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Complications of Anterior Cruciate Ligament Reconstruction With Bone–Patellar Tendon–Bone Constructs

Care and Prevention

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Rupture of the anterior cruciate ligament is a common injury. Correct diagnosis and patient selection, along with proper surgical technique, with careful attention to anatomic graft placement, followed by attention to proper rehabilitation, leads to predictably good to excellent results. This article reviews the recognition and avoidance of complications associated with bone–patellar tendon–bone contructs of anterior cruciate ligament reconstruction.

Keywords: anterior cruciate ligament; complications; knee instability; ligament reconstruction; fixation

Treatment of the anterior cruciate ligament (ACL)–deficient knee has evolved markedly over the few decades. More than 100 000 ACL reconstructions are performed annually in the United States,[15] and the incidence of ACL injury continues to rise along with the growing numbers of competitive and recreational athletes. The orthopaedic literature is replete with series of successful reconstructions performed using varying grafts and graft-fixation devices. Perioperative care has evolved from inpatient hospital stays with immobilization to outpatient surgery with immediate range of motion. Recent studies have demonstrated predictably good and excellent patient objective and subjective outcomes with full expectation of return to sport and work.

Complications in ACL surgery can be disastrous, as the majority of reconstructions are often performed on young patients. While surgical treatment can predictably restore stability and improve function in 85% to 90% of patients,[7,8,10,26,37,61,95,96,107,119] extrapolation of these results suggest a 10% to 15% failure rate. Although repeat injury and new trauma clearly play a role in failures, several authors cite technical errors as a contributing factor in up to 70% of failed ACL reconstructions.[7,46] This area is of considerable interest and the AOSSM is currently organizing and funding a multicenter revision ACL reconstruction study with failure and outcome analysis.

The best way to avoid a primary ACL failure is to understand the technical pitfalls in ACL reconstruction and to fully document and appropriately treat any concomitant injuries. Significant complications may be avoided by properly recognizing other patholaxities (eg, posterolateral corner injuries) that, if left untreated, may contribute to failure. Vigilance is also necessary throughout the postoperative period, to ensure adherence to well-established rehabilitation protocols, with emphasis on avoiding early postoperative graft injury, while enhancing maximal functional recovery. Thus, there are many areas in primary ACL surgery where complications may occur—from the time the surgeon meets the patient, until well into the postoperative period. A key to minimizing this risk is understanding the common complications encountered during care of the ACL-deficient knee, while having sound strategies to deal with these issues should they occur.

When complications occur, recognition and adherence to sound principles can correct, minimize, or salvage difficult problems. The goal of this article is to present some of the common complications that arise during the care of the patient with an ACL-deficient knee when using a bone–patellar tendon–bone graft for reconstruction. Emphasis is placed on the complete care of this injury— from the first patient contact preoperatively, to the management of intraoperative complications, and how to deal with troublesome postoperative issues (Table 1).

MINIMIZING ACL COMPLICATIONS IN THE PREOPERATIVE PATIENT

Diagnosis

Preoperative evaluation of a suspected ACL-deficient knee is critical to the success of surgical reconstruction. The goals of this evaluation should be to confirm the presence

TABLE 1
Complications of Primary Anterior Cruciate Ligament Surgery[a]

Preoperative	Intraoperative	Postoperative
Improper diagnosis	Improper graft choice	Infection
Poor indications	Graft harvest errors	Loss of motion/stiffness
Improper preoperative range of motion	Inadequate notchplasty	Extensor mechanism failure
Improper surgical timing	Improper tunnel placement	Graft failure
	Femoral tunnel blowout	
Failure to prepare for concomitant procedures	Dropped graft	Patellar pain
Failure to note concurrent diagnoses	Graft laceration	Deep venous thrombosis/pulmonary embolus
	Graft-construct mismatch	
	Screw-tunnel divergence	
	Improper tensioning	
	Inadequate graft fixation	

[a]Various factors have been associated with failure after a primary anterior cruciate ligament surgery and are divided here into preoperative, intraoperative, and postoperative issues.

of an ACL tear and also identify any associated conditions that could decrease the likelihood of successful treatment. First and foremost, one must be able to accurately diagnose an ACL injury. While many patients are referred to orthopaedists after an injury with MRI diagnosis of an ACL tear, MRI is not necessary to make an accurate diagnosis and should never replace the findings of an appropriately performed history and physical examination. One should ascertain the mechanism of injury, as an ACL tear is more frequently a noncontact event with a deceleration or a change of direction maneuver, as opposed to a contact or direct blow injury. Patients may use the "2-fist" sign to characterize joint instability, placing 1 fist over the other and shifting them to try to visually reproduce their sense of instability. Up to 80% of patients report an audible "pop" or "tearing" sensation at the time of the index injury.[71] The knee also typically develops a hemarthrosis within 3 hours, but there may be a gradual onset of swelling over 24 hours in a smaller subset of patients.

Two major physical examination tests assist the clinician in diagnosis: the Lachman[67] and the pivot-shift test.[45] The anterior drawer test, although commonly performed, is much less sensitive in the diagnosis of an acute ACL tear.[111] The pivot-shift phenomenon is considered pathognomonic of ACL deficiency.[42] It may vary from a grinding or slipping sensation (grade 1), to audible or palpable slipping (grade 2), to transient locking (grade 3). With the knee in extension, the tibia subluxates anteriorly as gravity allows the femur to fall posteriorly relative to the tibia in the ACL-deficient knee. The iliotibial band then lies anterior to the anatomic center of rotation. As the examiner flexes the knee to 20° to 25°, the knee reduces and the pivot-shift phenomenon occurs. The magnitude of the pivot-shift phenomenon is affected by axial load, valgus force, and hip flexion and iliotibial band tension. The position of the hip and the rotation of the tibia have been shown to greatly influence the magnitude of the pivot-shift phenomenon, with an abducted hip and an externally rotated foot producing the greatest effect, likely due to the relaxation of the iliotibial band.[12] Although a variety of modifications have been described, the key principle is that the pivot shift represents the subluxation-reduction phenomenon that occurs with ACL instability. In the acutely injured patient, guarding can make it difficult to

TABLE 2
KT-1000 Arthrometer[a] Findings[11]

	Max Manual	Index	Side to Side
Normal	<10 mm	≤2	<3 mm
Anterior cruciate ligament injury	>10 mm	>2	>3 mm

[a]The KT-1000 arthrometer (MEDmetric, San Diego, Calif) is a reliable and reproducible objective measure of anterior tibial translation relative to the femur. It has been demonstrated that a manual maximum difference of >3 mm versus the contralateral limb or an absolute measure of 10 mm is highly suggestive of anterior cruciate ligament insufficiency.

assess the pivot shift, and at times a positive pivot may only be elicited with an examination under anesthesia. The Lachman test has been shown to be reliable in the acute injury phase and is the most sensitive test to assess ACL injury.[67] It should be noted that no significant differences have been noted between genders with regard to preoperative assessments of Lachman, anterior drawer, and pivot-shift grades.[41]

Arthrometric evaluation also plays a valuable role. The KT-1000 arthrometer (MEDmetric, San Diego, Calif) allows measurement of anterior translation of the tibia on the femur at 15 and 20 pounds of applied force and at maximum manual testing (approximately 30 pounds), with the knee in approximately 20° to 30° of flexion. The maximum manual side-to-side difference is the strongest predictor of an injury when comparing normal to the ACL-deficient knee, whereas the compliance index offers the strongest variable for differentiating between an acute and chronic ACL tear.[11] A maximum manual side-to-side difference of 3 mm and an absolute displacement greater than 10 mm on the affected knee have a sensitivity of 99% for a torn ACL[1] (Table 2). Proper technique is critical, with patient relaxation and neutral rotation of both legs essential to ensure accurate and precise measurements.

