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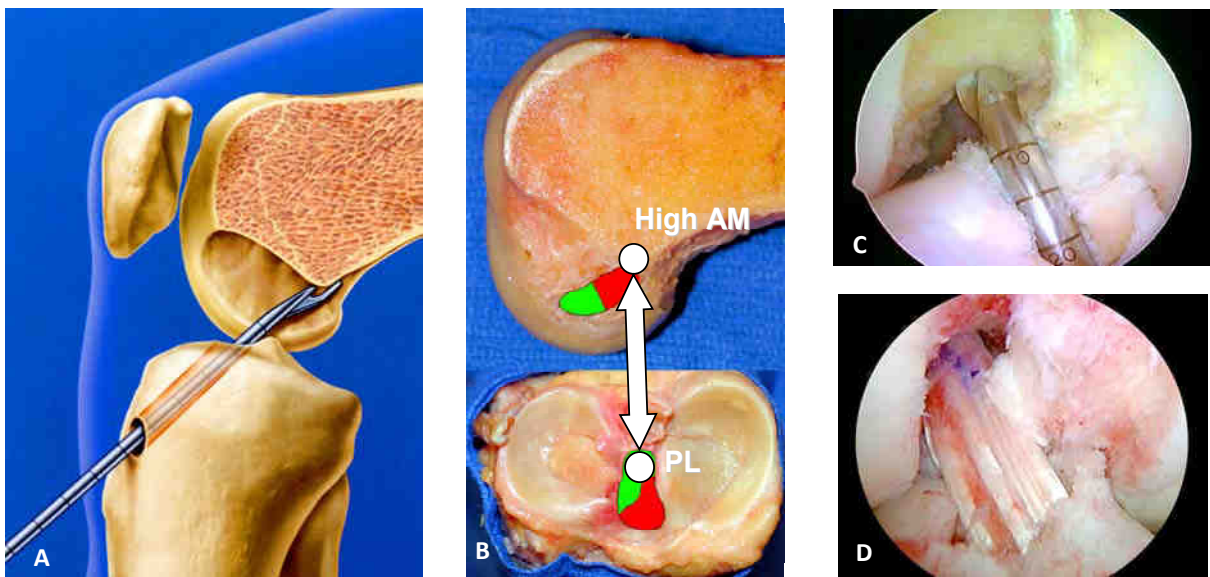
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## Medial Portal Technique for Single-Bundle ACL Reconstruction

### Introduction

Anatomic placement of an anterior cruciate ligament (ACL) graft is critical to the success and clinical outcome of ACL reconstruction. Anatomic ACL graft placement is defined as positioning the femoral and tibial bone tunnels of the ACL reconstruction at the center of the native ACL femoral and tibial attachment sites. Clinical studies have demonstrated that non-anatomic ACL graft placement is the most common technical error leading to recurrent instability following ACL reconstruction.<sup>1-2</sup> ACL reconstruction has been commonly performed using a transtibial technique in which the ACL femoral tunnel is drilled through a tibial tunnel positioned in the posterior half of the native ACL tibial attachment site. In the transtibial technique, positioning the ACL tibial tunnel in the posterior half of the ACL tibial attachment site is dictated by the need for the endoscopic drill bit to reach the region of the ACL femoral attachment site and the desire that the ACL graft avoid impingement against the roof of the intercondylar notch when the knee is in full extension. However, the resulting ACL femoral tunnel is often positioned too high and deep in the intercondylar notch, lying outside the native ACL femoral attachment site (Figure 1).

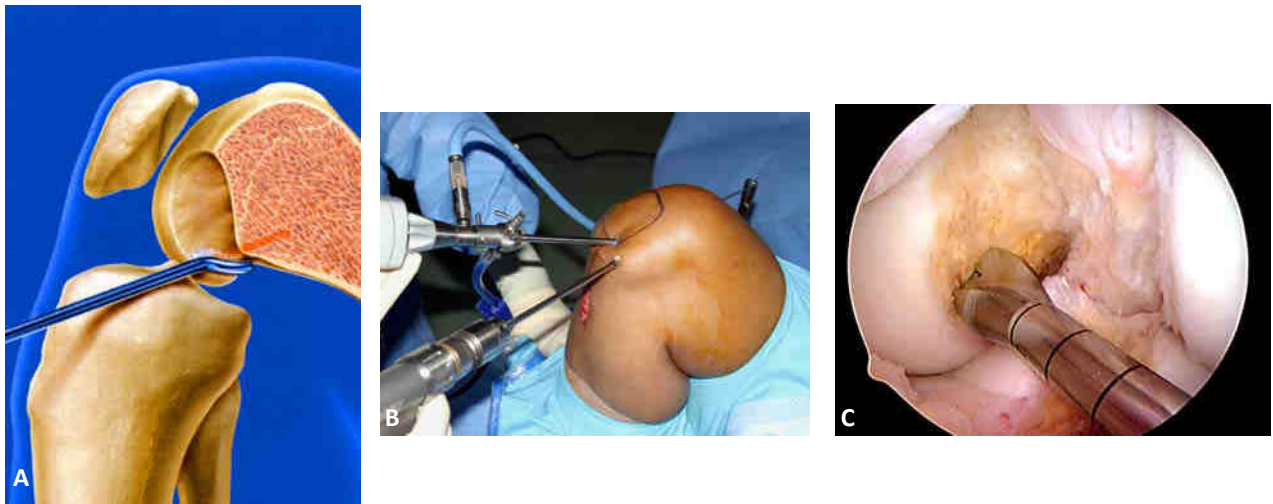
An ACL graft positioned at a posterior tibial and a high-deep femoral attachment site will be vertically oriented in both the coronal and sagittal planes. Biomechanical studies have shown that a vertically oriented ACL graft may resist the motion of anterior tibial translation, but may fail to control the combined motions of anterior tibial translation and internal tibial rotation which occur during the pivot-shift phenomenon.<sup>3</sup> The inability of a vertically oriented ACL graft to control these combined motions may result in the patient experiencing continued symptoms of instability and giving-way episodes due to the pivot-shift phenomenon.



**Figure 1** Transtibial tunnel technique. (A) The femoral guide pin is drilled using an ACL femoral offset aimer inserted through a tibial tunnel positioned in the posterior half of the ACL tibial attachment site. (B, C) Drilling the femoral tunnel drilled through a posteriorly positioned tibial tunnel results in a femoral tunnel positioned

high relative to the native ACL femoral attachment site. **(D)** An ACL graft positioned in a posterior tibial and high femoral tunnel results in a non-anatomic "vertical" AC

The medial portal technique for endoscopic drilling of the ACL femoral tunnel was first developed to address the issues of ACL graft laceration, violation of the posterior wall of the ACL femoral tunnel, divergence of ACL femoral interference screws, and tunnel-graft-length mismatch associated with bone-patellar tendon-bone autograft ACL reconstructions performed using the transtibial technique. In the medial portal technique described in this paper, the ACL femoral tunnel is drilled through an accessory anteromedial (AAM) portal with the knee flexed to 120° or higher (Figure 2)



**Figure 2** Medial portal technique. **(A)** The knee is hyperflexed and the ACL femoral tunnel is drilled through a medial portal. **(B)** The knee is hyperflexed with a 30° arthroscope positioned in the anteromedial (AM) portal. The ACL femoral tunnel is drilled through a low accessory anteromedial (AAM) portal. **(C)** View through the AM portal with the knee in hyperflexion. The ACL femoral tunnel is drilled into the center of the ACL femoral attachment site through a low AAM portal.

This approach provides several advantages compared to the traditional transtibial technique:

1. The ACL femoral tunnel is drilled independently of the tibial tunnel, which allows for consistent placement of the femoral tunnel within the native ACL femoral attachment site.
2. The angle of the ACL tibial tunnel does not have to be compromised to accommodate drilling of the ACL femoral tunnel. Therefore, the surgeon can opt to drill a steeper and thus longer tibial tunnel. A longer tibial tunnel minimizes the potential for graft-tunnel length mismatch and allows longer bone-tendon-bone graft constructs to be utilized.
3. Although guides are available, the medial portal technique does not require any special guides or instrumentation.
4. Inserting an ACL femoral interference fixation screw through the same medial portal which was used to drill the ACL femoral tunnel minimizes screw-tunnel divergence.
5. The medial portal technique provides improved arthroscopic visualization during ACL femoral tunnel drilling since the femoral tunnel can be drilled under ideal arthroscopic conditions, without the loss of joint distention due to fluid extravasation out of the tibial tunnel.

Similar to any surgical technique, there is a learning curve to the medial portal technique for ACL reconstruction. Surgeons making the transition from the transtibial to the medial portal technique may experience some unique issues and challenges not normally encountered when performing an ACL reconstruction using the transtibial technique. In the medial portal technique, the knee must be flexed to 120° or higher when a rigid guide pin and drill bit are used to drill the ACL femoral tunnel (Figure 3). Hyperflexion is necessary to avoid having the femoral guide pin exit the lateral soft tissues too posteriorly. The peroneal nerve is at risk when the femoral guide pin exits the lateral soft tissues in a too posterior position. Alternatively, the knee may be positioned at 90° of flexion and the ACL femoral tunnel drilled using flexible reamers.

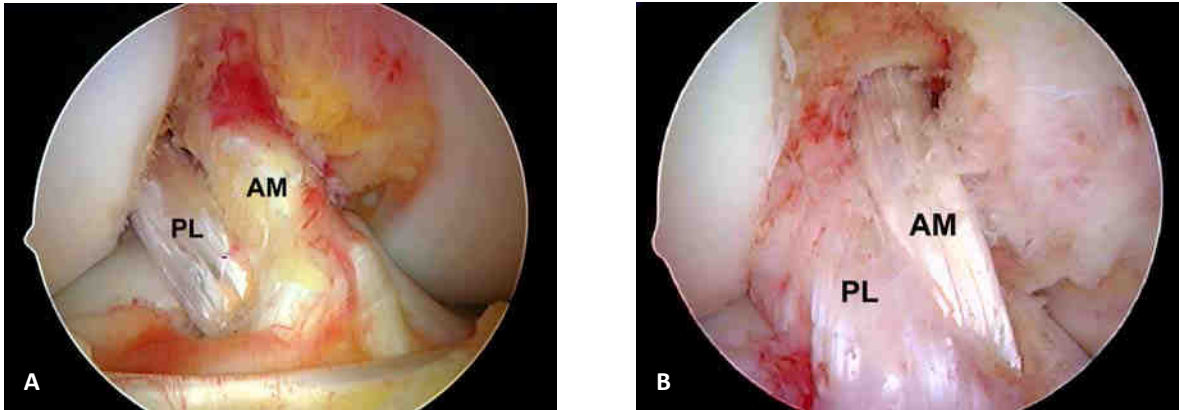


**Figure 3** The right knee is positioned in hyperflexion during drilling of the ACL femoral tunnel. The drilled-tip femoral guide pin exits the lateral soft tissues in the mid-thigh region, and is thus directed away from the peroneal nerve and posterior neurovascular structures.

