection for revision ACL surgery hamstring tendons: Rationale, technique and results. *Sports Med Arthrosc Rev.* 2005;13:73.
12. Garofalo R, Djahangiri A, Siegrist O. Revision anterior cruciate ligament reconstruction with quadriceps tendon-patellar bone autograft. *Arthroscopy.* 2006;22:205-214.
13. George MS, Dunn WR, Spindler KP. Current concepts review: revision anterior cruciate ligament reconstruction. *Am J Sports Med.* 2006;34:2026-2037.
14. Getelman MH, Friedman MJ. Revision anterior cruciate ligament reconstruction surgery. *J Am Acad Orthop Surg.* 1999;7:189-198.
15. Getelman MH, Schepsis AA, Zimmer J. Revision ACL reconstruction: autograft versus allograft. *Arthroscopy.* 1995;11:378.
16. Gibbons MJ, Butler DL, Grood ES, et al. Effects of gamma irradiation on the initial mechanical and material properties of goat bone-patellar tendon-bone allografts. *J Orthop Res.* 1991;9:209-218.
17. Greis PE, Johnson DL, Fu FH. Revision anterior cruciate ligament surgery: causes of graft failure and technical considerations of revision surgery. *Clin Sports Med.* 1993;12:839-852.
18. Grossman MG, ElAttrache NS, Shields CL, et al. Revision anterior cruciate ligament reconstruction: three- to nine-year follow-up. *Arthroscopy.* 2005;21:418-423.
19. Harner CD, Giffin JR, Dunteman RC, et al. Evaluation and treatment of recurrent instability after anterior cruciate ligament reconstruction. *Instr Course Lect.* 2001;50:463-474.
20. Hodrick JT, Moorman III CT. ACL reconstruction failure and posterolateral corner. *Sports Med Arthrosc Rev.* 2005;13:103.
21. Howell SM, Gittins ME, Gottlieb JE, et al. The relationship between the angle of the tibial tunnel in the coronal plane and loss of flexion and anterior laxity after anterior cruciate ligament reconstruction. *Am J Sports Med.* 2001;29:567-574.
22. Jackson DW, Grood ES, Goldstein JD, et al. A comparison of patellar tendon autograft and allograft used for anterior cruciate ligament reconstruction in the goat model. *Am J Sports Med.* 1993;21:176-185.
23. Jaureguito JW, Paulos LE. Why grafts fail. *Clin Orthop Relat Res.* 1996;325:25-41.
24. Johnson DL, Harner CD, Maday MG, et al. Revision anterior cruciate ligament surgery. In: Fu FH, Harner CD, Vince KD, eds. *Knee Surgery.* Baltimore, Md: Williams & Wilkins; 1994:877-895.
25. Johnson DL, Swenson TM, Irrgang JJ, et al. Revision anterior cruciate ligament surgery: experience from Pittsburgh. *Clin Orthop Relat Res.* 1996;325:100-109.
26. Kousa P, Jarvinen TL, Vihavainen M, et al. The fixation strength of six hamstring tendon graft fixation devices in anterior cruciate ligament reconstruction. Part I: femoral site. *Am J Sports Med.* 2003;31:174-181.
27. Kousa P, Jarvinen TL, Vihavainen M, et al. The fixation strength of six hamstring tendon graft fixation devices in anterior cruciate ligament reconstruction. Part II: tibial site. *Am J Sports Med.* 2003;31:182-188.
28. Kurosaka M, Yoshiya S, Andrish JT. A biomechanical comparison of different surgical techniques of graft fixation in anterior cruciate ligament reconstruction. *Am J Sports Med.* 1987;15:225-229.
29. Lahav A, Burks RT. Evaluation of the failed ACL reconstruction. *Sports Med Arthrosc Rev.* 2005;13:9.
30. Lawhorn KW, Howell SM. Scientific justification and technique for anterior cruciate ligament reconstruction using autogenous and allogeneic soft-tissue grafts. *Orthop Clin North Am.* 2003;34:19-30.
