

Posterior Wall Blowout in Anterior Cruciate Ligament Reconstruction

A Review of Anatomic and Surgical Considerations

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Violation of the posterior femoral cortex, commonly referred to as posterior wall blowout, can be a devastating intraoperative complication in anterior cruciate ligament (ACL) reconstruction and lead to loss of graft fixation or early graft failure. If cortical blowout occurs despite careful planning and adherence to proper surgical technique, a thorough knowledge of the anatomy and alternative fixation techniques is imperative to ensure optimal patient outcomes. This article highlights anatomic considerations for femoral tunnel placement in ACL reconstruction and techniques for avoidance and salvage of a posterior wall blowout.

Keywords: ACL; ligament; complications; ACL reconstruction; tunnel placement

Symptomatic tears of the anterior cruciate ligament (ACL) requiring surgical intervention are commonly encountered in young, active patients. However, with the increasingly active nature of the athletic and aging population, the demand for surgical treatment of the unstable knee has extended beyond the young athlete. It is estimated that 200,000 ACL reconstructions (ACLRs) are performed each year in the United States.²⁸

With the upsurge in surgical intervention, a heightened awareness of potential complications and causes of surgical failure arises. The sources of ACLR failure can be generally grouped into 3 categories: failure caused by surgical technique, those caused by failure of biological healing, and those resulting from postoperative trauma.³⁸ Of these, only technical failures can be prevented at the time of surgery, and therefore, avoidance strategies have been heavily documented in the literature. The most common reported technical error encountered in ACLR is tunnel

malposition, and specifically, inappropriate femoral tunnel placement. Anatomic tunnel placement in ACLR is crucial for sagittal stability and rotational control of the injured knee. Recent literature has demonstrated that tunnel malposition is a common cause of both intraoperative complications and graft failure after ACLR.^{1,4,7,10,30,42}

While femoral tunnel malposition in an anterior location can result in rotational laxity or graft impingement, a posteriorly placed femoral tunnel may result in immediate deleterious consequences such as a breach of the posterior femoral cortex and consequent lack of femoral graft fixation. Similarly, overreaming of the femoral tunnel can result in cortical violation at the lateral aspect of the lateral femoral condyle. These posterior or lateral cortical breaches lead to loss of graft containment and subsequent difficulty with graft fixation (Figure 1). If this intraoperative error is not promptly recognized and appropriately treated, the graft is at an increased risk of premature failure.^{10,20,38} Thus, in these situations, recognizing the complication and knowing strategies for alternative or salvage fixation are of paramount importance.^{8,17,18,20,37} The purpose of this article was to review the appropriate anatomic location and depth for femoral tunnel placement, strategies to avoid tunnel blowout, and salvage options in the setting of femoral cortical violation.

ANATOMY OF THE ACL FOOTPRINT AND FEMORAL TUNNEL POSITION IN ACLR

The first and most critical step to avoid complications such as femoral cortical violation is anatomic placement of the

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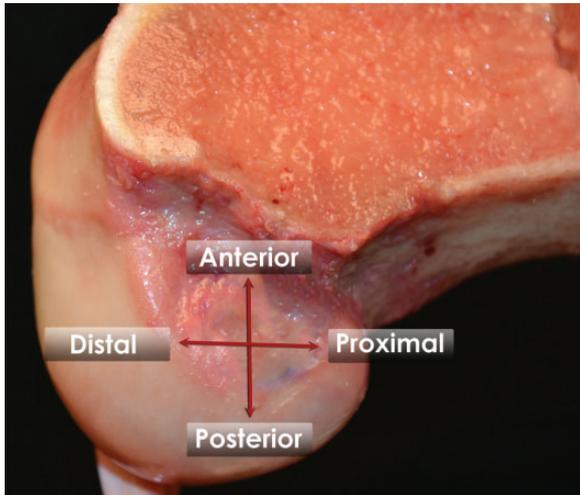


Figure 1. View of a right knee with the medial femoral condyle and intra-articular ligamentous structures removed (hemisectioned). The center of the cross represents the anatomic location for anterior cruciate ligament reconstruction, and reference orientation of tunnel location outside of the anatomic position is shown with the knee flexed to 90°.