Drilling the ACL femoral tunnel in hyperflexion can potentially compromise arthroscopic visualization and lead to spatial disorientation in the notch compared to drilling at the more familiar 90° of knee flexion. Other potential problems that can result from drilling the ACL femoral tunnel in hyperflexion include: (1) difficulty passing the endoscopic reamer over the guide pin due to the medial portal tightening in hyperflexion; (2) difficulty visualizing the endoscopic reamer due to the reamer dragging the fat pad into the notch; (3) difficulty advancing the endoscopic reamer over the guide wire due to a bend or kink in the guide pin. Drilling the ACL femoral tunnel through a medial portal which is placed too close to the medial femoral condyle can result in iatrogenic injury to the articular cartilage of the medial femoral condyle. Unless special attention is paid to proper portal placement and positioning the knee in hyperflexion while drilling the ACL femoral tunnel, the medial portal technique can result in a short ACL femoral tunnel length which may limit the amount of soft tissue graft inserted into the ACL femoral tunnel when using a cortical femoral fixation device such as the Endobutton continuous loop (CL). With attention to detail, all of these potential issues and challenges can be overcome.

#### **Indications and Contraindications**

The medial portal technique is versatile and can be used with any ACL graft type and for any primary, revision, single- or double-bundle ACL reconstruction. The medial portal technique is particularly useful in the situation where only one of the ACL bundles is torn and the surgeon wishes to preserve the remaining intact ACL fibers and augment the injured posterolateral (PL) or anteromedial (AM) bundle (Figure 4).



**Figure 4 (A)** Isolated PL bundle reconstruction. **(B)** Isolated AM bundle reconstruction

In the situation of revision ACL surgery, the medial portal technique often allows a new anatomic ACL femoral tunnel to be drilled away from a previous non-anatomic vertical femoral tunnel. This may eliminate the need to remove the original ACL femoral fixation hardware and can bypass a malpositioned or enlarged ACL femoral tunnel, thus avoiding the need for bone grafting of the original femoral tunnel and a two-stage revision (Figure 5).



**Figure 5** Anteromedial portal view at 90°. Failed ACL reconstruction. Cause of failure: Non-anatomic ACL femoral tunnel placement. Surgical technique: Transtibial. The old ACL femoral tunnel is located high above the anatomic ACL femoral attachment site. A new anatomic ACL femoral tunnel was drilled through an accessory anteromedial portal bypassing the original non-anatomic femoral tunnel.

The only contraindication to the medial portal technique when using rigid guide pins and drill bits is the inability to flex the knee to at least 120°. This limitation may be encountered in some obese patients, in which case consideration should be given to drilling the ACL femoral tunnel using an outside-in technique or using flexible reamers.

#### **Patient Positioning**

It is important to have the ability to achieve full, unrestricted knee flexion during the procedure. The requirement to achieve at least 120° of knee flexion can sometimes present problems when a circumferential leg holder is used, and the foot of the operating room table flexed down. Keeping the operating room table flat and using a thigh post and one or two foot rests allows full unrestricted knee flexion and facilitates performing the procedure.

1. Apply a thigh-length anti-embolism stocking and a foam heel protector to the nonoperative leg.



2. Place a padded pneumatic tourniquet high on the operative leg. It is rarely used during the procedure as adequate joint distention and visualization can be obtained using an infusion pump.
3. Attach a padded thigh post and padded lateral hip positioner to the operating room table at the level of the pneumatic tourniquet. The padded lateral hip positioner stabilizes the patient's pelvis and the padded thigh post supports the thigh and acts as a fulcrum during the application of valgus stress to open the medial compartment (Figure 6A).
4. Attach a padded L-shaped foot rest to the rail clamp along the operative side of the operating room table. Adjust the position of the distal foot rest to maintain the knee between 70 - 90° of flexion during most of the procedure (Figure 6B).
5. Place a second foot rest just proximal to the popliteal fossa and adjust it to maintain the knee in hyperflexion during drilling of the ACL femoral tunnel (Figure 6B, C). Place the patient's foot under the proximal foot rest to maintain the hyperflexion position while drilling the femoral tunnel (Figure 6C). With the knee in extension, the relative height of the two foot rests can be adjusted such that the knee can be maintained at a known flexion angle during tensioning and fixation of the ACL graft (Figure 6D).



**Figure 6A** The patient's pelvis is stabilized on the operating table by the lateral hip positioner and thigh post.



**Figure 6B** Distal foot rest is adjusted to maintain 70 - 90° of knee flexion.



**Figure 6C** Proximal foot rest is adjusted to maintain hyperflexion during drilling of the ACL femoral tunnel.

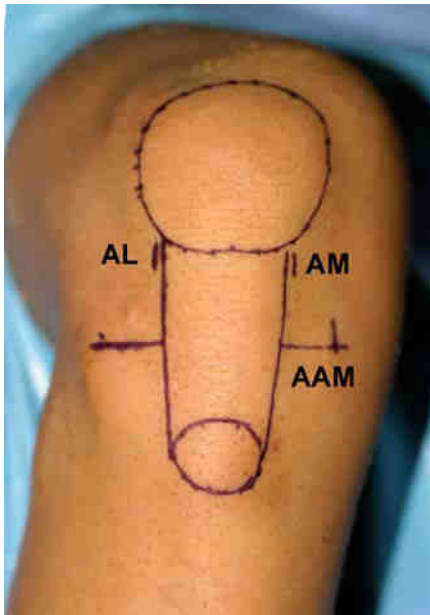


**Figure 6D** The proximal and distal foot rest can be adjusted to maintain the desired degree of knee flexion during graft tensioning and fixation.

### Portal Placement

Proper portal placement is critical to the success of the procedure. ACL reconstruction using the medial portal technique is facilitated by using three arthroscopic portals (Figure 7):

- The **anterolateral (AL) portal** - used as a viewing portal to perform diagnostic arthroscopy and meniscal surgery
- The **anteromedial (AM) portal** - used as both a working and viewing portal
- The **accessory anteromedial portal (AAM)** - used as a working portal to insert instrumentation into the notch and for drilling the ACL femoral tunnel.



**Figure 7** Three arthroscopic portals and their relationship to the inferior pole of the patella, medial and lateral borders of the patellar tendon, and the medial and lateral joint lines. AL high anterolateral portal, AM high anteromedial portal, AAM low accessory anteromedial portal.

The use of three portals provides the following advantages:

1. The additional medial portal allows the ACL femoral attachment site to be viewed through the AM portal, while working instrumentation is inserted into the notch through the AAM portal. As will be discussed later, viewing through the AM portal is the preferred method to visualize the ACL femoral attachment site.
2. Drilling the ACL femoral tunnel through an AAM portal increases the obliquity of the ACL femoral tunnel relative to lateral wall of the notch, resulting in a longer femoral tunnel length and a more elliptical ACL femoral tunnel aperture compared to drilling the femoral tunnel through the AM portal.

### Establish the Anterolateral Portal

Establish a high AL portal at the level of the inferior pole of the patella, as close as possible to the lateral border of the patellar tendon using a #11 knife blade. A high AL portal places the arthroscope above the widest part of the fat pad, minimizing interference of the visual field in the intercondylar notch when the knee is placed in hyperflexion. A high AL portal also provides a better, "look down" view of the ACL tibial attachment site.

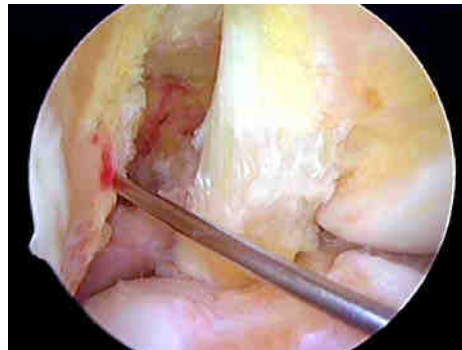
### Establish the Anteromedial Portal

Establishing the AM portal at the correct height above the medial joint line is extremely important to the success of the procedure. Placing the AM portal too close to the medial joint line will lead to instrument crowding when the AM and AAM portals are used simultaneously during notch preparation and ACL femoral tunnel drilling

1. Place a 30° arthroscope in the AL portal and perform a diagnostic arthroscopy.
2. With the knee flexed between 70 - 90°, establish the AM portal under direct visualization using an 18-gauge spinal needle.
3. Insert the spinal needle into the knee joint as close as possible to the medial border of the patellar tendon. Direct the spinal needle towards the intercondylar notch, adjusting the height of the spinal needle above the medial joint line as needed to ensure that it comes to lie parallel to the roof of the intercondylar notch.
4. Typically, the spinal needle is located at the height of the inferior pole of the patella or slightly higher. Placing the spinal needle at this level results in adequate spatial separation between the AM and the AAM portal which is created later and also results in the AM portal lying above the fat pad. The spinal needle position is too low if it enters the knee joint below the level of the roof of the intercondylar notch or passes through the fat pad. Placing the AM portal too close to the medial joint line will result in the arthroscope passing through the fat pad and will place the AM and AAM portals too close together. This will result in the fat pad being dragged into the visual field by the tip of the arthroscope and instrument crowding when the AM and AAM portals are used simultaneously to view the ACL femoral attachment site and drill the ACL femoral tunnel.
5. Insert a motorized shaver blade into the knee joint through the AM portal and resect the ligamentum mucosum. This step will release the fat pad and expose the intercondylar notch.