Recognition of associated injuries is crucial to avoid unanticipated intraoperative findings and to minimize the chances of a postoperative ACL reconstruction failure. Examination of the posterior cruciate ligament as well as varus-valgus testing at 0° and 30° of flexion is critical to diagnose associated

Figure 1. The dial test. An increase in external rotation at 30° of knee flexion is suggestive of posterolateral corner injury.

Figure 2. Bone bruise. T2-weighted sagittal MRI scan of a patient after a recent anterior cruciate ligament injury showing the typical appearance of the bone bruise seen on the mid-aspect of the lateral femoral condyle and the posterolateral tibial plateau. (Reprinted from Sellards R, Bach BR Jr. Management of acute Anterior cruciate ligament injuries, in Callahan, JJ, Rosenberg AG, Rubach HE, Simonian PR, Wickiewicz TL (eds.) The Knee, LWW. Phil Pa Ch 44, page 670 Figure 7B).

collateral ligament injuries. The dial test assesses the posterolateral structures of the knee by determining the differences in external rotation of the thigh-foot angles at 90° and 30° of knee flexion.[70] An increase in external rotation of 15° degrees with the knee in 30° of flexion is suggestive of posterolateral corner insufficiency (Figure 1). Clinical observations as well as basic science literature indicate that significant increases in joint laxity can occur with a disrupted posterolateral corner, even in the presence of an appropriately reconstructed ACL.[69] One should always document the gait to ensure that there is no evidence of a varus thrust or varus-hyperextension thrust that might signify injury to this area of the knee.[93] The varus-aligned knee has been shown to increase the stress on the ACL graft in a reconstructed knee. Gait inspection and a supine examination should be performed on all ACL-deficient patients to rule out a varus-aligned knee to ensure that an ACL reconstruction will have an optimized functional environment. The underlying cause of a varus knee should be investigated and potentially corrected in a concurrent or staged fashion.[90] Hip to knee weightbearing radiographs should be obtained in a patient with suspected malalignment. Failure to note these injuries and appropriately manage them may lead to possible graft failure and ultimately poorer outcomes.

Concomitant medial collateral ligament (MCL) injuries are typically treated nonoperatively. Proximal MCL injuries are more likely to result in delayed motion recovery.[103] Because of this observation, it has been suggested to defer surgery in the patient with a combined ACL-MCL injury until full flexion and resolution of MCL tenderness has been achieved.

Knees with acute ACL injuries should be evaluated for meniscal injuries as meniscal tears are identified approximately 50% of the time. The incidence increases to 60% to 80% in chronic ACL-deficient knees, reflecting the role of the menisci as secondary stabilizers of the knee.[17] Lateral meniscal tears are more frequently acute, whereas a medial meniscal tear is associated with chronic ACL deficiency.[94] Overall, bucket-handle tears affect the medial meniscus more often than the lateral meniscus in a 4:1 ratio.[17] In patients with a displaced bucket-handle tear, the joint-line tenderness is usually anteromedial rather than posteromedial; this reflects the displaced position of the bucket-handle meniscus. A displaced bucket-handle meniscal tear
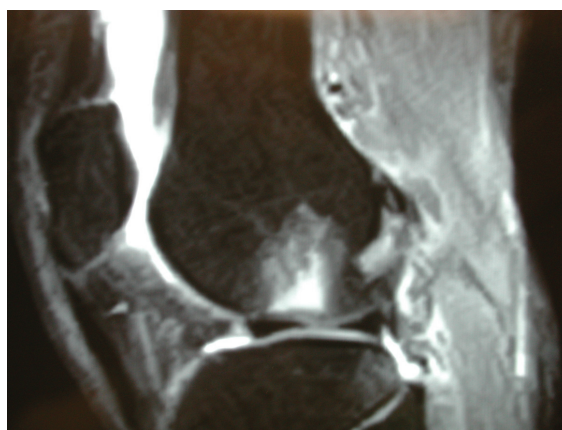
may prevent full range of motion of the knee (especially full extension), and earlier surgical management may be advocated to not only facilitate motion, but also to protect the meniscus tissue from additional trauma before repair.

Although correct diagnosis of an ACL-deficient knee can be made reliably without radiographic data, plain radiographs and MRI scans remain valuable preoperative tools to ensure recognition of concomitant diagnoses and note injuries and conditions that may alter surgical treatment. For example, recognition of patellar tendon ossicles as in Osgood-Schlatter or Sinding-Larsen-Johansson syndromes, may influence graft choice or harvest technique.[79] The Segond fracture, a lateral capsular avulsion seen on plain radiography or MRI, is correlated with ACL injury.[57] Degenerative changes may influence treatment choice. In addition, in adolescent patients, radiographs allow visualization of the state of the physis to determine if significant skeletal growth remains that might preclude standard surgical treatment, although the wrist bone (posterior-anterior view of the left wrist and hand) age provides more predictable assessment of skeletal age.[52] Finally, full lower extremity hip to ankle weightbearing radiographs are helpful to assess suspected malalignment.

Several studies have shown physical examination performed by a skilled practitioner to be at least as accurate as MRI in the diagnosis of meniscal and ACL injuries.[68,104] However, MRI remains useful in assessing bone contusions, tibial eminence fractures, intra-articular fractures, and associated ligament injuries, and can help delineate meniscal injury in the setting of the diffusely tender knee. The bone bruise is typically seen in acutely injured knees and is less frequently found in chronically ACL-deficient knees.[50] The bone bruise after an ACL injury is best visualized on the sagittal MRI scan and is typically found in the middle third of the lateral femoral condyle (sulcus terminalis) and the posterolateral aspect of the lateral tibial plateau[50] (Figure 2). Although theoretically beneficial, MRI

has been found to not be very useful in differentiating between partial and complete ACL injuries.[9] An important principle, regardless of how the ACL may be interpreted on MRI by a radiologist, is that an ACL injury is a complete injury until proven otherwise; "partial" ACL injuries are extremely unusual. Although discussion of the options available for osteochondral lesions is beyond the scope of this review, an accurate assessment of the radiographic and MRI findings of the lesions can assist the surgeon in preoperative planning and in counseling the patient regarding concomitant chondral injury.

Indications for Surgery

Anterior cruciate ligament injury is not an absolute indication for surgical reconstruction. Nevertheless, for the majority of active patients, treatment, results, and patient expectations have evolved such that ACL reconstruction is considered preferential to bracing and activity modification for most young individuals. The decision to proceed with surgical treatment of an ACL tear should be made only after a thorough discussion with the patient concerning their type of work, recreational activities, and future expectations. Patients should be educated on the surgical expectations and postoperative rehabilitation requirements. Patients who are sedentary or who are willing to modify their activity level can be considered for nonoperative treatment.[32] Age alone is not a contraindication to ACL reconstruction.[88,99] Several office visits and discussion of patient expectations may be required in order to determine the best course of action for some patients.