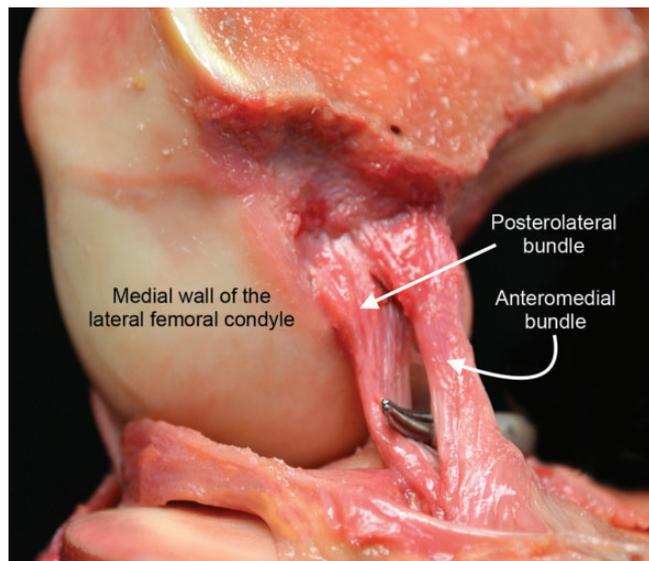


Figure 2. View of a right knee with the medial femoral condyle removed (hemisectioned). The anteromedial and posterolateral bundles of the anterior cruciate ligament are visualized in their anatomic location.

femoral tunnel. Knowledge of the anatomic position of the ACL on the femur is crucial to planning reconstructive surgery of the ligament and for avoidance of complications.²⁹ The femoral attachment site of the ACL is described as oval-shaped and is divided into 2 distinct bands based on the tibial attachment sites: the anteromedial (AM) and the posterolateral (PL) bundles.⁴⁴ Both bundles are similar in size at the femoral insertion. These bundles attach

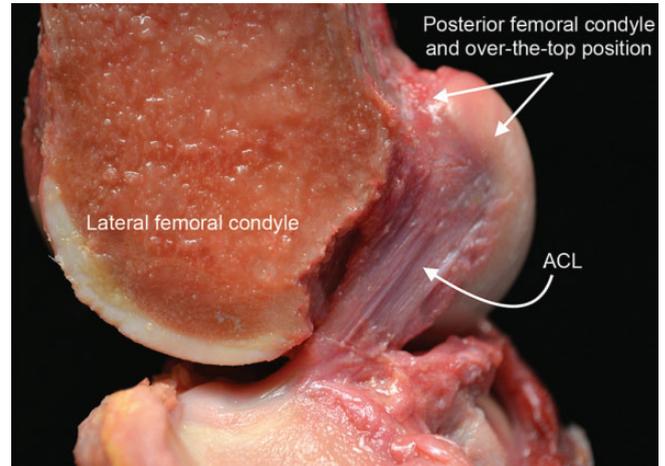


Figure 3. View of a right knee with the medial femoral condyle removed. With the knee in extension, the anatomic position of the anterior cruciate ligament (ACL) related to the over-the-top position can be seen.

proximally at the posterior aspect of the medial wall of the lateral femoral condyle (Figure 2).

The AM bundle attaches proximally and posteriorly to the PL bundle on the femur, and together these bundles create an attachment oriented with the long axis of the femur, measuring approximately 18 mm in length and 11 mm in width, closely abutting the articular cartilage margin posteriorly.^{29,33,36} The center of this insertion is located proximal and posterior to the bony lateral intercondylar ridge (LIR), coined “resident’s ridge” by Clancy¹¹ in the late 1990s, approximately 15 mm distally from the “over-the-top position.”^{23,36,39} This position has historically been described as the junction between the posterior aspect of the femoral shaft and the most proximal portion of the lateral femoral condyle (Figure 3).^{2,24}

A thorough understanding of the anatomy is crucial, as Hensler et al¹⁹ reported that only 61% of the femoral native insertion is restored with standard tunnel reaming. The overall ACL attachment center is 6.1 mm posterior to the LIR, 1.7 mm proximal to the bifurcate ridge, 14.7 mm proximal to the distal cartilage margin, and 8.5 mm anterior to the posterior cartilage margin.⁴⁴ The footprint of the AM bundle is approximately 52% of the total femoral ACL insertion area, and that of the PL bundle is approximately 48%.⁴⁰ The AM bundle femoral attachment center is 7.1 mm posterior to the LIR, 4.8 mm proximal to the bifurcate ridge, 18.6 mm proximal to the distal cartilage margin, and 11.7 mm anterodistal to the proximal point. The PL bundle attachment center is 3.6 mm posterior to the LIR, 5.2 mm distal to the bifurcate ridge, 10.7 mm proximal to the distal cartilage margin, and 5.7 mm anterior to the posterior cartilage margin.⁴⁴ Slight variations in the size may exist depending on the age, sex, or size of the patient.