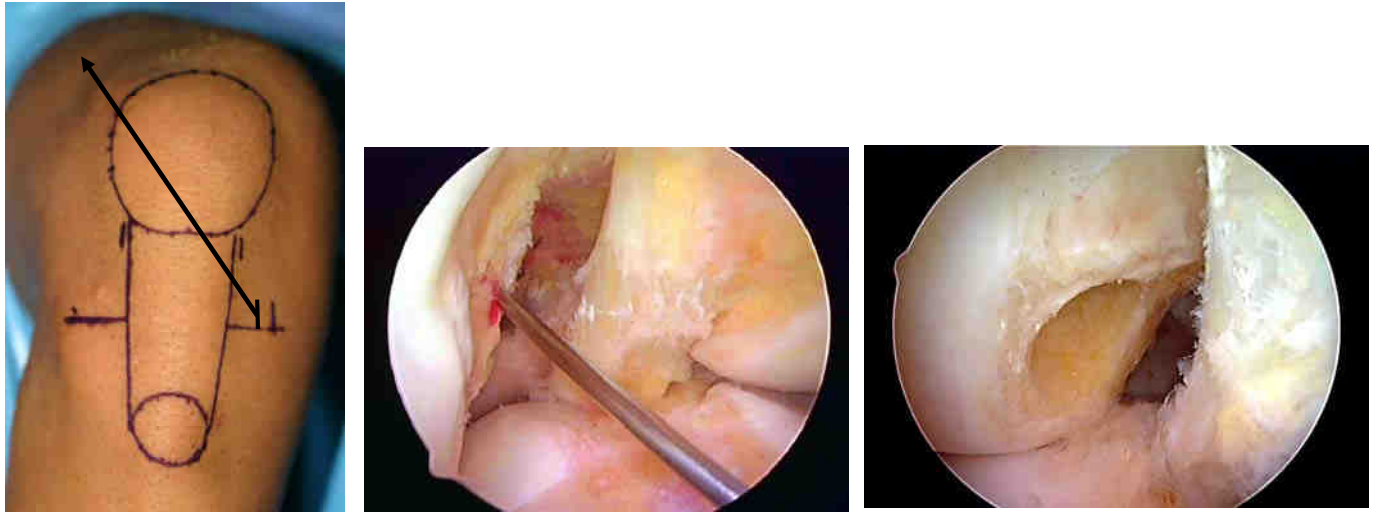
### Placement of the Accessory Anteromedial Portal

Proper placement of the AAM portal is also critical to the success of the procedure, as it is the **most** important factor affecting the length of the ACL femoral tunnel. The medial-lateral placement of the AAM portal determines both the length of the ACL femoral tunnel and the shape of the tunnel's aperture. Positioning the AAM portal more medially results in a more perpendicular orientation of the femoral drill bit with respect to the lateral wall of the notch and produces a shorter ACL femoral tunnel and a more circular-shaped tunnel aperture (Figure 8).<sup>4</sup> However, placing the AAM portal too medially can result in damage to the medial femoral condyle when the AAM portal is used to drill the ACL femoral tunnel.



**Figure 8 (above)** Medial placement of the AAM portal results in a more perpendicular orientation of the spinal needle relative to the lateral wall of the notch. This orientation will produce a more circularly shaped aperture of the ACL femoral tunnel and a shorter ACL femoral tunnel length.

Moving the AAM portal more laterally, towards the medial border of the patellar ligament, orients the femoral guide pin more obliquely with respect to the lateral wall of the notch and produces a longer ACL femoral tunnel length and a more elliptically-shaped tunnel aperture (Figure 9).<sup>4</sup>



**Figure 9** A more lateral placement of the AAM portal results in a more oblique orientation of the spinal needle relative to the lateral wall of the notch. This orientation will produce a more elliptically-shaped aperture of the femoral tunnel and a longer ACL femoral tunnel length.

Based on the ACL graft type and femoral fixation method, the position of the AAM portal is adjusted to achieve the desired ACL femoral tunnel length. For example, if a bone-patellar tendon-bone ACL graft with interference screw fixation of the femoral bone block is used for the ACL reconstruction, the optimal femoral tunnel length can be in the 25 to 30 mm range. For this graft type and fixation method, the AAM portal can be positioned more medially compared to an ACL reconstruction performed using a multiple-stranded hamstring tendon graft with Endobutton femoral fixation.

When performing hamstring ACL reconstructions using a cortical fixation device such as the Endobutton CL implant for femoral fixation of the graft, it is optimal to achieve a femoral tunnel length of around 40 mm, with a minimum tunnel length of around 35 mm. A 40 mm femoral tunnel allows for 25 mm of the hamstring tendon graft to be inserted into the ACL femoral socket when using a 15 mm Endobutton CL.

#### **Establish the Accessory Anteromedial Portal**

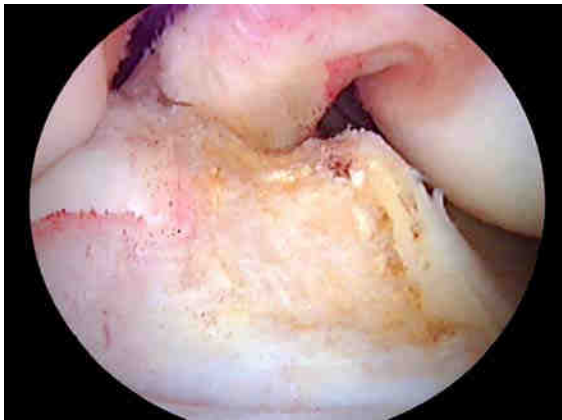
1. Use an 18-gauge spinal needle to determine the optimal position for the AAM portal. The AAM portal should be located as low as possible above the medial joint line while avoiding the anterior horn of the medial meniscus. Rotate the arthroscope medially to determine if the spinal needle is positioned too closely to the medial femoral condyle. Adjust the position of the portal accordingly.
2. Create the AAM portal using a # 11 knife blade, with the cutting edge of the blade oriented away from the anterior horn of the medial meniscus.
3. Dilate the AAM portal by inserting the tips of the Metzenbaum scissors or a small curved clamp into the incision and spreading the tips in-line with the direction of the portal. This step will ease future instrument passage through the AAM portal.



### Prepare the ACL Tibial Attachment Site

Carefully inspect the remnants of the torn ACL. An attempt should be made to preserve large stumps and remnant ACL fibers with intact connections from the tibia to the femur.

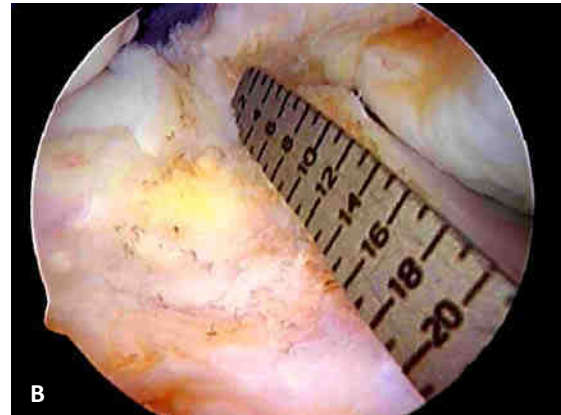
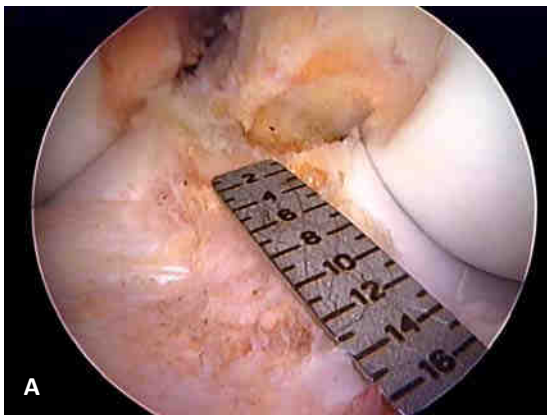
1. Insert a motorized shaver blade into the knee joint through the AM portal and resect the mid-section of the ACL. Preserve some of the remaining native ACL fibers at the tibial and femoral attachment sites to aid with anatomic placement of the ACL bone tunnels.
2. Insert a 90° bipolar thermal probe through the AM portal and mark the borders of the ACL tibial attachment site (Figure 10). Note that a majority of the ACL tibial attachment site extends anterior to the posterior margin of the anterior horn of the lateral meniscus. The anterior margin of the ACL tibial attachment site lies just posterior to the intermeniscal ligament, and the posterior margin lies just anterior to a bony ridge connecting the medial and lateral tubercles (spines). The medial border of the ACL tibial attachment site is defined by a bony ridge, the medial intercondylar ridge of the tibia, which extends anteriorly from the medial tubercle.



**Figure 10** ACL tibial attachment site. The medial and lateral tibial tubercles (spines) with the interconnecting ACL ridge and the medial intercondylar ridge of the tibia are well seen.

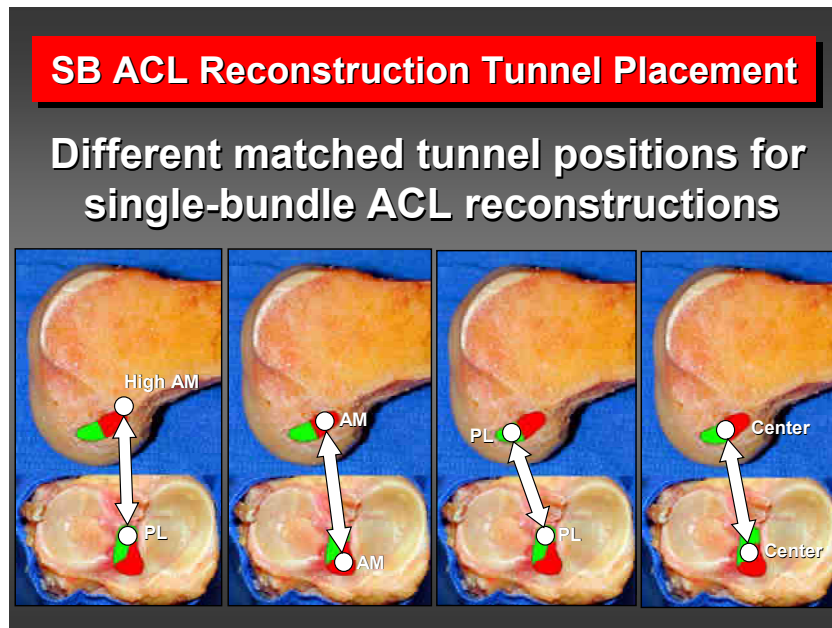
### Measure the Length of the ACL Tibial Attachment Site