Activity level is one of the most important factors to consider before offering ACL surgery. Daniel et al[36] classified sports and occupations into levels 1 through 3. Level 1 sports require pivoting, cutting, and jumping actions and include basketball, football, and soccer. Baseball, tennis, and skiing, which require lateral motions but less jumping, are considered level 2, whereas linear sports such as jogging are considered level 3. Level 1 occupations mirror level 1 sports. Level 2 work includes heavy labor, with climbing or working on uneven surfaces. Level 3 work activities would include activities of daily living.[36] Patients whose occupation or avocation involves level 1 activities are clear candidates for reconstruction, and most patients involved in level 2 activities should consider reconstruction as well[9] (Table 3). Although activity level serves as a guideline, longitudinal studies investigating the nonoperative treatment of ACL injuries have demonstrated that unrestricted return to function is not as predictable with an ACL-deficient knee.[14,36,55,92]

Timing of Surgery

Once the diagnosis of ACL injury has been made and surgical treatment has been recommended, the timing of the intervention and the type of surgical graft are other factors that must be considered. Arthrofibrosis is a well-documented but infrequent complication of ACL reconstruction. Patients failing to achieve full knee extension report anterior knee pain, patellofemoral crepitus, stiffness, impaired gait, slower

TABLE 3
Indications for Anterior Cruciate
Ligament (ACL) Reconstruction[a]

Active lifestyle, sport, and/or occupation (level 1 or 2)
Hard-cutting, decelerating sports >5 hours/week
Associated repairable meniscal tear
Recurrent instability
High skill level
Social considerations
Multiligament knee injury
KT-1000 side-to-side differences >3 mm
Failed conservative treatment with bracing

[a]Various patient profiles and activities are listed that have been shown to benefit most from ACL reconstruction.

rehabilitation progress, and inability to resume previous activity levels.[108] Although it has been reported that arthrofibrosis is a greater problem when reconstruction is performed acutely,[33] others have demonstrated that the state of the knee, rather than chronology, is the most important factor.[60] A preoperative therapy protocol should be considered that emphasizes achieving normal or nearly normal motion, having good quadriceps control, and resolution of effusion before proceeding with ACL reconstructive surgery. Although some authors recommend obtaining completely symmetrical hyperextension before surgery is performed, we have noted that an incarcerated stump of ACL tissue may prevent recovery of the last few degrees of extension. Although the initial description of a "cyclops lesion" concerned postoperative stiffness,[63] in the chronically deficient knee, a cyclops lesion (a synovialized remnant of ACL tissue impinging in the notch) has been described as a possible contributing factor in patients failing to achieve full extension.[82] Postoperatively, accelerated rehabilitation emphasizing immediate weightbearing and early extension protocols have also helped reduce the incidence of arthrofibrosis. These protocols are discussed in the section concerning postoperative management.

Graft Choice

Graft choice is another important preoperative consideration. Many reports are available advocating 1 graft choice versus another, but well-designed randomized trials have been published less frequently. Recently, systematic reviews of randomized controlled trials comparing hamstring and bone–patellar tendon–bone autografts have suggested that graft type is not the primary determinant of successful ACL reconstruction. These reviews suggest that hamstring grafts may help prevent anterior knee pain, while more weakly suggesting that patellar tendon grafts may yield slightly better stability.[100] Because failures are more likely related to technical errors than graft choice, the surgeon should consider his or her own experience with a particular technique when advising patients in the preoperative setting. Other considerations include preexisting patellofemoral disease or malalignment that may preclude a bone-tendon-bone autograft. Regardless of type, a strong graft that is properly placed and rigidly fixed will generally result in a stable knee.

MINIMIZING INTRAOPERATIVE COMPLICATIONS

This review focuses on those complications associated with bone–patellar tendon–bone grafts, including harvest, implantation, and specific rehabilitation concerns.

Patellar Tendon Autograft

Patellar Tendon Sizing. The goals of a bone–patellar tendon–bone harvest are to obtain an appropriately sized graft while avoiding harvest complications. The surgeon should palpate the patellar tendon prior to surgery to ensure adequate size for autograft. A patellar tendon that is narrower than approximately 25 mm may be at higher risk for postoperative extensor mechanism problems. In this case, a smaller patellar tendon graft can be obtained, or consideration made for alternative grafts.

In order to obtain a reliable patellar tendon graft, an 8-cm incision bordering the medial edge of the patellar tendon allows visualization of the entire tendon for harvest and placement of the tibial tunnel through the same incision. Although a smaller incision may be cosmetically more pleasing, and may reduce the possibility of injury to the infrapatellar branch of the saphenous nerve, one should not compromise visualization while obtaining the graft. It is important to measure the distal width of the tendon, as it usually tapers from proximal to distal. This ensures an adequate tissue harvest, as well as adequate residual patellar tendon. Flexing the knee keeps tension on the graft and assists the surgeon in making longitudinal cuts in line with the tendon fibers. A curved 3/8-in osteotome is 10 mm wide and can be used as a cutting guide. Alternatively, sizing templates are available.

Patellar Tendon Bone Plugs. Bone cuts beginning on the tibial side prevent blood from the patella obscuring tendon visualization. This also allows the surgeon to place traction on the tendon during the patellar harvest, allowing for a shorter incision by pulling the patella distally. Making the tibial bone plug triangular in shape maximizes the remaining tubercle bone at the patellar tendon insertion, reducing the risk of postoperative patellar tendon rupture. The patellar bone plug should be trapezoidal in shape and taken to a depth of 6 to 8 mm. This prevents articular surface penetration and chondral damage. When making osseous cuts, the oscillating saw can be held in the right hand when making right-sided cuts and in the left hand when making left-sided cuts in order to fully visualize the blade and bone during the cuts. The oscillating saw should be used similarly to a cast saw, allowing for a feeling of "give" as the saw penetrates cortical bone and enters cancellous bone; this allows a depth of approximately 8 to 10 mm. A Steri-strip applied at the 10-mm mark or saw blade with a 10-mm mark may be utilized to prevent overpenetration by the sagittal saw. The cuts are initiated at the tendo-osseous junction both distally (tibia) and proximally (patella). Once the cuts have been made, the surgeon must resist any effort to aggressively lever the graft from the osseous beds. Levering may splinter the plugs or lead to an intraoperative patellar fracture. Should splintering of the bone plug

occur, several options exist. If some bone remains, it can be augmented by obtaining bone from a coring reamer and attaching it to the plug with suture through drill holes.[28] Another option is to undersize the femoral tunnel to match the bone plug. If 1 bone plug has inadequate circumference, the smaller bone plug can be augmented with the larger plug as an additional wafer of cortical bone.[106] If insufficient bone remains, soft-tissue fixation is another option. A Krackow suture can be placed in the tendon in order to use interference fixation or a screw and post construct on the tibia. Securing any remaining bone plug on the tibia with sutures and a backup post is another option.

On the patellar side, aggressive levering or deep plunging during cutting may result in intraoperative patella fracture. These are typically longitudinal cracks and are seen arthroscopically as a "crease" in the patellar hyaline cartilage.[19] Berg[19] recommends nonlagged (so as not to cause iatrogenic fracture propagation), medial-to-lateral bicortical fixation of these fractures to allow for an unrestricted rehabilitation protocol. Any remaining autograft bone after tibial and femoral tunnel reaming should primarily be grafted into the patella harvest site.

Fat Pad Compromise. During removal of the soft-tissue portion of the bone–patellar tendon–bone graft, the surgeon must avoid disrupting the fat pad as it attaches on the tendon. Aggressive removal of fat pad will lead to fluid extravasation and difficulty with visualization for the remainder of the arthroscopic procedure. Should this occur, the defect can be sutured or the case can be completed with "dry" arthroscopic techniques.[106]

Allograft Tissue

Allograft tissue is another commonly used graft choice with predictable excellent results.[8,61] Graft harvesting complications are virtually eliminated; however, the surgeon must be aware of potential pitfalls when using allografts. Disease transmission is an issue paramount to the patient and the surgeon. The American Association of Tissue Banks and the US Food and Drug Administration have set guidelines for tissue harvest and processing; however, multiple case reports from the Centers for Disease Control have demonstrated possible disease transmission.[30,31] Secondary sterilization with irradiation could conceivably eliminate viral vectors. A dose of 3 mrads (30 000 Gy) of gamma irradiation is necessary to sterilize fresh frozen allograft.[43] However, this dose causes significant mechanical and material deficiencies in allograft tissue[48]; therefore, irradiation at this dose as an effort to terminally sterilize the graft is not recommended. Despite the federal guidelines for allograft tissue banking and harvesting, the harvest, processing, and storage of allograft tissue continues to evolve.[115] The surgeon must be aware of the tissue bank used at his or her respective institution and be sure that appropriate precautions are taken during harvest and preservation to ensure that contaminated or mechanically compromised tissues are not used.[2] One should also be familiar with the specific terminal sterilization procedures for each graft type and tissue bank.