Although a great amount of literature exists regarding ACL tunnel positioning, it has been reported that between 10% and 40% of tunnel placements in ACL reconstructions are malpositioned,²¹ comprising the main reason for ACL

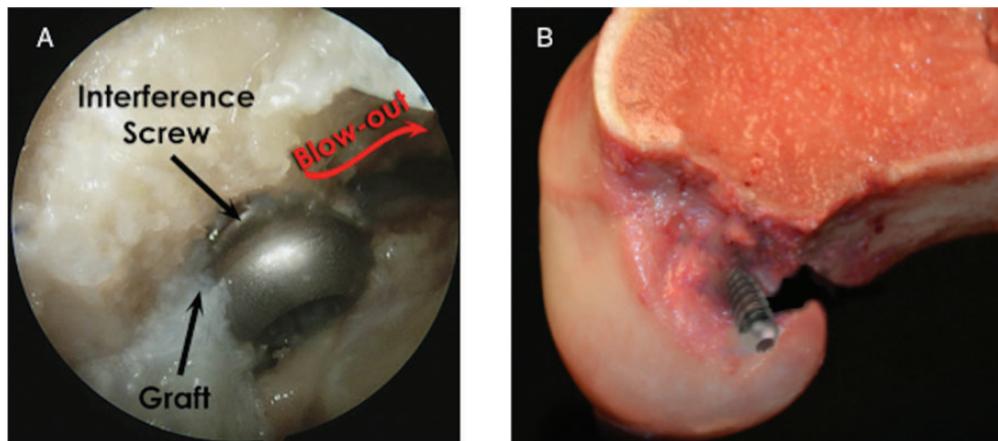


Figure 4. (A) Intraoperative arthroscopic view of an interference screw adjacent to a cortical wall blowout as viewed through the anteromedial portal. (B) View of the medial wall of the lateral femoral condyle with the medial condyle removed. This image demonstrates a representation of a cortical wall blowout similar to that seen arthroscopically.

revision surgery in as many as 52% of cases.⁹ The high rate of tunnel misplacement can be attributed to the position of the portals, the degree of flexion during identification of the footprints, anatomical variation, or arthroscopic image distortion.^{5,22}

An important concept to understand is the variation of the anatomical femoral attachments as the knee flexion angle changes. Of note, knee flexion angle has been assumed to be the most influential and modifiable factor affecting the arthroscopic view, and therefore, accurate placement of the femoral tunnel.²¹ The optimal knee flexion angle to determine femoral tunnel placement has been reported to be 90° because the ACL footprint can be more accurately reproduced with the knee in this position than in a hyperflexed state.^{5,21} However, femoral drilling in a more hyperflexed position (110°-120°) after identification of appropriate tunnel location allows for the lateral femoral condyle to acquire a lower and shallower position in the arthroscopic view. Therefore, there is less risk of blowing out the posterior wall of the lateral femoral condyle, creating a tunnel with insufficient length, or damaging the lateral structures.^{6,22,34,36}

The most accurate anatomic landmark for arthroscopic ACL reconstruction is the native ACL remnant. However, in a revision or chronic injury setting, ACL remnants might not be evident. Therefore, for the femoral tunnels in a transportal ACL reconstruction, the over-the-top position and the LIR remain the most reliable osseous landmarks.⁴⁰ Thus, an offset guide can be inserted through an accessory anteromedial portal to place the tunnel anterior to the posterior margin of the femoral condyle.³¹ A motorized burr or an awl can be used demarcate the desired area of the tunnel entrance. With regard to the ideal lateral femoral condyle clock-face position, it differs among surgeons and has not shown to be a reliable method.^{31,32} As an alternative means for identifying the location of the ACL, Bernard et al⁶ previously reported on a “quadrant method” for describing the center of the femoral insertion site of the ACL by utilizing conventional radiographs. They divided the intercondylar fossa into 4 quadrants, noting that the center of the