Insert an ACL ruler through the AAM portal and measure the length of the ACL tibial attachment site (Figure 11). One of the goals of ACL reconstruction is to restore the maximum amount of the tibial and femoral attachment sites. Long and wide ACL tibial attachment sites are best restored with larger diameter ACL grafts such as 5- and 6-strand hamstring tendon grafts, a bone-patellar tendon-bone graft, a quadriceps tendon graft, or by performing a double-bundle ACL reconstruction.<sup>4</sup>



**Figure 11** Measuring tibial attachment site length. **(A)** Short tibial insertion site (13 mm) **(B)** Long tibial insertion site (18 mm)

## ACL Graft Placement



Biomechanical studies have demonstrated that a single-bundle ACL graft positioned at the center of the ACL femoral and tibial attachment sites best controls anterior tibial translation and the combined motions of anterior tibial translation and internal tibial rotation (simulated pivot shift test) and restores kinematics more closely to those of the normal knee compared to other anatomic ACL graft placements.<sup>3</sup>

### Anatomic ACL Femoral Tunnel Position

Although the clock-face reference method is often used to specify ACL femoral tunnel placement, the clock-face reference method has several shortcomings: it ignores the depth of the notch; there is no agreed upon reference position for the 3 and 9 o'clock locations; it relies on no known anatomic landmarks; and it cannot be used when viewing the ACL femoral attachment site through the AM portal. ACL femoral tunnel placement is more accurately defined and specified using the following methods:

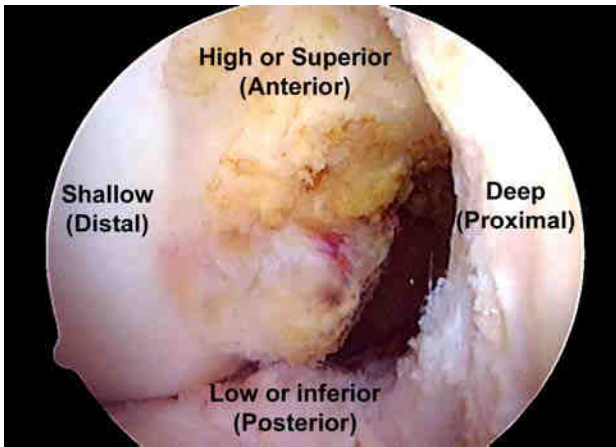
#### I. Native ACL Footprint

In most situations, remnants of the native ACL fibers are present at the ACL femoral attachment site and these can aid with anatomic ACL femoral tunnel placement (Figure 12).



**Figure 12** AM portal view at 90° of flexion. Remnants of the native ACL fibers at the ACL femoral attachment site are clearly seen.

The view of the intercondylar notch and the ACL femoral attachment site changes significantly depending on the arthroscopic portal utilized. Viewing the ACL femoral attachment site through the AM portal provides an orthogonal view of the lateral wall of the notch, allowing accurate assessment of the ACL femoral tunnel position in both the shallow-deep and high-low directions (Figure 13).



**Figure 13** AM portal view at 90° of flexion (arthroscopic position). In the arthroscopic terminology, directions along the lateral wall of the intercondylar notch are referred to as: high or superior, low or inferior, shallow and deep. The directions using the corresponding anatomical terminology (shown in parenthesis) which references the knee in the extended position are: anterior, posterior and distal. Remnant ligament fibers of the native ACL are seen along the lower-third of the lateral wall of the notch.

As a result, the AM portal is the preferred portal for viewing the anatomic ACL femoral attachment site. Viewing the ACL femoral attachment site through the AM portal also eliminates the need to perform a routine notchplasty for visualization purposes. Avoid using a curette, motorized shaver blade or burr to initially perform a notchplasty or to completely remove all of the soft tissue remnants from the lateral wall of the notch as this destroys the remaining native ACL fibers and underlying bony landmarks.

To use the native ACL footprint method:

1. View the lateral wall of the notch with the scope in the AM portal. Insert a 90° bipolar thermal probe through the AAM and mark the borders of the native ACL femoral attachment site.
2. Insert a 45° angle microfracture awl through the AAM and mark the center of the ACL femoral attachment site.

## II. Osseous Ridges

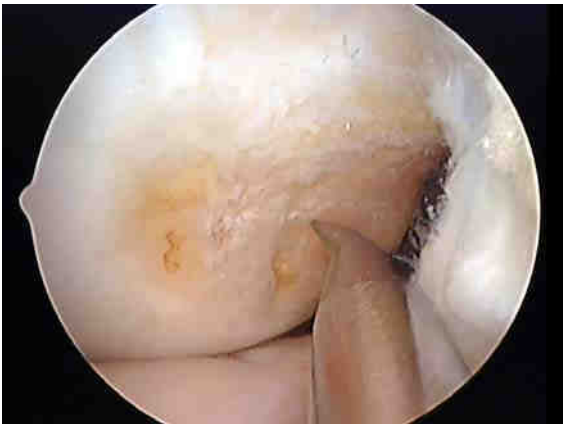
When there are no soft tissue remnants of the native ACL present, the underlying bony morphology of the ACL femoral attachment site can provide useful anatomical landmarks to assist with anatomic ACL femoral tunnel placement. Anatomic studies have demonstrated that the ACL femoral attachment site is defined by two osseous ridges.<sup>6</sup> The lateral intercondylar ridge ("resident's ridge") runs at approximately a 30 - 35° angle with respect to the long axis of the femoral shaft and represents the upper or superior limit of the ACL femoral attachment site. The lateral intercondylar ridge has been shown to be present and visible in 88 - 100 % of chronic ACL deficient knees.<sup>7,8</sup> When present, the lateral intercondylar ridge is critical to anatomic ACL femoral tunnel placement since the ACL femoral attachment site **always** lies below or inferior to this ridge. In some knees it may be possible to identify a second bony ridge, the lateral bifurcate ridge, which separates the attachment sites of the AM and PL bundle fibers.<sup>6</sup> It is important to remember that because the cross-sectional area of the PL and AM bundles is variable from patient-to-patient, the location of the bifurcate ridge, when present, does not necessarily represent the true center of the ACL femoral attachment site (Figure 14).



**Figure 14** View through the AM portal at 90° of flexion. The lateral intercondylar and bifurcate ridges are clearly visible.

To use osseous ridges:

1. Use a bipolar 90° thermal probe to remove soft tissue along the lower third of the lateral wall of the notch.
2. With the knee at 90° of flexion, identify the lateral intercondylar ridge and the margin of the lower articular cartilage border. The lateral intercondylar ridge is most easily identified by starting the dissection in the lower part of the footprint and working in a superior (high) direction. A distinct endpoint will be encountered as the thermal probe contacts the ridge. The center of the ACL femoral attachment site in the high-low direction is located half-way between these two landmarks (Figure 15).
3. "Eyeball" or use an ACL ruler or fluoroscopy to determine the shallow-deep position of the ACL femoral tunnel.



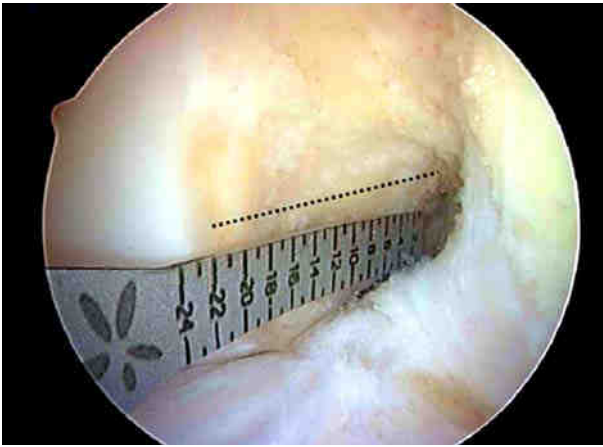
**Figure 15** Anteromedial portal view at 90°. The tip of the microfracture awl is positioned mid-way between the lateral intercondylar ridge and the inferior (low) articular cartilage margin.

### III. ACL Template

An ACL template allows the surgeon to individualize the location of the ACL femoral tunnel based on the specific anatomy of the patient. This approach allows for "a la carte" or patient specific surgery to be performed versus the "one size fits all" approach associated with the use of offset ACL femoral aimers.

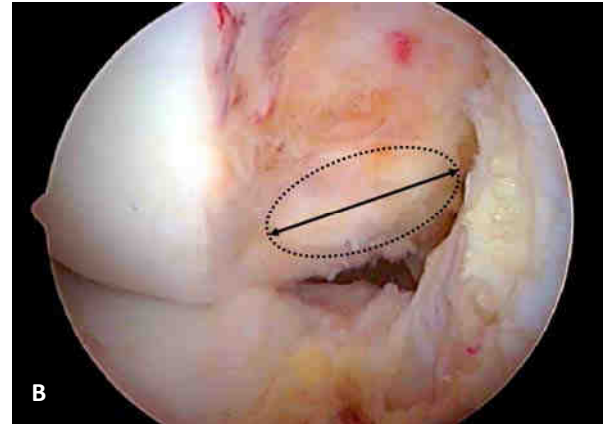
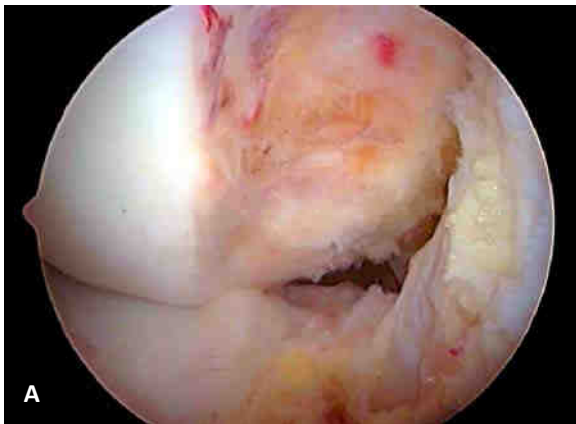


1. With the knee at 90° of flexion, place the arthroscope in the AM portal to view the ACL femoral attachment site.
2. Bend the ruler to approximately a 45° angle at the 24 mm mark to allow it to lie flat along the lateral wall of the notch.
3. Insert the ACL ruler into the knee joint through either the AL or the AAM portal (Figure 16). Inserting the ruler through the AL portal allows a microfracture awl to be inserted through the AAM portal, giving the surgeon the ability to measure and simultaneously mark the ACL femoral attachment site. However, due to the height of the AL portal above the lateral joint line, in some knees it may be more difficult to position the ACL ruler lower down the sidewall of the notch at the ACL femoral attachment site. In this situation, it may be advantageous to insert the ruler through the AAM. The lower position of the AAM portal allows the ruler to be easily positioned at the ACL femoral attachment site.