Graft construct mismatches can be a significant problem when using patellar tendon allografts, particularly if a graft from a tall donor is used for a smaller patient. The "n + 7" or "n + 10" rule[84] (add either 7 mm or 10 mm to the intra-articular tendon length) helps guide tibial tunnel length and guide settings. Salvage procedures for significant graft-construct mismatch are discussed in detail below. When utilizing bone–patellar tendon–bone allograft, it is advisable to inform your bone bank of the patient's height and provide tendon length parameters to reduce the likelihood of a significant graft-construct mismatch. Other allograft options (Achilles, tibialis anterior or posterior, and other soft-tissue grafts) do not present problems with graft-construct mismatch.

Intraoperative Contamination. Once a suitable graft has been obtained, great care must be taken to avoid contamination. The surgeon who performed the graft harvest should remain in possession of the graft and personally walk it to the back table in order to decrease the risk of dropping the graft. Molina et al[86] demonstrated a 58% incidence of positive cultures when an ACL was dropped on the operating room floor (and remained there for 15 seconds). They also found a 4% chlorhexidine gluconate soak for 90 seconds to be more effective in sterilizing grafts (2% positive culture) than bacitracin and polymyxin (6% positive culture) and 10% povidone-iodine solution (24% positive culture).[5,86] Another report on contaminated rabbit patellar tendon grafts found that a 30-minute soak in 4% chlorhexidine gluconate followed by a 30-minute soak in a triple antibiotic solution followed by a sterile saline wash was 100% effective in decontaminating grafts.[49] Washing the chlorhexidine from the graft is a crucial step as chondrolysis has been reported.[113] A survey of sports medicine specialists regarding their preferred method of managing contaminated grafts found that most would elect to clean the graft.[62] A total of 57 surgeons reported contaminated grafts and 43 elected to cleanse and salvage the original graft via a variety of cleansing techniques; 0 postoperative infections were noted.[62] Another option is choosing an alternative graft. This requires preoperative consent from the patient or intraoperative consent from a family member and may be problematic for a patient who expects a certain graft type but ends up with another. Some surgeons routinely consent their patients for the use of an allograft should the autograft become contaminated or otherwise compromised. Again, if this option is selected, preoperative discussion with the patient is best as cultural or religious beliefs may preclude the use of cadaveric tissue.

Graft Tunnel Placement

Proper placement of the graft remains paramount, with improper tunnel alignment a significant cause of technical failure.[7,64,65] Key points to remember include removal of any residual ACL tissue, adequate notchplasty, and anatomic referencing for the ACL origin. We prefer 10 mm of space between the lateral intercondylar wall and the lateral edge of the posterior cruciate ligament. Notchplasty is performed from anterior to posterior, working toward the over-the-top position, debriding past "resident's ridge."[5] Placing the tibial tunnel correctly helps ensure proper
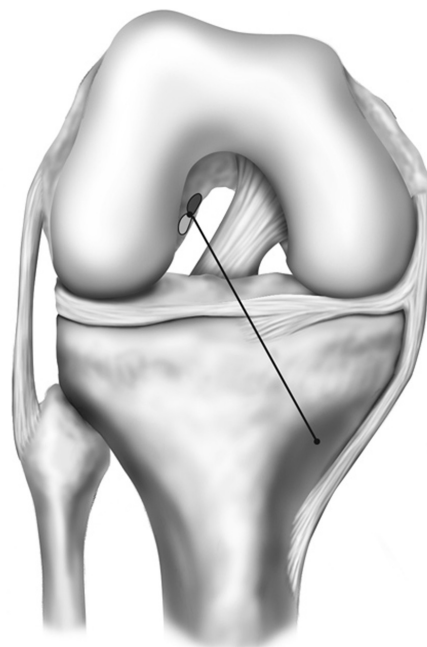

Figure 3. Illustration demonstrating influence of tibial tunnel position on femoral tunnel position.

femoral tunnel positioning as well, if retrograde transtibial drilling is performed (Figure 3). Positioning the variable-angle tibial aimer to exit at a point 3 to 4 mm posterior to the posterior edge of the anterior horn of the lateral meniscus places the new graft within the former ACL insertion site. Medial-to-lateral orientation must be checked to be sure one can place the femoral tunnel at the 10:00 to 10:30 position on the right knee or 1:30 to 2:00 on the left. The guide is set based on the n + 10 rule, by adding 10 to the tendinous graft length to set the guide in degrees (eg, 45 mm + 10 = 55°). This is a modification of the n + 7 rule advocated by Miller and Hinkin.[84] This assists in matching the graft and tunnel lengths.[84] The femoral tunnel should be drilled with the knee flexed between 80° and 90°. If extension is necessary to obtain the over-the-top position, the tibial tunnel may be too anterior,[5] risking graft impingement at the intercondylar notch.

Placing the femoral tunnel in a vertical orientation will result in a stable Lachman test, but a persistent pivot shift, as rotational stability has not been restored (Figure 4). In this setting, the surgeon is reconstructing the anteromedial bundle of the ACL, whereas the posterolateral bundle is more critical in controlling rotation.[44] This observation has resulted in the genesis of double-bundle ACL reconstruction. One must continually reassess the orientation of the camera to be sure the femoral tunnel will be low enough on the lateral intercondylar wall. Improper camera orientation can lead to a deceptive picture and an improperly positioned tunnel. Another method to ensure the tunnel is positioned correctly is to hold a long guidewire outside the knee in the proposed orientation to be sure the femoral tunnel is oriented correctly and not too vertical (Figure 5). The key principle is that it may be difficult to use a standard inferomedial portal for tibial aimer placement and achieve transtibial retrograde femoral tunnel placement that reconstructs at least a portion of the
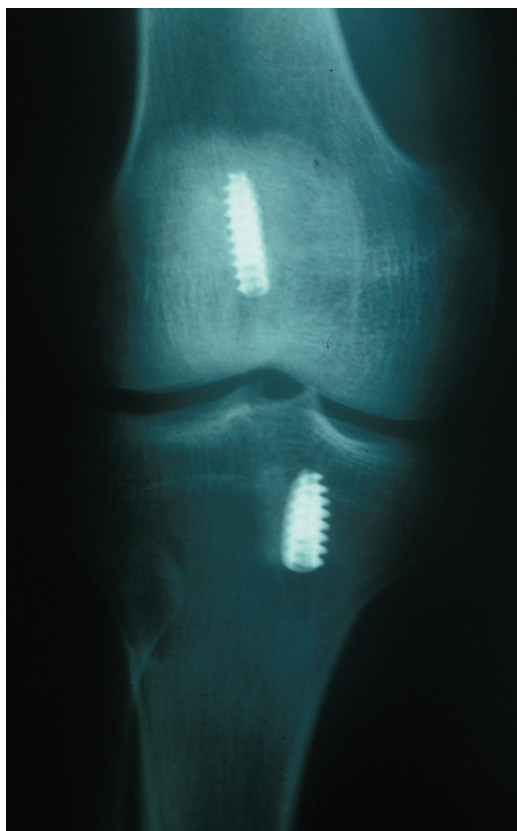
Figure 4. Vertical femoral tunnel. A vertical femoral tunnel can restore anterior to posterior stability, but will not restore rotational stability.

posterolateral bundle. However, if one places the tibial aimer through a transpatellar tendon portal, the aimer can more easily be rotated to achieve lower placement of the femoral tunnel on the intercondylar wall. Cadaveric studies from our institution (unpublished data) have shown that using this modification, a 10-mm femoral tunnel will fill approximately 60% of the posterolateral bundle and 40% of the anteromedial bundle, thus achieving a "hybrid" technique (Figure 6).