attachment is 24.8% of the distance from the intersection of the Blumensaat line and the contour of the lateral femoral condyle on lateral radiographs and 28.5% of the height of the lateral femoral condyle from the Blumensaat line. In anatomic terms, this means that the center of the ACL is localized from the posterior border of the lateral femoral condyle at approximately 25% of the entire sagittal diameter of the condyle and from the roof of the notch at approximately 25% of the notch height. However, more recent literature has suggested that the location described by Bernard et al⁶ actually represents the insertion of the AM bundle,^{14,15,36,41,43} and a systematic review by Piefer et al³⁵ suggested that based on the available literature, the center of the ACL femoral footprint is located 43% of the proximal-to-distal length of the lateral femoral intercondylar notch wall and an anterior distance from the posterior articular margin equaling the sum of the femoral socket radius plus 2.5 mm.

After positioning a guide pin in the desired femoral location, a 10-mm reamer is typically utilized to create a closed socket tunnel. Proper sizing of the tunnel, however, is determined by the dimensions of the chosen graft. Attention should then be turned to the position of the reamer in relation with the femoral wall because oblique positioning of the reamer can create an oval-shaped entrance to the tunnel. With the knee in 90° of flexion, the reamer is used to “score” a footprint of the anticipated tunnel on the inner aspect of the posterolateral notch.³ The reamer is then backed up enough to allow direct visual confirmation of an adequate posterior wall prior to drilling the remainder of the tunnel. If the tunnel appears too far posterior, this can be easily corrected with repositioning of the guide pin, thereby preventing a posterior wall blowout.

CAUSES OF FEMORAL CORTICAL VIOLATION AND TECHNIQUES FOR AVOIDANCE

Understanding the causes and common locations of femoral cortical violation is of utmost importance to

prevent this complication. Blowout can occur distally at the aperture of the tunnel near the medial aspect of the lateral femoral condyle (Figure 4), within the tunnel just proximal to the aperture, or more proximally at the lateral margin of the tunnel.^{17,18,20,37,38} Specific technical maneuvers and arthroscopic views can prevent and identify loss of femoral containment at each of these locations.

Improper surgical technique remains one of the most common sources of failure of primary ACL reconstructions.^{1,10,28,30,38,42} Although careful surgical planning and knowledge of pertinent anatomical landmarks are key to prevent unexpected intraoperative complications, breach of the posterior or lateral cortex during reaming of the femoral tunnel remains one of the most challenging situations to properly address. Without thorough evaluation of the integrity of the femoral tunnel and posterior wall of the lateral femoral condyle, this complication can remain unrecognized and therefore place the graft at greater risk of failure due to loss of fixation or altered biomechanics.¹⁶

There have been a number of reported causes of posterior wall blowout in the literature.^{17,18,38} To avoid this complication, exposure of the posterior wall is the first step in proper tunnel placement. Inadequate visualization due to a lack of removal of the surrounding soft tissues and preparation of the posterolateral notch may preclude the surgeon's ability to place an offset guide or guide pin in the correct position. Once the notch is fully visualized, the recommended minimum distance of 1.5 to 2 mm of a posterior wall should be calculated into the offset guide and added to the planned tunnel radius.³ For this purpose, a simple calculation can be performed by dividing the desired femoral tunnel diameter in half (which equals its radius) and adding 2 for the thickness of the posterior wall.^{3,37}

It is very important, however, that the knee is placed in at least 90° of flexion while drilling as stated above. The reported likelihood of blowout is increased if the knee is in less than 70° of flexion during creation of the femoral tunnel.^{1,20,38} Therefore, if the knee is not maintained in flexion throughout the drilling process, an intratunnel blowout may occur proximally. This is often characterized by an intact cortical rim at the notch with a compromised posterior wall within the tunnel more proximally.^{3,38}

The methodology by which the femoral tunnel is created is also important to consider for avoidance of cortical violation. Transtibial tunnel drilling allows for a deeper femoral tunnel, while creation of the femoral tunnel through an accessory medial portal typically yields a shorter or shallower tunnel.²⁰ This shorter tunnel can predispose the surgeon to drilling through the entire thickness of the lateral femoral cortex in an attempt to create a deep enough socket to fully contain the graft, especially in revision ACL reconstruction cases where bone may have been removed previously. As a result, surgeons utilizing the accessory medial portal technique must critically evaluate tunnel positioning by direct visualization from the anteromedial and anterolateral arthroscopic portals and tunnel depth both during and on completion of reaming and to ensure integrity of the tunnel.