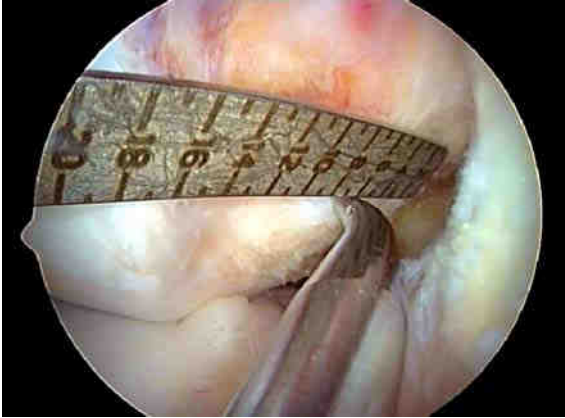
**Figure 16** View through the AM portal at 90° of flexion. The ACL ruler has been bent to lie flat along the lateral wall of the intercondylar notch. The ruler is inserted through the AL portal and is positioned to lie parallel to the wall of the notch just below the lateral intercondylar ridge (dotted line).

4. If remnant fibers of the ACL are clearly visible, measure the length of the ACL femoral attachment site along the long axis of the footprint using the ACL ruler (Figure 17).



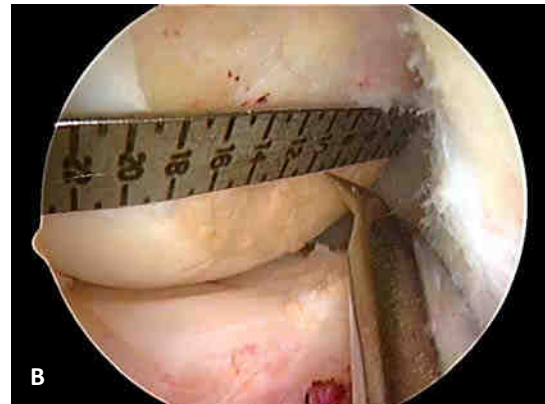
**Figure 17** Anteromedial portal view at 90° of flexion. **(A)** Remnant fibers of the native ACL are seen along the lateral wall of the notch. **(B)** The ACL femoral attachment site is shown by the dotted ellipse. The length of the ACL femoral attachment site length is measured along its long axis (black line).

5. To create an ACL femoral tunnel located in the center of the ACL femoral attachment site, the center of the ACL femoral tunnel should be located at a shallow-deep position that is 50% of the measured length of the ACL femoral attachment site (Figure 18). The high-low placement of the ACL femoral tunnel should be half-way between top and the bottom of the footprint.



**Figure 18** Anteromedial portal view at 90° of flexion (same knee as shown in Figure 17). The ACL ruler is inserted through the AL portal and the 45° microfracture awl through the AAM portal. In this case, the ACL femoral attachment site length measures 14 mm, so the center of the ACL femoral tunnel is placed at the 7 mm mark.

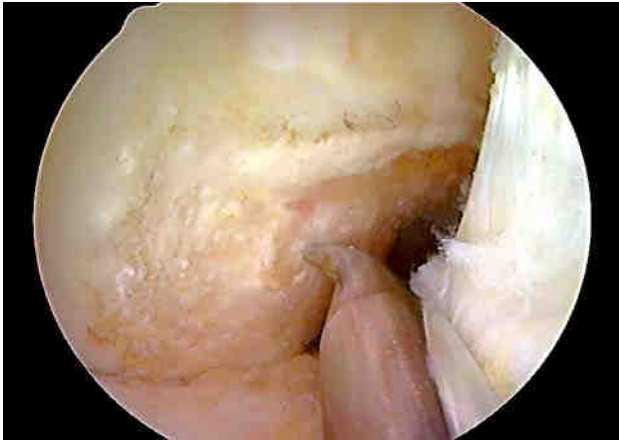
6. If there are no remnant fibers of the ACL clearly visible, insert the upper edge of the ACL ruler parallel and inferior to the lateral intercondylar ridge. Insert the ruler into the notch until the tip is positioned at the proximal (deep) margin of the articular cartilage. The proximal articular cartilage margin represents the deep point of the ACL femoral attachment site. The length of the ACL femoral attachment site is measured where the ACL ruler touches the shallow margin or the articular cartilage (Figure 19).<sup>9</sup>



**Figure 19** Chronic ACL-deficient knee. Anteromedial portal view at 90° of flexion. **(A)** The lateral intercondylar ridge is clearly seen. However, there are no remnants of the native ACL fibers visible. **(B)** The ACL ruler is inserted through the AL portal. The length of the ACL femoral attachment site measures 18 mm. A 45° microfracture awl is inserted through the AAM portal and is used to mark the ACL femoral attachment site at 9 mm, which represents 50% of the measured ACL femoral attachment site length.

Insert a 45° microfracture awl through the AAM portal and use it to mark the location of the ACL femoral tunnel. The center of the femoral tunnel should be located at a shallow-deep position that is 50% of the measured distance from the deep aspect of the ACL femoral attachment site to the shallow articular cartilage margin. The high-low position of the ACL femoral tunnel is located half-way between the lateral intercondylar ridge and the low (posterior) articular cartilage margin (Figure 20).

**Note:** At 90° of flexion, the native ACL femoral attachment site does not extend completely to the shallow margin of the articular cartilage. Therefore, calculating to the shallow margin of the articular cartilage slightly overestimates the true length of the ACL femoral attachment site. Calculating 50% of this distance will result in the ACL femoral tunnel being positioned slightly more shallow than the true center of the ACL femoral attachment site. Therefore, it is better to error by marking the ACL femoral attachment site 0.5 - 1 mm deeper than the calculated 50% position. This will ensure that the ACL femoral tunnel will not be positioned too shallow in the notch.



**Figure 20.** Anteromedial portal view at 90°. The tip of the 45° microfracture awl is placed half-way between the lateral intercondylar ridge and the low (posterior) articular cartilage margin and 50% of the length of the ACL femoral attachment site as measured using the ACL ruler. Note that in this particular case, the center of the ACL femoral attachment site lies slightly deep (proximal) to the lateral bifurcate ridge.

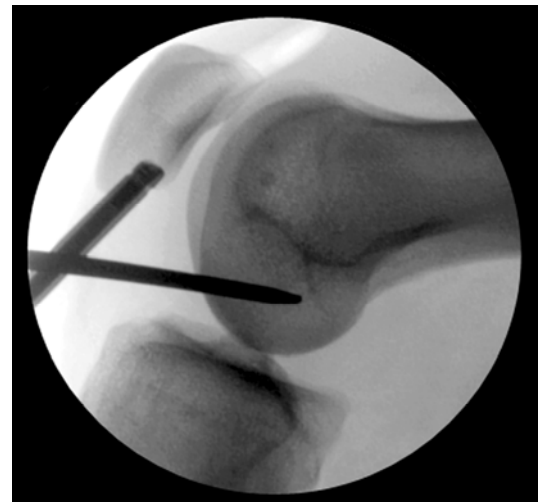
#### IV. Intraoperative Fluoroscopy

At the present time, interoperative fluoroscopy is the most accurate method to measure and document ACL femoral tunnel placement.<sup>10,11</sup> Fluoroscopy gives the surgeon the ability to intraoperatively measure and change the ACL femoral tunnel position, and also serves as a quality control for the ACL femoral tunnel position.

1. With the knee at 90° of flexion and the 45° microfracture awl positioned at the chosen ACL femoral tunnel location, a sterile draped digital c-arm is used to take a true lateral radiograph of the knee. A true lateral radiograph is one in which the inferior and deep margins of the medial and lateral femoral condyles overlap (Figure 21A, B).

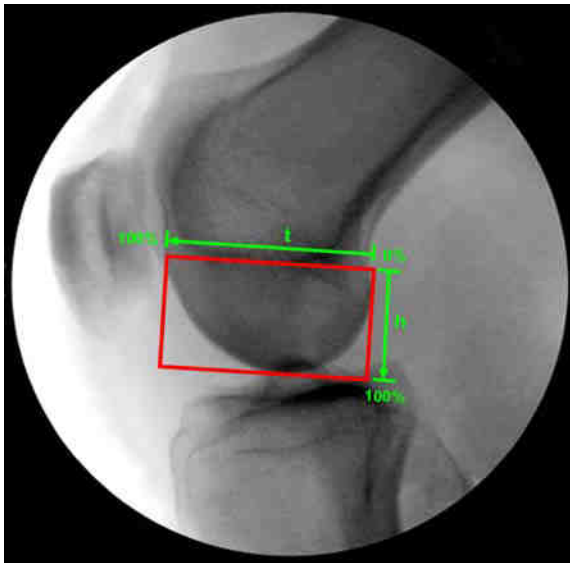


**Figure 21A** Intraoperative c-arm



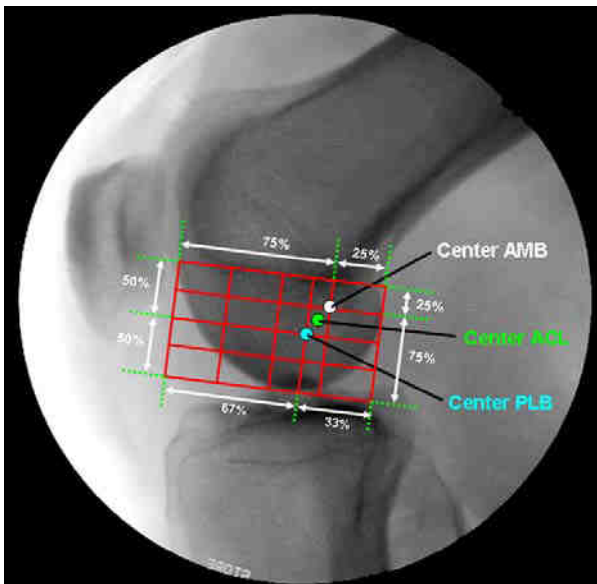
**Figure 21B** True lateral image of the knee.