Graft Fixation

When using a bone-tendon-bone graft, fixation via a single-incision endoscopic technique places the graft at risk of laceration if care is not taken. The surgeon must be sure that no rotation of the soft-tissue portion of the graft occurs during screw placement. If the soft tissue is rotating, it could be wrapping around the screw, risking laceration. As with most complications in ACL surgery, prevention is key. The bone plug should be inserted with the cortex, and therefore the tendon, facing posteriorly, as this places the soft tissue at a reduced likelihood of injury during screw insertion. The surgeon can create a recess or notch anteriorly for the guidewire with a hemostat or curette. If the bone portion of the graft extends outside the intra-articular tunnel aperture, it can act as a skid to direct the guidewire into the tunnel parallel to the bone plug. The guidewire should be placed as parallel as possible to the femoral tunnel and be fully seated in the tunnel to optimize parallel screw placement.
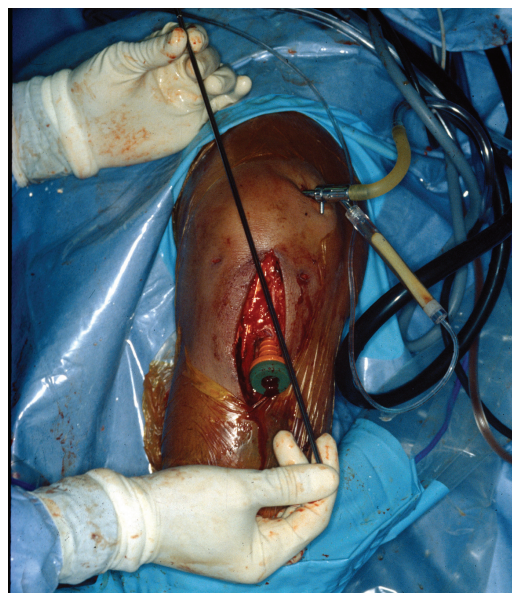

Figure 5. A guidewire placed externally anterior to the knee, demonstrating proper coronal orientation of the femoral and tibial tunnels.

Figure 6. Hybrid femoral tunnel placement. Illustration demonstrating how placement of femoral tunnel at the 10 o'clock position incorporates both the anteromedial and posterolateral bundles.

Additional flexion of the knee allows the wire to pass parallel to the bone plug. After placing the guidewire, the bone plug can be fully seated in the tunnel and any construct mismatch can be assessed. The screw is then inserted on the cancellous (anterior) side of the plug so that it is away from the tendon insertion. During screw placement, the tendinous portion of the graft must be continually visualized to be sure the fibers are not twisting. If the screw begins to twist the fibers of the graft, the surgeon should stop inserting it and remove the screw. During screw insertion, the guidewire has a tendency to shift clockwise (independent of left or right knee) as the screw is tightened. One should

reassess the insertion angle of the guidewire to be sure it has not moved away from the cancellous surface of the bone plug onto the tendinous graft. If necessary, the trough for the guidewire can be deepened to help prevent the wire from shifting off the cancellous surface. If the bone plug has been recessed into the tunnel, preventing the screw from contacting and potentially lacerating the graft becomes more difficult. One option is to use a graft protector (8-mm cannula) to protect the graft until the screw engages the bone block.

Graft Amputation

If graft amputation does occur, the surgeon has several options. Salvage is possible by converting to a 2-incision technique and using soft-tissue fixation after placing a Krackow suture.[3] In addition, the original graft can often be salvaged by removing the entire graft and reversing it.[18] The amputated graft becomes essentially a "pseudo quadriceps" or Achilles tendon graft, and the bone plug from the tibial side can then be placed on the femoral side. The tibial side can then be secured with a free bone block method.[89] This is performed by placing a Krackow or baseball whip stitch in the free end of the tendon, and 2 sutures in the free bone block to prevent it from being pushed into the joint. The bone block is placed on the anterior surface of the tendon and the graft with its free bone block is secured ("sandwiched"), using a standard interference screw (Figure 7). Additionally, the suture can be tied over a cortical or ligament button. If the amputation results in a tendon length that is too short to allow the free bone block technique, the tendon can be secured using a screw and post construct. Femoral soft-tissue suspension fixation is another viable option.

If amputation leads to a graft that is too short even for the options discussed above, the surgeon then must consider alternative graft choices. Allograft is an option with predictably good and excellent results,[8] but its use requires preoperative consent or intraoperative consultation with the patient's family members as some patients may have concerns that preclude the use of cadaveric tissue. In addition, a suitable allograft may not be available at the time of surgery. Converting to a hamstring or quadriceps tendon autograft is another option, although some patients may not consider an alternative graft an acceptable option when performed without explicit preoperative discussion. Furthermore, the potential increased morbidity of a double graft harvest on the same knee may be significant.

Posterior Wall Blowout

If a posterior wall "blowout" (Figures 8 and 9) occurs during tunnel reaming or screw placement, several salvage options exist. The likelihood of a blowout is increased by drilling the femoral tunnel with the knee in less than 70° of flexion. In single-incision endoscopic ACL reconstruction, initial reaming of the femoral tunnel to a depth of only 5 to 8 mm allows the surgeon to ensure the posterior wall is not compromised. The creation of a femoral footprint allows the surgeon to carefully inspect the back wall to ensure that 1 to 2 mm of posterior cortical rim remains (Figure 10). If compromise is noted at this depth, the knee
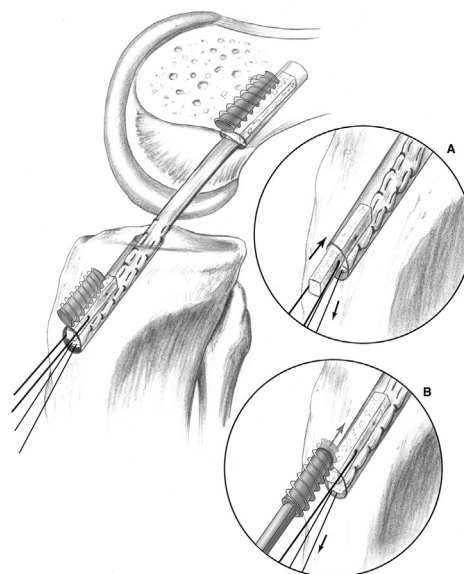

Figure 7. Tibial fixation with a free bone block method provides an option when encountering significant graft-construct mismatch. A, the free bone block is inserted anterior to the graft with tension placed on the sutures holding the graft. B, the interference screw is then placed anterior to the bone block. (Reprinted with permission from Bach BR Jr, Fox JA, Mazzocca AD. Revision ACL reconstruction. In: Grana WA, ed. Orthopaedic Knowledge Online. Rosemont, IL: American Academy of Orthopaedic Surgeons. Available at http://www5.aaos.org/OKO/menus/sports.cfm).
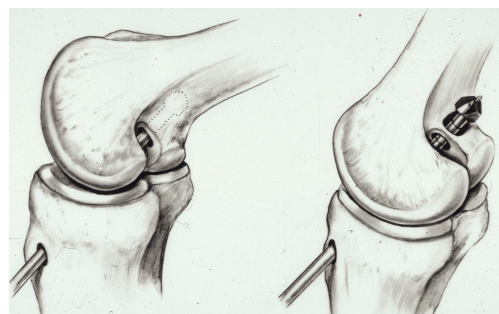

Figure 8. Femoral tunnel blowout. Illustration demonstrating how insufficient knee flexion can result in violation of the posterior femoral cortex.

can be further flexed and the tunnel redirected to allow proper placement and standard interference fixation.