Once the proper starting point has been obtained by ensuring a sufficient posterior wall and anatomic position, drilling of the tunnel is performed using an appropriately sized reamer over a guide wire. Initial scoring of the bony surface or reaming of the tunnel to a depth of 5 to 6 mm followed by retraction of the reamer from the tunnel and critical evaluation of the tunnel location allows the surgeon to carefully examine the posterior wall to ensure a rim remains intact.⁸ Regardless of the technique chosen, careful evaluation of the femoral tunnel during reaming is critical. As mentioned earlier, initial scoring of the medial wall of the lateral femoral condyle ensures that 1 to 2 mm of posterior cortex remains intact as reaming is initiated. However, to evaluate for and to avoid intratunnel cortical compromise, it is also beneficial to ream to a depth of approximately 10 mm and withdraw the reamer to allow for visualization of the tunnel. The surgeon may then complete reaming of the femoral tunnel and similarly withdraw the reamer to allow careful inspection of the tunnel. This can be accomplished by placing the arthroscope at the medial aperture of the femoral tunnel through the medial portal or by passing the arthroscope in a retrograde fashion up the tibial tunnel to completely visualize the tunnel and posterior wall to confirm an intact bony circumference.

SURGICAL MANAGEMENT OF FEMORAL CORTICAL VIOLATION

In the event that femoral cortical violation occurs during ACLR, several salvage options are available to allow for successful completion of the surgery.

Continue With Planned Fixation

When the posterior femoral cortex has been breached and the complication is immediately recognized, it may be possible to continue with planned suspensory (soft tissue grafts) or interference screw fixation (bone-tendon-bone [BTB] grafts) if the cortical defect is minimal. It is important to note that this technique can be technically challenging, as even a small posterior wall violation can make appropriate graft fixation difficult, and attempts at correcting the tunnel trajectory may lead to nonanatomic graft placement, convergence or widening of the tunnels, or further posterior wall blowout. As a result, continuing with planned fixation should be considered only in cases of very early recognition and when the tunnel can be fully evaluated. A posterior cortical breach that does not extend beyond 3 to 5 mm from the entrance of the tunnel may be salvaged by slight anterior redirection of the reamer and continuation of deeper reaming followed by fixation as planned.^{3,38} Prior to continuation of reaming, however, a probe should be used to assess and confirm the degree of blowout.^{3,13} If posterior wall blowout is found to be substantial, as defined by extending beyond 5 mm, one of the techniques in the following sections should be considered.

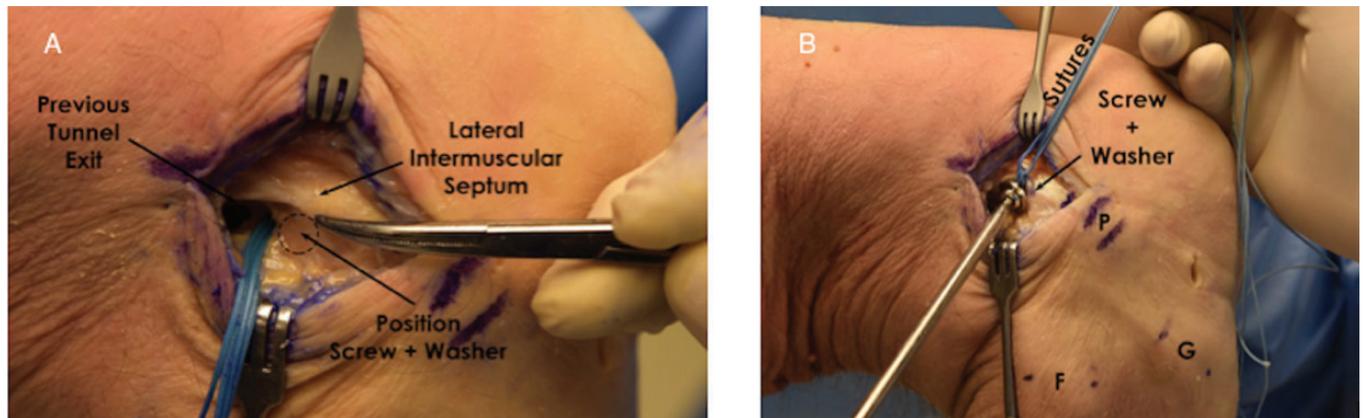


Figure 5. (A) Dissection of the lateral aspect of the distal femur with exposure of the anterior cruciate ligament (ACL) tunnel and planned location for placement of a screw and washer post for suspensory cortical fixation. (B) Securing of the ACL graft to the lateral femoral cortex utilizing a screw and washer construct. F, fibular head; G, Gerdy tubercle; P, proximal insertion of the fibular collateral ligament.