- The grid system described by Bernard and Hertel is used to measure the position of the ACL femoral tunnel (Figure 22A,B).<sup>12</sup> This method is easy to use, is reproducible, and has been shown to be independent of knee size, shape, and the distance between the x-ray tube and the patient.<sup>12</sup>



**Figure 22A** Bernard-Hertel Grid. How to draw the Bernard-Hertel grid:

- Draw a tangent to the roof of the intercondylar notch (Blumensaat's line). Draw two lines perpendicular to that line, one at the intersection of the tangent line with the shallow border of the lateral femoral condyle and the other with intersection of the tangent line and the deep border of the lateral femoral condyle. The lateral femoral condyle can be identified by an indentation (Grant's notch) and the fact that the medial femoral condyle extends more distal.
- Draw another line parallel to Blumensaat's line and tangent to the inferior border of the condyles. Measurements are made as percentages along Blumensaat's line (t), which represents the maximum sagittal diameter of the lateral femoral condyle, and line (h), which represents the maximum intercondylar notch height.





**Figure 22B (above)** The center of the AM and PL bundles are shown according to the data of Columbet et al.<sup>13</sup> In this study, the center of the AM bundle was found to lie at a point 25% along Blumensaat's line (t), and 25% along line (h). The center of the PL bundle was located at a point 33% along line (t), and 50% along line (h).

3. Intraoperatively, the Smith & Nephew ACUFEX Director Application Anatomic Guide software can be used to plot the Bernard and Hertel grid on the c-arm image. Alternatively the images can be saved to an image capture unit and the grid applied later as a quality control check (Figure 23). The microfracture awl position can be adjusted under arthroscopic and fluoroscopic guidance until the desired position is obtained.

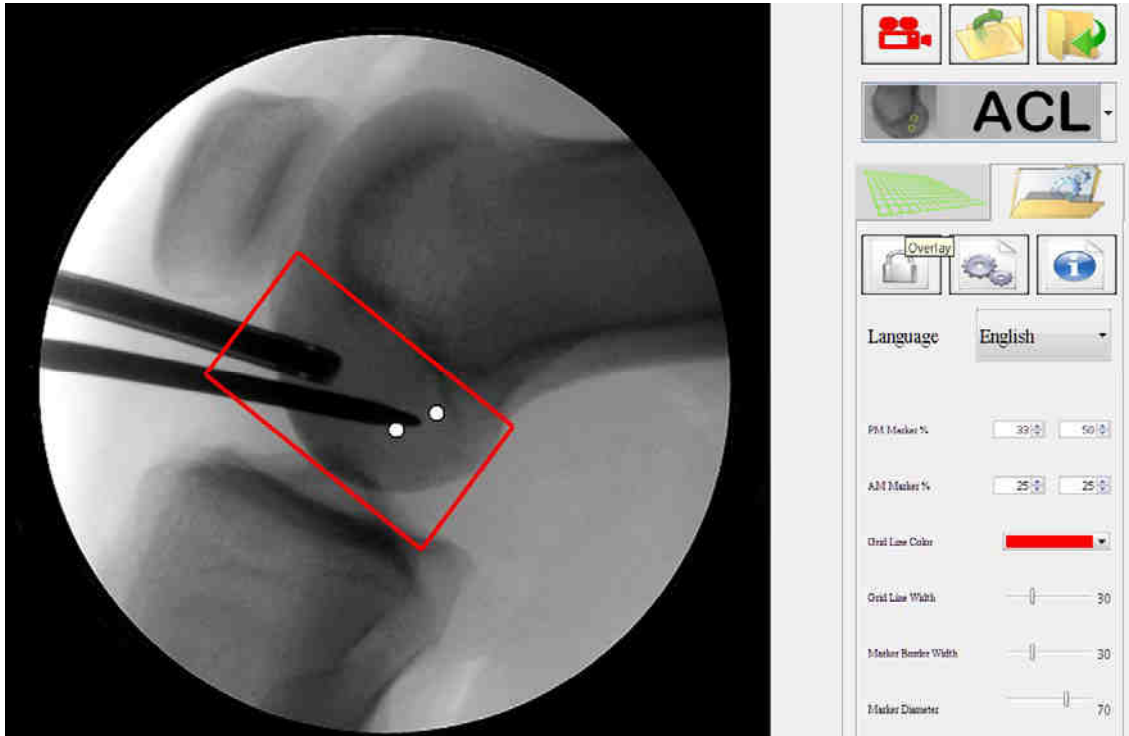


Figure 23. The Smith & Nephew ACUFEX Director Application Anatomic Guide software was used to plot the location of the AM and PL bundles (white circles) based on the data of Columbet et al.<sup>13</sup> The software also allows other coordinates for the center of the AM and PM bundles to be selected. In this example, the tip of the microfracture awl is positioned half-way between the center of the AM and PL bundles (white circles). This location would position the ACL femoral tunnel in the center of the ACL femoral attachment site.

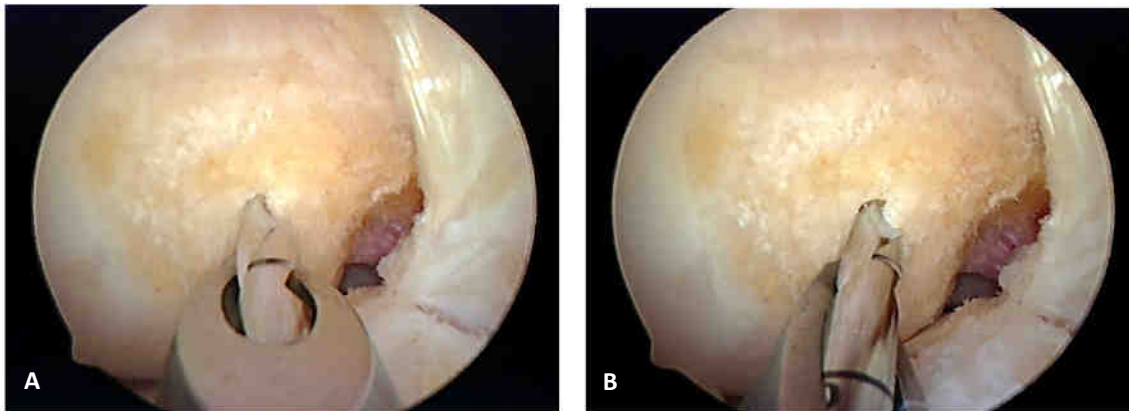
Using any or all of the above guidelines eliminates the need to use an offset ACL femoral aimer and referencing off the “over-the-top” position to determine the femoral tunnel placement. Offset ACL aimers can constrain the location of the femoral guide pin and can lead to non-anatomic placement of the ACL femoral tunnel. The above guidelines allow the surgeon to select and verify the location of the ACL femoral tunnel position using established anatomic and radiographic landmarks.

#### Drill the Femoral Tunnel

1. After selecting and confirming the desired location for the ACL femoral tunnel, use a 45° microfracture awl to mark the location along the lateral wall of the notch.
2. Insert a 0° mm offset guide through the AAM portal and place it at the desired location for the ACL femoral tunnel. Slowly flex the knee to 120° or higher. Increasing the degree of knee flexion increases the ACL femoral tunnel length.

**Note:** Hyperflexion of the knee results in a loss of joint distension due to external compression of the knee joint capsule by the soft tissues of the thigh. This can result in bleeding and a loss of joint visualization due to encroachment of the fat pad into the notch. To maintain adequate joint distension and visualization, it is necessary to increase the fluid pressure up to 120 mm Hg while working in the notch with the knee in hyperflexion. Decrease the pump pressure to the normal setting after the ACL femoral tunnel has been drilled and the knee is extended back to 70 - 90° of flexion. If the fat pad still obscures visualization, limited resection of the fat pad should be performed using a motorized shaver blade inserted through the AAM.

3. Insert a 2.7 mm drill-tip graduated guide pin through the 0 mm offset aimer and use a small mallet to tap the drill-tip part of the guide pin into the pilot hole created by the microfracture awl (Figure 24).
4. Keeping the tip of the 2.7 mm drill-tip guide pin in the pilot hole, slowly angle the handle of the 0° mm offset aimer laterally and tap the guide pin into the lateral wall of the notch until the drill-tip part of the guide pin is fully buried into the bone. This maneuver increases the obliquity of the guide pin relative to the lateral wall of the notch, resulting in a longer femoral tunnel length and a more elliptically-shaped tunnel aperture (Figure 24).<sup>4</sup> An elliptically-shaped tunnel covers more of the ACL femoral attachment site and more closely reproduces the anatomy of the native ACL attachment site versus a circular-shaped femoral tunnel.<sup>4</sup>



**Figure 24** Anteromedial portal view in hyperflexion. **(A)** The femoral drill-tip passing pin is oriented perpendicular to the lateral wall of the notch. This guide pin orientation will result in a short femoral tunnel length and a more circular shape of the ACL femoral tunnel aperture. **(B)** The 0 degree offset aimer has been angled laterally which results in the femoral guide pin being oriented more obliquely to the lateral wall of the notch. A more oblique orientation of the guide pin will increase the length of the ACL femoral tunnel and produce a more elliptically-shaped femoral tunnel aperture.<sup>4</sup>

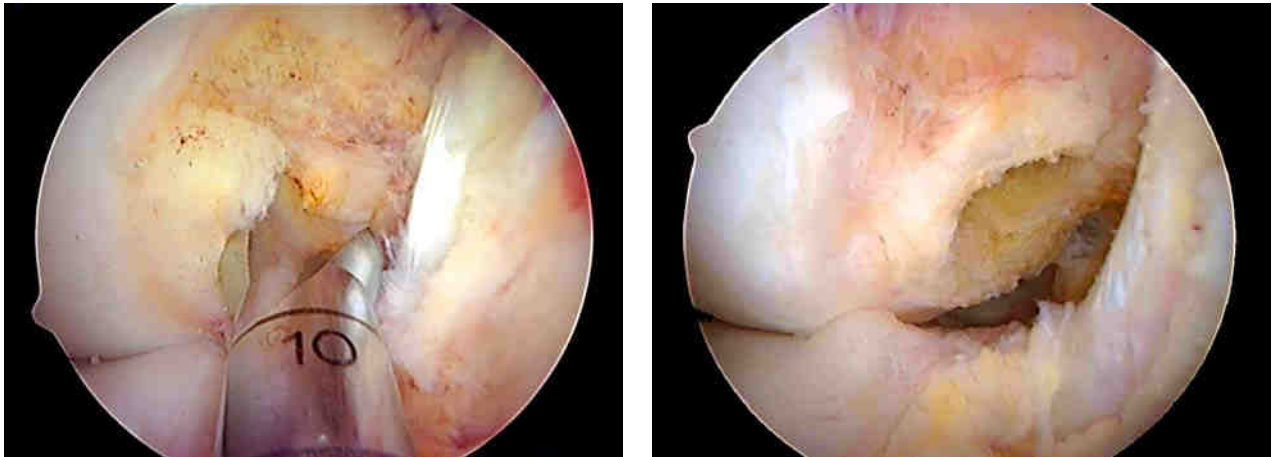
5. Slowly drill the 2.7 mm drill-tip graduated guide pin through the lateral femoral condyle until the resistance of the lateral femoral cortex is encountered.
6. Note the depth mark on the graduated drill-tip passing pin at the point of maximum resistance. This distance will provide a good estimate of the ACL femoral tunnel length. If the resulting ACL femoral tunnel length is significantly less than desired, it is possible to increase the femoral tunnel length by reversing the guide pin back to the entry point, angling the offset aimer more laterally, and increasing the knee flexion angle. These maneuvers can often redirect the drill-tip guide pin more proximally up the femoral shaft, producing a longer femoral tunnel length.