The depth and circumference of compromise may vary from a short narrow opening to a tunnel with no posterior edge. If the compromise or blowout is noted past the 5-mm mark or involves a large circumference, several salvage options exist. One is to convert to an over-the-top graft passage and use screw and post fixation. Another option is to use femoral suspension fixation (eg, Endobutton [Smith & Nephew Endoscopy, Andover, Mass]) (Figure 11). This device is available with an option for bone-tendon-bone usage (Endobutton CL BTB). If that device is not available, high-strength No. 5 suture can be placed through transcortical
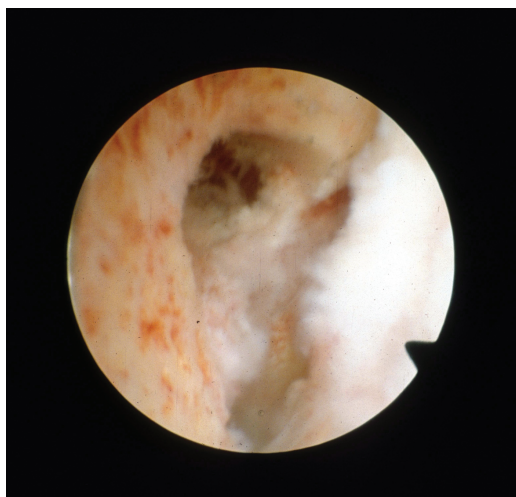
Figure 9. Femoral tunnel blowout: Arthroscopic image of posterior femoral cortical violation.
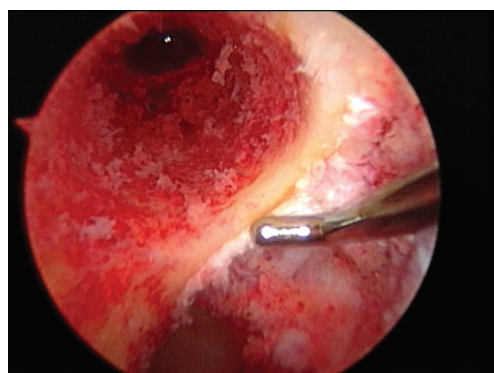

Figure 10. Endoscopic femoral footprint, confirming cortical integrity and a 1-mm to 2-mm femoral posterior cortical rim.

drill holes in the bone-tendon-bone graft and secured over a standard ligament button via a small lateral incision. Another option is to use the 2-incision technique and redrill the tunnel in an antegrade direction.[25]

Screw-Tunnel Divergence

Femoral screw-tunnel divergence has been identified as another potential problem in ACL reconstruction.[6,38,39,66,72,73,76,77,83,98] Potential problems include bone-plug fracture, loss of fixation, and even posterior femoral tunnel blowout. The integrity of the femoral fixation should be confirmed by the "rock" test, by applying enough load to the graft to "rock" the patient on the operating table, typically 20 to 30 pounds of force.[102] One should strive for parallel placement of the screw in the femoral tunnel. If using femoral interference screw fixation, several steps can be routinely performed to minimize screw divergence. Once the graft is positioned in the femur, it can be pulled retrograde into the joint a few millimeters, thus acting as a "skid" for the flexible wire over which an interference screw is placed. The knee should be further flexed to allow the wire to be advanced into the depths of the femoral tunnel. If the wire is inadequately positioned,
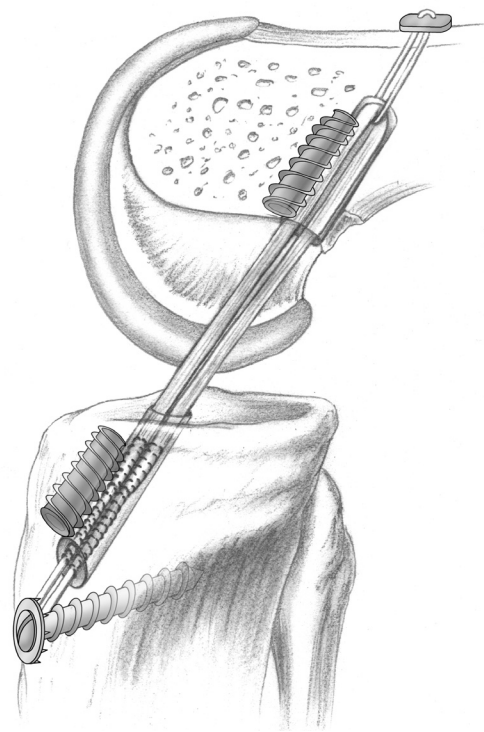

Figure 11. Femoral suspension fixation can be used with a deficient posterior wall. If the blowout is minor, suspension fixation can be augmented with interference fixation, as illustrated here. (Reprinted with permission from Bach BR Jr, Fox JA, Mazzocca AD. Revision ACL reconstruction. In: Grana WA, ed. *Orthopaedic Knowledge Online*. Rosemont, IL: American Academy of Orthopaedic Surgeons. Available at http://www5.aaos.org/OKO/menus/sports.cfm).

there is an increased likelihood of wire rotation, possibly leading to screw divergence, bone-plug fracture, wall blowout, or graft laceration. The knee should be flexed at least 80° during screw placement. This knee flexion angle accounts for the angle created between the tibial tunnel angle and the angle created by insertion of the screw through the inferomedial portal. An inferomedial accessory portal made under direct visualization with an 18-gauge spinal needle directly up the femoral tunnel diminishes the likelihood of screw divergence. Another technique is that of the 2-pin passer. This fenestrated device allows the guide pin to be pulled through the lateral cortex through the femoral tunnel, ensuring a parallel placement of the screw. The true clinical significance of screw-tunnel divergence is not known. Despite divergence noted radiographically, Dworsky et al[39] did not report clinical or arthrometric failures. They proposed that divergence with endoscopic screw insertion leads to a "wedge" effect, effectively blocking the plug from pulling out[39] (Figure 12). Biomechanically, 7-mm and 9-mm-diameter interference screws have comparable biomechanical pullout characteristics in the femur[22] but not in the tibia.[47] To reduce the chance of graft laceration, it is advisable to use a 7-mm-diameter interference screw on the femur. The tibial screw is generally a 9 mm diameter screw as fixation strength is better than a 7 mm diameter screw. It is generally 20 mm in length, but if the
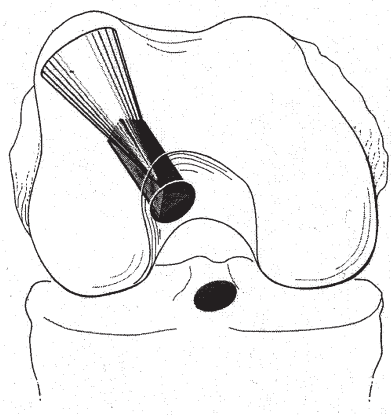
Figure 12. The wedge concept of endoscopic femoral screw placement. If the screw is placed divergently, it can act as a wedge, as the bone plug is pulled toward the screw. (Reprinted with permission from Dworsky BD, Jewell BF, Bach BR Jr. Interference screw divergence in endoscopic anterior cruciate ligament reconstruction. *Arthroscopy.* 1996;12:45-49).

graft is recessed within the tibial tunnel a longer screw is used to avoid burying the screw intraosseously.