Suspensory Cortical Fixation With Screw and Washer Post

If the posterior wall blowout is significant such that planned fixation cannot be safely completed, suspensory fixation utilizing the lateral femoral cortex may be used. These fixation methods are beneficial because they do not require an intact posterior cortex. Our preferred methodology for ACL graft fixation after substantial posterior or lateral femoral cortical blowout is conversion to fixation utilizing suture suspension around a screw and washer post. The benefit of this technique is the versatility for use in all locations of cortical violation and the ability for use in both soft tissue and BTB grafts. Furthermore, the instrumentation required for this technique is available at most centers without the requirement for specialized surgical equipment.^{12,25}

A longitudinal incision is made over the distal lateral femur centered on the lateral supracondylar ridge, and the iliotibial band is incised such that the vastus lateralis muscle can be elevated subperiosteally off of the lateral femur. The femoral tunnel is exposed on the posterolateral aspect of the femur, and a partially threaded 4.5-mm cancellous screw is placed through a washer approximately 1 cm anterodistally to the femoral tunnel (so the pressure is shifted to the anterior aspect of the tunnel), near the metadiaphyseal flare of the femur. The screw length should be long enough to ensure appropriate fixation, and a partially threaded screw is chosen to allow for a smooth surface around which the suture or umbilical tape can be tied without cutting or fraying. It is important to place the screw posterior to the lateral intermuscular septum to avoid iliotibial band friction symptoms (Figure 5).

The sutures connected to the ACL graft are shuttled through the femoral tunnel under direct visualization and are secured around the screw and washer. To strengthen the construct, 2 sutures are passed through each side of the screw and firmly tied to the screw. The sutures should be

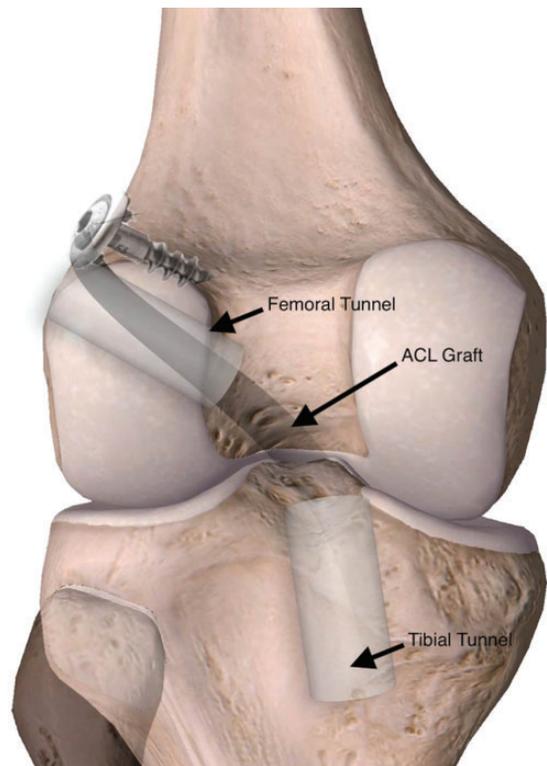


Figure 6. Representative image of the posterior aspect of a left knee after suspensory cortical fixation using a screw and washer post after posterior wall blowout at the time of anterior cruciate ligament reconstruction surgery.

adjusted to ensure appropriate graft-tunnel match on both the femur and tibial side. The screw is then secured such that the washer compresses the sutures against the lateral femoral cortex. Standard tibial fixation can then proceed as previously planned (Figure 6).