31. Miller MD. Complex (double-bundle and revision) anterior cruciate ligament reconstruction. In: Miller MD, Cole BJ, Cosgarea AJ, et al, eds. *Operative Techniques Sports Knee Surgery.* Philadelphia, PA: Saunders Elsevier; 2008:299-300-314.
32. Noyes FR, Barber-Westin SD. Revision anterior cruciate ligament reconstruction: report of 11-year experience and results in 114 consecutive patients. *Instr Course Lect.* 2001;50:451-461.
33. Noyes FR, Barber-Westin SD. Revision anterior cruciate surgery with use of bone-patellar tendon-bone autogenous grafts. *J Bone Joint Surg Am.* 2001;83A:1131-1143.
34. Noyes FR, Butler DL, Grood ES, et al. Biomechanical analysis of human ligament grafts used in knee-ligament repairs and reconstructions. *J Bone Joint Surg Am.* 1984;66:344-352.
35. Rollier JC, Besse JL, Lerat JL, et al. Anterior cruciate ligament revision: analysis and results from a series of 74 cases. *Rev Chir Orthop Reparatrice Appar Mot.* 2007;93:344-350.
36. Rosenberg TD, Paulos LE, Parker RD, et al. The forty-five-degree posteroanterior flexion weight-bearing radiograph of the knee. *J Bone Joint Surg Am.* 1988;70:1479-1483.
37. Rue JP, Ghodadra N, Bach BR Jr. Femoral tunnel placement in single-bundle anterior cruciate ligament reconstruction: a cadaveric study relating transtibial lateralized femoral tunnel position to the anteromedial and posterolateral bundle femoral origins of the anterior cruciate ligament. *Am J Sports Med.* 2008;36:73-79.
38. Salmon LJ, Pinczewski LA, Russell VJ, et al. Revision anterior cruciate ligament reconstruction with hamstring tendon autograft: 5- to 9-year follow-up. *Am J Sports Med.* 2006;34:1604-1614.
39. Shelbourne KD, Thomas JA. Contralateral patellar tendon and the Shelbourne experience. Part 1. Revision anterior cruciate ligament reconstruction and rehabilitation. *Sports Med Arthrosc Rev.* 2005;13:25.
40. Shelbourne KD, Thomas JA. Contralateral patellar tendon and the Shelbourne experience. Part 2. Results of revision anterior cruciate ligament reconstruction. *Sports Med Arthrosc Rev.* 2005;13:69.
41. Steadman JR, Bollom TS. Principles of ACL revision surgery and rehabilitation. *Sports Med Arthrosc Rev.* 2005;13:53.
42. Tuman JM, Diduch DR, Rubino LJ, et al. Predictors for hamstring graft diameter in anterior cruciate ligament reconstruction. *Am J Sports Med.* 2007;35:1945-1949.
43. Uribe JW, Hechtman KS, Zvijac JE, et al. Revision anterior cruciate ligament surgery: experience from Miami. *Clin Orthop Relat Res.* 1996;325:91-99.

44. Weiler A, Schmeling A, Stohr I, et al. Primary versus single-stage revision anterior cruciate ligament reconstruction using autologous hamstring tendon grafts: a prospective matched-group analysis. *Am J Sports Med*. 2007;35:1643-1652.
45. Wetzler MJ, Bartolozzi AR, Gillespie MJ, et al. Revision anterior cruciate ligament reconstruction. *Oper Tech Orthop*. 1996;6:181-189.
46. Yoshiya S, Andrish JT, Manley MT, et al. Graft tension in anterior cruciate ligament reconstruction. An in vivo study in dogs. *Am J Sports Med*. 1987;15:464-470.
47. Zavatsky AB, Beard DJ, O'Connor JJ. Cruciate ligament loading during isometric muscle contractions. A theoretical basis for rehabilitation. *Am J Sports Med*. 1994;22:418-423.
48. Bach BR Jr, Fox J, Mazzocca AD, Rue J-PH. Revision ACL reconstruction. OKO online.
49. Bush-Joseph CA, Bach BR Jr, Bryan JM. Posterior cortical violation of the femoral tunnel during endoscopic anterior cruciate ligament reconstruction. *Am J Knee Surg*. 1995;8(4):130-133.