Graft-Construct Mismatch

In the case of graft-tunnel mismatch using the bone–patellar tendon–bone graft, there are several options. While recessing the femoral tunnel is an option, this increases the likelihood of lacerating the graft as the screw encounters the soft-tissue component. In marked construct mismatches, femoral suspension fixation could be used to recess the graft even further to avoid the risk of graft laceration with an interference screw. Another option is rotating the graft up to 540°. This shortens it by approximately 5 to 6 mm, or 10% of its initial length.[116] Recent biomechanical data suggest that this rotation might place increased strain on the graft during cyclic loading[20]; however, the significance of this is unknown as adverse clinical outcomes have not been reported.[117]

For more significant mismatch, a free tibial bone block technique can be performed. In this technique, the tendon is sharply resected from the bone plug and a Krackow suture is placed in the tendon. After securing the femoral side of the graft, the bone plug is placed anterior to the soft tissue within the tibial tunnel while maintaining tension on the graft and the bone plug to prevent dislodgement. Interference screw fixation is then placed along the cortical edge of the plug.[89] Clinical results with this technique have been consistent with those of standard fixation.[7]

Another option is the "flipped patellar tendon" as advocated by Barber. In this scenario, the bone block can be flipped 180° back on the tendon to shorten the construct length. Excellent results have been reported with this technique.[13]

Graft Tensioning and Tibial Fixation

No clear consensus exists on the amount of tension or the position of the knee during final graft fixation. It is clear, however,

that tensioning the graft with the knee in flexion may lead to decreased range of motion as the graft effectively captures the knee, preventing full extension.[4] Failure to fully examine the knee and cycle it after graft tensioning and fixation may lead to a flexion contracture. Authors have recommended tensioning with the knee in 10° to 30° of flexion.[56,114] Tensioning the graft in full extension under axial compression with approximately 20 to 30 pounds of force ensures that the knee will achieve full extension without excessive stress on the graft.[5,27,87] For bone-tendon-bone grafts, the graft can be rotated prior to tibial fixation in order to shorten the graft and orient the cortical surface of the bone plug anteriorly. The interference screw is placed anteriorly on the cortical plug surface. Cancellous-to-cancellous fixation is biomechanically superior to cortical-to-cancellous fixation.[105]

MINIMIZING POSTOPERATIVE COMPLICATIONS

Postoperative complications include infection, loss of motion, graft failure, patellar pain, and patella fracture, among others. With the advent of routine preoperative antibiotics (typically a cephalosporin or clindamycin in penicillin allergic patients), postoperative septic arthritis is fortunately an uncommon complication, with an incidence less than 1%.[23,78,122] Matava et al[75] surveyed sports medicine fellowship directors and subsequently recommended culture-specific antibiotics and surgical irrigation with graft retention as initial treatment. Graft and hardware removal was recommended only for persistent infection or an infected allograft. The earliest recommended time for revision reconstruction was 6 to 9 months.[75] More recently, Burks et al reported on the successful revision reconstruction of 4 patients with postoperative septic arthritis treated with immediate graft removal and reimplantation within 6 weeks of completion of antibiotics.[23,35,121] We have successfully salvaged grafts in 5 patients with arthroscopic irrigation and debridement with 40 to 50 L of lavage while maintaining an early active motion protocol.

Postoperative deep venous thrombosis and pulmonary embolism are major concerns in orthopaedics. Fortunately, the reported incidence in knee arthroscopy and ACL reconstruction is low and routine prophylaxis remains controversial.[35,121] The senior author's (B.R.B.) experience includes 1 nonfatal pulmonary embolus in over 1800 ACL reconstructions. Our protocol includes obtaining a careful family and patient history, early mobilization, and the use of sequential compression devices in any patient with risk factors (ie, obesity, smoking history, positive family history, oral contraceptive usage). Furthermore, in all our patients we strongly encourage early mobilization and recommend a daily aspirin if no contraindications exist. A universally accepted algorithm to prevent deep venous thrombosis and pulmonary embolism has yet to be fully defined for ACL surgery.

Postoperative Rehabilitation

Rehabilitation protocols have evolved markedly over the past several decades, with a realistic goal of return to activity at 4 to 6 months postoperatively. Full weightbearing and immediate mobilization are encouraged. The classic works of Noyes

et al[91] and Shelbourne and Gray[107] in the 1980s and 1990s demonstrated the adverse effects of early postoperative immobilization and no increase in complications from an accelerated rehabilitation protocol. More recently, Beynnon et al[21] confirmed these observations in bone–patellar tendon–bone autograft patients in a prospective, randomized, double-blind comparison of 2 rehabilitation protocols. They reported no differences in clinical assessment, patient satisfaction, or functional performance between a 19-week (accelerated) or a 32-week (nonaccelerated) program. Howell and Taylor[59] demonstrated successful return to full activity of Air Force personnel at 4 months after surgery using hamstring autografts. A recent randomized clinical trial indicated that a minimally supervised physical therapy program can result in improvements over an extended supervised program in recreational athletes.[51]

Continuous Passive Motion

With the advent of outpatient ACL reconstruction and an accelerated rehabilitation protocol, continuous passive motion (CPM) usage has generally fallen out of favor. Continuous passive motion machines were eliminated from our rehabilitation protocol in 1993. Our annual reoperation rate is 1% to 2% for symptomatic knee flexion contractures since transitioning to outpatient ACL surgery in 1994. This is less than when our patients used CPM for either 1 day or 3 days postoperatively (unpublished data, 1986-1993). One could give consideration to CPM usage for patients more prone to motion problems postoperatively, such as those with a history of arthrofibrosis or those undergoing concomitant microfracture.

Bracing

Postoperative bracing can be either rehabilitative or functional. Rehabilitative braces are hinged and allow controlled motion in the sagittal plane to protect the knee during simple exercises. Functional braces, on the other hand, are designed to limit aberrant motion during exercise.[80] No randomized controlled trials have been able to demonstrate superiority of a braced rehabilitation protocol over a nonbraced one in bone-tendon-bone autograft-reconstructed patients.[81,101] Our standard protocol for bone-tendon-bone autograft involves a rehabilitation brace in the early postoperative period to protect the donor site and to promote extension. While bracing is not likely needed to protect the graft,[81] one can consider a hinged brace, locked in extension for ambulation in order to protect the extensor mechanism should a fall occur, especially during winter months when snow and ice can be a danger. The patient removes the brace for range of motion exercises and during physical therapy sessions. The brace is discontinued at 6 weeks postoperatively. Functional bracing can be added for associated MCL injuries.[80]

Motion Problems

Successful early return to function does not indicate that complications concerning motion will not arise in the postoperative period. Motion needs to be diligently monitored and any failure to progress must be treated aggressively.

Figure 13. Prone hangs with ankle weights to encourage full extension.

In general, most motion problems can be identified within 2 to 3 weeks postoperatively. Current concepts encourage extension splinting, prone heel hangs (Figure 13), patellar mobilization, early quadriceps activation, and early weightbearing.

Improperly positioned tunnels are the usual culprit in a patient with motion problems. If the graft has been optimally placed, loss of extension is generally related to a scar within the intercondylar notch, whereas loss of flexion usually is related to a scar within the gutters and/or within the suprapatellar pouch. Nonoperative treatment consists of nonsteroidal anti-inflammatory drugs, intra-articular steroids, oral steroids (Medrol Dosepak), and ensuring patient compliance with a supervised physical therapy program.[34] This program should include an extension board, prone hangs with ankle weights, quadriceps activations, patellar mobilization, and modalities to reduce hemarthrosis. If a patient is struggling with recovery of extension, it is advisable to monitor the patient more frequently; we will see patients on a weekly basis if needed. Use of an extension brace at night may be helpful. Should nonoperative modalities fail, arthroscopic resection of the scar followed by casting or bracing in full extension has demonstrated predictable improvements in motion.[54,108] This is typically not indicated before 6 to 12 weeks.