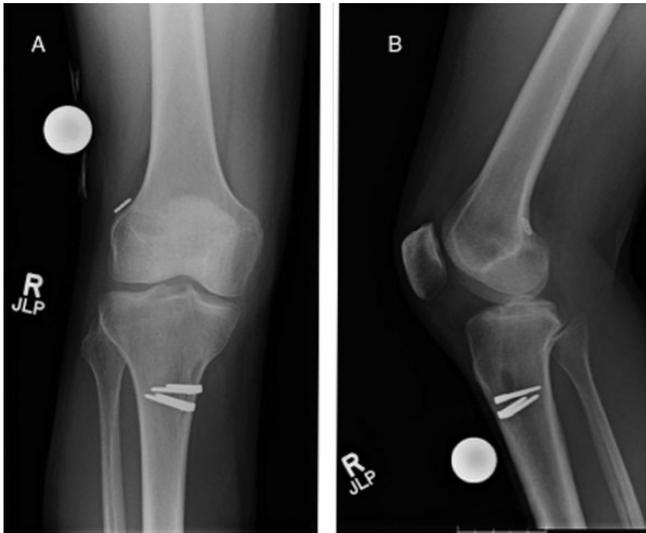


Figure 7. Radiographic (A) anteroposterior and (B) lateral images of a right knee after anterior cruciate ligament reconstruction with posterior wall blowout salvaged with suspensory fixation utilizing a cortical button.

Suspensory Fixation With Cortical Button

Commercially available cortical suspension devices can be utilized for both soft tissue and BTB grafts; however, to obtain maximal fixation from these type of devices, medial and lateral tunnel integrity is required.^{12,20,25} While providing ease of use in salvage situations, these devices are limited in their utility if the lateral femoral cortex is breached with the reamer. Femoral tunnels are typically reamed to a diameter of at least 7 mm to accommodate graft passage, and this is approaching the upper limit of length available for standard cortical fixation in most devices. In these situations, specialized extended cortical suspension buttons are available in lengths up to 20 mm (XtendoButton; Smith & Nephew Endoscopy) (Figure 7). The benefit of these devices is that the original graft can still be used, indeterminate of whether it was a BTB graft or a soft tissue graft, as there are also BTB-specific devices available.^{12,25,27}

However, if BTB-specific devices are unavailable, 1 or 2 drill holes may be placed through the bone plug, and large nonabsorbable sutures are passed through the drill holes and secured to the bone plug.³⁸ The suspensory device is then secured to the other end of the sutures so that it may be secured to the lateral femoral cortex. When calculating the required length, it is necessary to add the tunnel depth to the length of the suspensory fixation device to ensure there is enough length to flip the device after it passes through the tunnel.³

Hybrid Fixation: Suspensory Plus Interference Screw

In addition to suspensory fixation, hybrid fixation has been described for potential use when posterior wall blowout occurs.^{17,18,20} Simply, this is a combination of

suspensory fixation with the addition of an interference screw. In a biomechanical study using a porcine model, Herbort et al²⁰ demonstrated superior mechanical fixation with the use of hybrid fixation compared with suspensory fixation alone when the posterolateral cortex was penetrated with a 7- to 9-mm drill. However, a biomechanical study by Hammond et al¹⁸ suggested that when the cortical defect is 8 mm or less, the addition of an interference screw does not provide increased fixation. This method of fixation is similarly limited in that the posterior cortex must remain intact and the tunnel violation must be small enough to accommodate the length of suspensory button fixation.

Over-the-Top Fixation

Another option for femoral ACL fixation when posterior wall blowout occurs is over-the-top fixation. This is performed by creating a small incision on the lateral femur, slightly proximal to the lateral epicondyle. Next, the ilio-tibial band is incised and dissection is extended down to the posterolateral femur. The intermuscular septum is dissected to create a posterior passage to the intercondylar notch. The ACL graft is then fixed to the femur with screw and post fixation or staples.^{3,8}

It is important to note that this fixation technique is not ideal for BTB grafts because the graft may not be of adequate length to reach the posterolateral femoral cortex. If BTB is the only graft available, it can be secured with a technique similar to posterior cruciate ligament tibial inlay fixation. The graft is placed in the breached femoral tunnel and a posterolateral approach is used to secure a 3.5-mm cortical screw into the graft.³⁸

This technique has historically been used with success in skeletally immature patients with reasonable outcomes; however, there are limited data on the outcomes in skeletally mature patients.²⁶ More extensive dissection is also required to reach the posterior position of the graft, and the graft is placed in a nonanatomic position outside of the femoral footprint.