**Note:** Do not use power to initially insert the femoral guide pin into the bone. The guide pin will skive off of the pilot hole if power is initially used. Guide pin breakage can also occur if an attempt is made to simultaneously angle and drill the femoral guide pin into the bone under power. To prevent guide pin breakage, ensure that the drill-tip portion of the guide pin is fully inserted into the bone before using power to drill the pin through the bone.

7. Drill the ACL femoral socket using an endoscopic drill bit that corresponds to the diameter of the ACL graft (Figure 25).

**Note:** If an Endobutton CL implant is used as the ACL femoral fixation device, use a 4.5 mm Endobutton Drill bit to drill a tunnel through the lateral femoral cortex. Measure the length of the femoral tunnel by noting the mark on the Endobutton drill bit at the time of cortical breakthrough. The ACL femoral tunnel length can also be measured by slowly withdrawing the Endobutton drill bit until the fluted part of the drill bit is felt to engage the lateral femoral cortex. The distance at the femoral tunnel entrance is noted and 10 mm (the length of the fluted part of the 4.5 mm Endobutton drill bit) is subtracted to obtain the ACL femoral tunnel length.

**Note:** Knowing the length of the ACL femoral tunnel allows the femoral socket to be drilled all the way to the femoral cortex. Drilling the femoral socket close to the lateral femoral cortex will allow room for the Endobutton fixation device to flip in all situations, eliminating the need to calculate how deep to drill the femoral socket.



**Figure 25 (A)** Anteromedial portal view in hyperflexion. The endoscopic drill bit is inserted through into the intercondylar notch through the AAM portal and is seen to lie at the center of the ACL femoral attachment site. **(B)** Anteromedial portal view at 90°. The elliptically-shaped aperture of the ACL femoral tunnel is centered in the ACL femoral footprint.

Damage to the medial femoral condyle which can be caused by an endoscopic reamer introduced through the AAM portal can be avoided by using the “passing pin maneuver” described by Siebold et al.<sup>14</sup> Due to their smaller diameter, this technique is rarely necessary in the case of hamstring tendon ACL grafts. Iatrogenic damage to the cartilage of the medial femoral condyle is more likely to occur in the situation where a 10 mm drill bit is used to drill the femoral socket for a bone-patellar tendon-bone or bone-quadriceps tendon graft. In this maneuver, the femoral guide pin is drilled out through the lateral soft tissues in the usual fashion. To avoid damage to the articular cartilage from the endoscopic reamer, the drilled-tipped end of the femoral guide pin is reversed until the tip of the guide pin is visible in the intercondylar notch.

The guide pin is then angled away from the medial femoral condyle and the cannulated endoscopic reamer inserted over the guide pin into the notch. Once the endoscopic reamer has safely bypassed the medial femoral condyle, the tip of the guide pin is re-inserted back into its original hole in lateral wall of the notch. Having safely bypassed the medial femoral condyle, the femoral socket can be drilled in the conventional fashion. To withdraw the endoscopic reamer, the passing pin is withdrawn from the femoral tunnel, and the reamer maneuvered into the notch away from the medial femoral condyle and the reamer safely removed from the joint.

If a 3-portal technique has been used, fluid flow and visualization in the notch with the knee in hyperflexion can be facilitated by introducing a motorized shaver blade through the AL portal. The suction on the shaver can be used to maintain fluid flow and to suction bone debris created during the drilling of the ACL femoral

tunnel, thus maintaining a clear visual field. The shaver can also be used to resect any portions of the fat pad restricting passage of the endoscopic reamer or obstructing visualization in the notch.

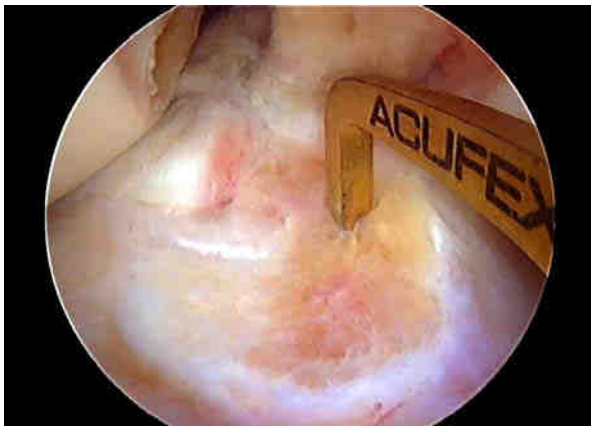
8. Load a #2 or #5 polyester suture into the slotted end of the 2.7 mm drilled-tipped passing pin and pass the free ends of the suture out through the lateral soft tissues, leaving the looped end of the suture in the ACL femoral tunnel.
9. When a multiple-stranded hamstring tendon graft is used as an ACL graft, use the EndoButton depth gauge to measure the length of the ACL femoral tunnel.
10. Chamfer the edges of the ACL femoral tunnel with an ACL chamfer rasp to minimize abrasion of the ACL graft.
11. In chronic cases with notch osteophytes or in patients with small width notches, a limited wallplasty at the shallow border of the notch is performed using a small curved compound gouge (Figure 26). If required, the wallplasty should be performed after the ACL femoral tunnel has been drilled to avoid lateralizing the position of the ACL femoral tunnel. Use a motorized shaver blade to contour and flatten the wall of the notch.



**Figure 26** Chronic ACL deficient knee with osteophytes along the lateral wall of the intercondylar notch. After drilling the ACL femoral tunnel, a curved compound gouge is used to excise the osteophytes along the lateral wall, widen the width of the intercondylar notch.

#### **Drill the Tibial Tunnel**

Place the knee at 70 - 90° of flexion. While viewing through the AM or AL portal, insert an ACL tibial guide set at a 55° angle with a tip aimer through the AM or AAM portal into the knee joint. Position the tip of the aimer, 2 – 3 mm anterior to the posterior margin of the anterior horn of the lateral meniscus and slightly medial to mid-line of the ACL tibial attachment site (Figure 27).





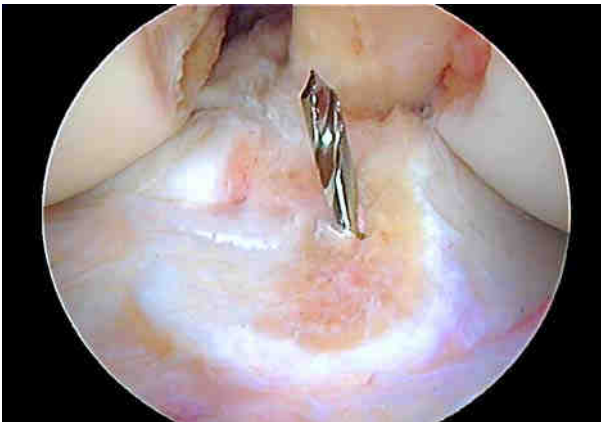
**Figure 27 (above)** The tip of the ACL tip aimer is positioned slightly anterior to the posterior margin of the anterior horn of the lateral meniscus and slightly medial to the mid-line of the tibial footprint.

1. Mark the ACL tibial aimer bullet with a surgical marker at the desired tibial tunnel length.
2. Position the bullet medial to the crest of the tibia, in the middle of the skin incision used to harvest the ACL graft. Raise or lower the handle of the tibial guide aimer until the mark on the bullet is located at the end of the aimer handle when the bullet is flush with the anterior cortex of the tibia. These steps allow a tibial tunnel of a known length to be drilled, thus allowing the issue of graft-tunnel length mismatch to be addressed.
3. Drill a 2.4 mm drill-tip guide pin into the tibia until the resistance of the aimer tip is encountered.

**Note:** Avoid drilling the tibial guide pin completely into the knee joint as this will result in the guide pin hitting the tip of the tibia aimer and deflecting away from its intended target. Instead, remove the tibial aimer from the joint and use a small mallet to tap the 2.4 mm drill-tip guide pin until it is visible in the joint.

In general, the tip of the tibial passing pin should lay 1- 2 mm anterior to the posterior margin of the anterior horn of the lateral meniscus and slightly medial to the mid-line of the ACL tibial attachment site (Figure 28). The most common error made when converting from the transtibial tunnel technique to the anteromedial portal technique is to position the tibial guide pin in the posterior half of the ACL tibial attachment site.

**Note:** Placement of the tibial guide pin posterior to the posterior margin of the anterior horn of the lateral meniscus will result in a non-anatomic tibial tunnel positioned in the region of the PL bundle. Positioning the tibial guide pin too far laterally in the ACL tibial attachment site can result in impingement of the ACL graft against the lateral wall of the notch.



**Figure 28** The tibial guide pin is positioned slightly anterior to the posterior margin of the anterior horn of the lateral meniscus and slightly medial to the mid-line of the insertion site.

Due to the large degree of variability of the intercondylar notch roof angle and the amount of knee hyperextension from patient-to-patient, it is extremely helpful to use fluoroscopy to confirm correct anterior-posterior placement of the ACL tibial guide pin.