Loss of patellar mobility can lead to range of motion deficits as well. The risk of infrapatellar contracture syndrome can be reduced by correct technical performance of ACL reconstruction as well as therapist-directed patellar mobilizations in all directions and avoiding forceful, painful manipulations.[97] Quadriceps activation is critical. Electrical stimulation has been shown to be beneficial in enhancing return of quadriceps function following ACL reconstruction.[110] Another factor in avoiding postoperative motion loss is management of hemarthrosis. Significant effusions can inhibit quadriceps activation via affect neural activity leading to a quadriceps-avoidance gait pattern and motion loss.[58] Since 1994, we have performed all of our ACL reconstructions on an outpatient basis, and routinely evaluate patients in the office setting on the first postoperative day in order to evaluate the knee, change the primary dressings, remove and replace Steri-strips to reduce the likelihood of traction blisters, perform an arthrocentesis if necessary, and reinforce early motion goals.[80]

Figure 14. Transverse patella fracture. Plain radiograph of a postoperative patellar fracture.

The best treatment for symptomatic motion loss is prevention.[34,54,108] As discussed earlier, proper preoperative patient rehabilitation and selection is an important factor. In addition, appropriate postoperative management and early recognition of motion problems can facilitate return to function without deficits.

Tunnel Widening

Although often clinically silent, radiographic evidence of tunnel widening after ACL surgery is a well-documented phenomenon. Both mechanical and biologic factors affect the development of widened tunnels. Widening has not been demonstrated to affect stability clinically in the short term; however, the long-term relationship is unknown. Tunnel expansion complicates revision surgery, possibly necessitating a staged procedure with bone grafting of the tunnels. In order to reduce the likelihood of tunnel widening, authors have advocated aperture fixation to reduce mobility of the graft in the tunnel, emphasized proper tunnel placement, and called for rehabilitation protocols that allow for sufficient graft incorporation.[123] Certainly aperture fixation is an attractive idea, but one must consider that deeply positioned tibial screws may complicate screw removal in a revision situation.

Extensor Mechanism Macrotrauma

Postoperative fractures occur with 1 of 2 possible mechanisms. A direct blow results in an impaction injury with the fracture being stellate or Y-shaped, while rapid eccentric

Figure 15. Bone-chip collector. Significant amounts of cancellous bone can be harvested during reaming of the tibial tunnel for grafting the patellar defect.

quadriceps contraction, which may occur as the result of a fall, typically results in a transverse fracture pattern (Figure 14). Patella fractures are rare, with large series reporting only 3 in 1320 patients[118] and 8 in 2300.[16] Our experience is similar, with 1 postoperative fracture in over 1700 bone-tendon-bone autograft ACL reconstructions. Bone grafting the patellar defect aids in restoring patellar stability as the graft incorporates. One can use a cannulated bone-chip collector during reaming of the tibial tunnel and make a concerted effort to collect reamings from the femoral tunnel as well[40] (Figure 15). These are then grafted in the patellar defect. In 1 study, the incidence of patellar pain was higher in nongrafted patients up until 2 years postoperatively.[74] In addition, protecting the extensor mechanism in the early postoperative period is beneficial.

Rigid fixation to allow early mobilization is the recommended treatment for most isolated patella fractures,[85] as well as for patella fractures in the postoperative period after ACL reconstruction. Nonoperative treatment and treatments requiring extended immobilization should be reserved for those patients unwilling or unable to undergo surgery, or a fracture pattern that cannot be rigidly fixed. Once a patella fracture occurs, the short-term rehabilitation goals for the patient should be altered in order to enhance the likelihood of long-term success. Fracture healing without displacement is critical. A variety of fixation methods exist. Tension-band fixation has been reported with successful results[118]; however, as reported in the trauma literature, 22% of patients treated with tension-band wiring and early motion had displacement of ≥2 mm, and over 10% of patients will require hardware removal due to overlying irritation from the wire.[109] Other options include cannulated screw fixation, with or without a tension-band augment, or bicortical (superior to inferior) small or large fragment screw fixation. Biomechanical testing of a modified tension band compared to either 4.5-mm screws or an anterior tension band placed through 4.0-mm cannulated screws showed the cannulated screws and tension band to be the strongest construct.[29] No matter which method is selected, the surgeon must achieve reduction of the articular surface with stability throughout range of

TABLE 4
Criteria for Return[a] to Unrestricted Activity[80]

Full range of motion
Quadriceps strength >85% of contralateral side
Hamstring strength 100% of contralateral side
Appropriate muscle balance with hamstring to quadriceps
  strength ratio of >70%
Single-legged hop distance and times single-legged hop over
  20 feet within 85% of contralateral side
Side-to-side difference of <3 mm on KT-1000 arthrometer testing

[a]Too early a return may compromise graft healing and the success of anterior cruciate ligament reconstruction.

motion. Once the fracture is reduced and stabilized, the knee must be taken through a range of motion to ensure no displacement is noted prior to closure. Postoperatively, the patient is allowed protected progressive range of motion in a brace, but weightbearing is allowed only in full extension. In addition, the brace should be locked in extension during sleep to help reinforce extension recovery. Beginning at the first postoperative visit, range of motion can begin from 0° to 30°, with a goal of 0° to 90° by 6 weeks. Aggressive, forceful flexion, even in supervised therapy, must be avoided until fracture consolidation is noted radiographically. The patient should be thoroughly counseled to ensure the protocol is followed, as noncompliance is associated with fixation failure.[109] Hardware need not be routinely removed,[24] but if symptomatic, it can be removed after the fracture is healed and ACL rehabilitation is complete. The keys to avoiding an intraoperative patella fracture are to avoid larger bone plugs, minimize crosscuts that can act as stress risers, avoid deep cuts that might violate the articular surfaces, avoid levering the graft with osteotomes, and backfilling the defects with bone graft obtained at graft harvest or during tibial tunnel creation. Postoperatively, it is important not to overload the patella in the first 6 to 8 weeks.

Patellar tendon disruptions are similarly rare, with 3 senior knee surgeons at our institution having 1 in over 3000 ACL reconstructions. Aggressive surgical care of this complication, followed by a modified rehabilitation protocol to ensure tendon healing, should result in an excellent outcome. Once again, careful surgical technique at the time of graft harvest is essential. Interestingly, despite harvesting the central third of the patellar tendon, it is universally noted that the patellar tendon width postoperatively is wider than the contralateral patellar tendon width.[112]

Return to Sport and Work

Anterior cruciate ligament reconstruction allows patients a predictable opportunity to return to an active lifestyle. Determining the appropriate time to allow participation in sporting and work activities can be difficult given the lack of objective, scientific studies outlining return-to-play guidelines. Timetables for return have varied from 4 months to 1 year. The process of graft healing, incorporation, and the return of the patient's proprioceptive abilities and muscle strength is multifactorial. Our criteria are outlined in Table 4.

Anterior cruciate ligament reconstruction achieves consistently good and excellent results provided preoperative, intraoperative, and postoperative complications are avoided or corrected. Unlike other areas of orthopaedics,[53] ACL reconstruction in the workers' compensation population does not appear to result in inferior outcomes.[120] A functional capacity evaluation and/or a work-hardening program can be beneficial in the workers' compensation population as the worker prepares to return to full duty.

CONCLUSION

Anterior cruciate ligament reconstruction provides patients with a predictable opportunity to return to full function and sporting activities. However, as with any surgical procedure, complications can and do arise. The recognition of complications begins with a thorough clinical history and physical examination in order to identify any preoperative factors that may lead to a suboptimal outcome. Intraoperatively, it is imperative to understand the common pitfalls associated with ACL reconstruction and to have an appropriate bailout strategy should they arise. A heightened awareness of the common postoperative complications leads to prompt treatment and improved outcomes. As the number of surgically reconstructed ACL injuries continues to rise, it is imperative that we understand and recognize the complications that may occur in the care of the ACL-deficient patient. Hopefully, through the recognition and use of sound ACL complication management strategies, our overall rate of failed ACL reconstructions will continue to decrease.

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