Two-Incision Technique

Alternatively, a 2-incision technique can be used. This is performed by making an incision on the lateral femur, similar to the over-the-top technique. After dissecting down to the lateral femoral cortex, a femoral guide is used to create a second (divergent) tunnel with a guide pin and then over-reamed. This second tunnel is typically placed more lateral³ and/or anterior³⁸ than the first attempted tunnel. The tunnel should be directed to exit intra-articularly at the center of the ACL femoral footprint.³⁸

DELAYED DIAGNOSIS OR REVISION SURGERY

As has been noted in prior sections, careful intraoperative examination of both the placement and integrity of the femoral tunnel is imperative for successful ACLR. If these steps are not followed, a diagnosis of posterior wall

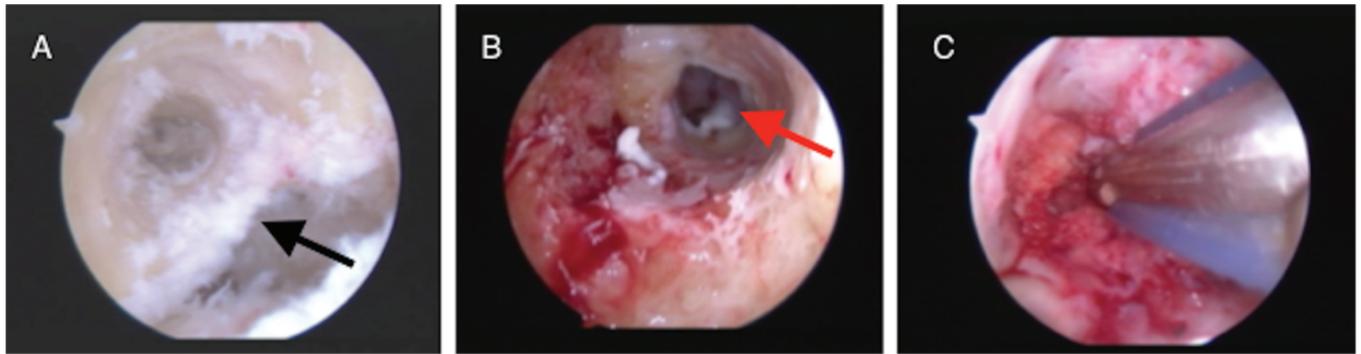


Figure 8. Arthroscopic images of a right knee during a revision anterior cruciate ligament reconstruction viewing through the anteromedial portal. (A, black arrow) Posterior wall and (B, red arrow) lateral wall blowout is seen. (C) This complication is managed in a revision setting with cancellous bone grafting.

blowout may not be immediately recognized. This may later be discovered on postoperative radiographs, revealing a femoral interference screw located in the subcutaneous tissues in the posterior aspect of the knee.

In these situations, it is imperative to disclose the complication to the patient and perform a careful examination. If the knee remains clinically stable, it may be reasonable to continue to follow the patient closely. Modification of the rehabilitation protocol to limit stress on the ACL graft may also be considered.³⁸ Advanced imaging with computed tomography or magnetic resonance imaging can identify the bony anatomy in cases where the integrity of the tunnel is in question. Revision ACLR surgery utilizing the aforementioned techniques should be undertaken in those patients with persistent instability or a complete loss of graft fixation.

In some situations of revision ACLR, the previously placed femoral tunnel may be found to have violated the femoral cortex due to osteolysis (widening) of greater than 12 mm or misplacement. When the femoral tunnel is widened to such an extent that it cannot be utilized for a single-stage ACL revision, a bone grafting procedure of the femoral tunnel with 2-stage revision reconstruction is warranted (Figure 8). This technique is beneficial in that it allows for replacement of the tunnel in native bone to a more anatomic position at a later surgery.

If the tunnel is significantly misplaced and found to have either intratunnel or lateral cortical breach, it may be possible to place a biocomposite screw in the original tunnel to fill the defect. The revision femoral tunnel can then be placed in a more anatomic position with reaming of a new tunnel over a small portion of the screw. If there is significant convergence of tunnels such that a large portion of the screw is violated, the remaining intact screw fixation may not provide adequate tunnel integrity, and other techniques should be considered.

CONCLUSION

While complications in ACLR can cause deleterious outcomes for patients, careful planning and understanding

of the surgical anatomy can limit technical pitfalls. When complications such as femoral cortical violation do occur, prompt recognition and knowledge of salvage techniques are imperative to ensure successful completion of the procedure. If substantial cortical violation is noted, we recommend utilization of one of the described techniques (our preferred method is the cortical fixation with the screw and washer) to achieve stable ACL graft fixation.

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