4. Place the knee in maximum extension and obtain a true lateral radiographic view of the knee (Figure 29).



**Figure 29** The c-arm is used to take a lateral radiograph of the knee in full hyperextension.

***Note:** For soft tissue grafts, which will be centered along the line of the guide pin, the tibial guide pin should lie approximately 4 - 5 mm posterior to Blumensaat's line. For bone-patellar tendon-bone grafts the tibial guide pin placement can be approximately 2 – 3 mm posterior to Blumensaat's line since the patellar tendon graft fibers are offset from the bone block and will come to lie posterior to the line of the guide pin.*

#### **Measure the ACL Tibial Guide Pin Position**

The Smith & Nephew ACUFEX DIRECTOR Application Anatomic Guide software can be used to accurately analyze and measure the position of the ACL tibial guide pin in the sagittal plane.

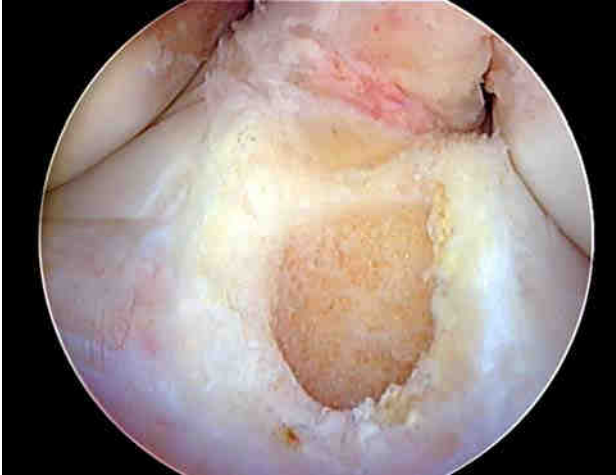
1. Measure the tibial guide pin position using the method of Amis and Jakob (Figure 30).<sup>15</sup> The goal is to place the tibial guide pin in the center of the ACL tibial insertion site, which has been shown to lie at 41 - 44% along the Amis-Jacob line.<sup>16</sup>



**Figure 30** Amis-Jacob line.<sup>13</sup> The medial joint line is marked by the dotted white line. The Amis-Jacob line (red line) passes through the posterior corner of the widest part of the medial tibial plateau (square posterior border) parallel to the medial joint line. The anterior tibial cortex represents 0% and the posterior tibial cortex 100% of the sagittal width of the tibia. The tibial guide pin position is calculated by dropping an orthogonal line (green line) from the point where the tibial guide pin crosses the medial joint line onto the Amis-Jacob line. The distance from the anterior tibial cortex (0%) to the orthogonal projection onto the Amis-Jacob line

(blue line with arrowheads) is represented as a percentage of the total length of the Amis-Jakob line. The tibial guide pin in this case is located at 44% along the Amis-Jakob line, which places the guide pin in the center of the ACL tibial attachment site.

2. With proper placement of the tibial guide pin confirmed, use a fully fluted cannulated drill bit sized equal to the measured diameter of the ACL graft to drill the tibial tunnel (Figure 31).



**Figure 31.** The tibial tunnel is elliptically shaped and in this case almost completely restores the cross-sectional area of the ACL tibial attachment site.

3. Small adjustments in the final position of the ACL tibial tunnel can be made by first using a 5 mm drill bit to drill the initial tibial tunnel. Adjustments to the final tibial tunnel position can be made by maintaining and repositioning the tibial guide pin eccentrically in the tibial tunnel using a small clamp. The tibial guide pin can be moved in the desired direction and the tibial tunnel drilled sequentially by 1 mm increments up to the desired size of the tunnel using an endoscopic drill bit.
4. In the situation where the tibial guide pin is malpositioned more than 3 - 4 mm, the tibial guide pin can be exchanged by leaving the original malpositioned guide pin in place, repositioning the tip of the ACL tibial aimer at the desired intra-articular location, and changing the external starting point of the aimer on the tibia. Leaving the original guide pin in place prevents the new guide pin from tracking up the path of the original guide pin.

### Graft Passage

1. Use an arthroscopic probe or grasper to retrieve the suture loop that was left in the ACL femoral tunnel and pull the suture out of the knee joint through the tibial tunnel. Pass the passing sutures for the ACL graft through the suture loop and pass them out of the lateral thigh. The ACL graft is passed into the knee joint using the graft passing sutures.
2. When a femoral bone-patellar tendon-bone or bone-quadriceps tendon ACL graft is used for the ACL reconstruction, the length of the femoral bone block should not exceed 20 – 22 mm in length, as longer bone blocks may present difficulties during graft passage. Unlike the transtibial technique where the ACL femoral and tibial bone tunnels are collinear, drilling the ACL femoral tunnel through a medial portal results in divergence of the two tunnels. As a result, the femoral bone block of the ACL graft must rotate in the notch away from the PCL to enter the ACL femoral tunnel (Figure 33). If the femoral bone block is longer than 20 - 22 mm, it may be difficult to get it to rotate in the notch and

enter the femoral tunnel. It is often helpful to use an arthroscopic probe as a pulley to redirect the angle of the femoral bone block sutures in the direction of the ACL femoral tunnel (Figure 32).



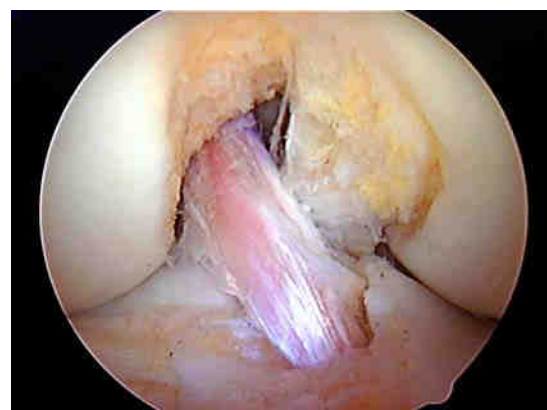
**Figure 32.** Passing femoral bone block. An arthroscopic probe can be used to assist with rotation of the femoral bone block into the ACL femoral tunnel.

#### ACL Graft Tensioning and Tibial Fixation

1. Use the following table to find the correct angle of flexion for tensioning the ACL graft, based on the location of ACL femoral tunnel.

Femoral Tunnel Position:	Tension the ACL graft at:
Near the center of the AM attachment site	45°
Near the center of the ACL attachment site	20 - 30°
Near the center of the PL bundle	0°

2. For multiple stranded hamstring tendon ACL grafts, use a graft tensioning device applied to opposite ends of the ACL graft limbs and apply 10-15 N of force per strand (40-80 N total).
3. For multiple stranded hamstring tendon ACL grafts, cycle the knee from 0 to 90° for a minimum of 30 cycles with an 80 N preload applied to the ACL graft using a graft tensioning device,
4. Fix the multiple-strand hamstring tendon ACL graft at the flexion angle shown in the above table with the graft tensioned to 10 – 15 N per strand (40 – 80 N).
5. Insert the 30° arthroscope into the AL or AM portal and check for wall and roof impingement of the ACL graft (Figure 33).



**Figure 33.** (A) 6-strand (9.5 mm) hamstring ACL graft. (B) 10 mm bone-patellar tendon-bone ACL graft.



## References

1. Ganesh G, Redfern J, Greis P, Burks R. Revision anterior cruciate ligament reconstruction. *Am J Sports Med.* 2011; 39(1):199-217.
2. Marchant B, Noyes F, Barber-Westin S, Fleckenstein C. Prevalence of nonanatomical graft placement in a series of failed anterior cruciate ligament reconstruction. *Am J Sports Med.* 2010; 38(10):1987-1996.
3. Kato Y, Ingham JM, Kramer S, Smolinski P, Saito P, Fu F. Effect of tunnel position for anatomic single-bundle ACL reconstruction on knee biomechanics in a porcine model. *Knee Surg Sports Traumatol Arthrosc.* 2010; 18(1):2-10.
4. Hensler D, Working Z, Illingworth K, Thorhauer E, Tashman S, Fu F. Medial portal drilling: effects on the femoral tunnel aperture morphology during anterior cruciate ligament reconstruction. *J Bone Joint Surg Am.* 2011; 93(22):2063-2071.
5. Siebold, R. The concept of complete footprint restoration with guidelines for single- and double-bundle ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2011; 19(5):699-706.
6. Ferretti M, Ekdahl M, Shen W, Fu F. The topography of the femoral insertion of the anterior cruciate ligament: an anatomical study. *Arthroscopy.* 2007; 23(11):1218-1225.
7. Van Eck C, Morse K, Lesniak B, Kropf E, et al. Does the lateral intercondylar ridge disappear in ACL deficient patients. *Knee Surg Sports Traumatol Arthrosc.* 2010; 18(9):1184-1188.
8. Shino K, Suzuki T, Iwahashi T, Mae T, et al. The resident's ridge as an arthroscopic landmark or anatomical femoral tunnel drilling in ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2010; 18(9):1164-1168.
9. Bird J, Carmont M, Dhillon M, Smith N, Brown C, Thompson P, Spalding T. Validation of a new technique to determine midbundle femoral tunnel position in anterior cruciate ligament reconstruction using 3-D computed tomography analysis. *Arthroscopy.* 2011; 27(9):1259-1267.
10. Lobenhoffer P, Bernard M, Agneskirchner J. Quality assurance in cruciate ligament surgery. *Arthroscopie.* 2003; 16:202-208. German
11. Passler H, Hoher J. Intraoperative quality control of the placement of bone tunnels for the anterior cruciate ligament. *Unfallchirurg.* 2004;107(4):263-72. German
12. Bernard M, Hertel P, Hornung H, Cierpinski Th. Femoral insertion of the ACL. Radiographic quadrant method. *Am J Knee Surg.* 1997; 10:14-22.
13. Columbet P, Robinson J, Christel P, Franceschi J-P, et al. Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. *Arthroscopy.* 2006; 22(9):984-992.
14. Siebold, R, Benetos I, Sartory N, He Z, et al. How to avoid the risk of intraoperative cartilage damage in anatomic four tunnel double bundle anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2010; 18(1):64-67.
15. Amis A, Jakob R. Anterior cruciate ligament graft positioning, tensioning and twisting. *Knee Surg Sports Traumatol Arthrosc* 1998; 6:S2-S12 (Suppl 1)

16. Staubli HU, Rauschning W. Tibial attachment area of the anterior cruciate ligament in the extended knee position. Anatomy and cryosections in vitro complemented by magnetic resonance arthrography in vivo. *Knee Surg Sports Traumatol Arthrosc.* 1994; 2:138-146.