19 Femoral Bone Tunnel Placement (Arthroscopically and with Fluoroscopy)

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Contents

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19.1 Introduction

Anatomic placement of the femoral tunnel is critical to the success and clinical outcome of anterior cruciate ligament (ACL) reconstruction [1–11]. Anatomic single-bundle ACL reconstruction is defined as a single-bundle ACL reconstruction in which the femoral and tibial bone tunnels are positioned at the center of the native ACL femoral and tibial attachment sites [1, 3, 12, 13]. Nonanatomic ACL tunnel placement is the most common technical error leading to recurrent instability and a failed ACL reconstruction [2, 4–11]. Proper placement of the ACL femoral tunnel is especially important because the length and tension of the ACL replacement graft is most influenced by the position of the ACL femoral tunnel [14–18]. Malposition of the ACL femoral tunnel can cause excessive tightening or loosening of the ACL graft, which may result in a loss of motion and or patholaxity of the knee [2, 4–11, 15–18]. Proper placement of the femoral tunnel during ACL reconstruction is therefore a critical part of the surgical procedure. A working knowledge of the anatomy of the ACL femoral attachment site is important to ensure anatomic placement of the ACL femoral tunnel. The anatomy of the ACL has been discussed in greater detail elsewhere in this book. To summarize, the ACL femoral attachment site is oval in appearance and is located along the lower third of the inner wall of the lateral femoral condyle [13, 14, 19–26]. The ACL femoral attachment site is defined by two bony ridges,

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the lateral intercondylar and the lateral bifurcate ridges [13, 20, 22–24, 26, 27] (Fig. 19.1). The lateral intercondylar ridge is an important anatomic landmark since the native ACL always attaches inferior (arthroscopic description) or posterior (anatomic description) to the lateral intercondylar ridge [3, 20, 22–24, 26–28] (Fig. 19.1). The lateral intercondylar ridge can be identified arthroscopically in 88 % of subacute and chronic ACL-deficient knees and therefore is a consistent anatomic landmark to assist the knee surgeon with placement of the ACL femoral tunnel [29]. The lateral bifurcate ridge which can be identified arthroscopically in 48 % of subacute and chronic knees runs perpendicular to the lateral intercondylar ridge and divides the ACL femoral attachment site into the attachment site areas for the posterolateral (PL) and anteromedial (AM) bundles [3, 12, 13, 20, 22, 24, 26] (Fig. 19.1). The center of the ACL femoral attachment site is 1.7 mm deep or proximal to the bifurcate ridge and 7.3–8.5 mm superior or anterior to the inferior or posterior articular cartilage margin of the lateral femoral condyle [21, 26]. For anatomic single-bundle ACL reconstruction, the center of the ACL femoral attachment site is chosen as the position for the ACL femoral tunnel [1, 3, 5, 12, 13, 30–32]. Biomechanical and clinical studies have demonstrated that ACL reconstruction using a replacement graft placed at the center of the ACL femoral and tibial attachment sites is more effective at controlling anterior tibial translation and the combined motions of anterior tibial translation and internal tibial rotation (simulated pivot shift test) and restores knee kinematics more closely to that of the normal knee compared to "isometric" ACL femoral tunnel placement, other anatomic ACL tunnel placements, or techniques that have traditionally restored predominantly the AM bundle fibers [1, 6, 30–38].

19.2 Outline of the Surgical Technique

To obtain a clear view of the ACL femoral attachment site and to place the ACL femoral tunnel in the center of the ACL femoral attachment site, an orderly sequence of steps is recommended. This chapter details the following technical aspects of

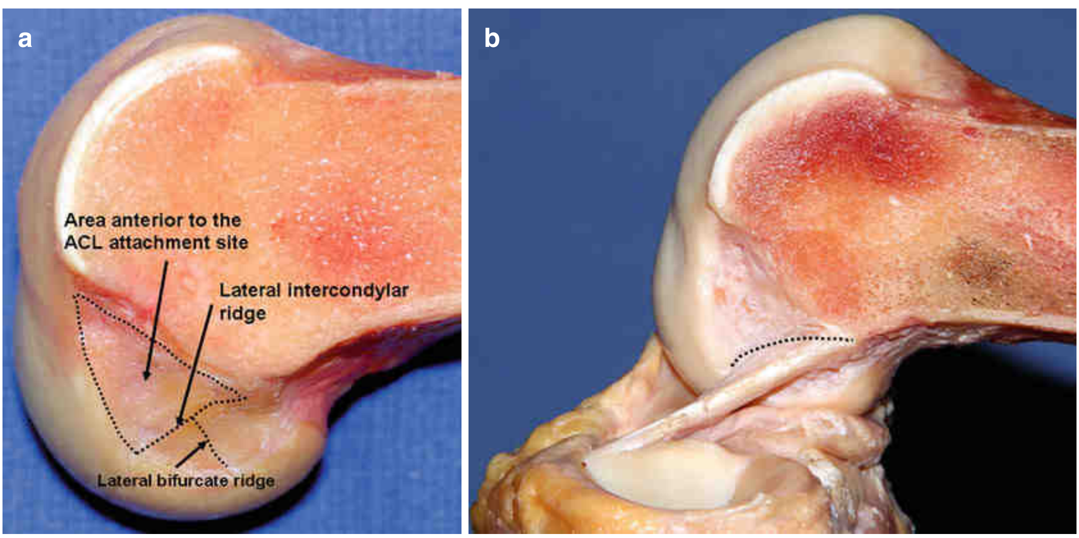

Fig. 19.1 Right knee, human cadaveric specimen. The medial femoral condyle has been removed. (**a**) The ACL femoral attachment site is located on the lower third of inner wall of the lateral femoral condyle. The ACL femoral attachment site is defined by the lateral intercondylar and lateral bifurcate ridges. (**b**) The native ACL is seen to attach inferior to the lateral intercondylar ridge

each component of the surgical technique for anatomic single-bundle ACL femoral tunnel placement:

1. Patient positioning
2. Portal placement
3. Preparation of the intercondylar notch
4. Identification of the center of the ACL femoral attachment site
5. Use of intraoperative fluoroscopy
6. Drilling the ACL femoral tunnel
7. Assessment of the ACL femoral tunnel

19.3 Patient Positioning

When drilling the ACL femoral tunnel through an anteromedial (AM) or accessory anteromedial (AAM) portal, it is important to have the ability to achieve full, unrestricted knee flexion during the procedure. Hyperflexion of the knee is necessary to avoid having the femoral guide pin exit the lateral soft tissues too posteriorly. The peroneal nerve and posterior neurovascular structures are at risk for injury when the femoral guide pin exits the lateral soft tissues in a too posterior position. The requirement to achieve at least 120° of knee flexion while drilling the ACL femoral tunnel may 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 posts allow full unrestricted knee flexion and facilitate drilling the ACL femoral tunnel. The patient is positioned supine with the feet close to the end of the operating table. Time out is called and the correct operative side, site, and procedure confirmed. A foam heel protector is placed on the nonoperative leg. The operative knee is shaved and a padded tourniquet placed high on the operative leg. A padded thigh post is clamped to the side rail of the operating table on the operative side at the level of the tourniquet. A padded lateral hip positioner is clamped to the side rail of the operating table opposite the thigh post on the side of the nonoperative leg. The padded lateral hip positioner stabilizes the patient's pelvis on the operating table and prevents the patient's pelvis from sliding on the operating table during the application of valgus stress to open the medial compartment. Two padded foot posts are clamped to the operating table. The distal foot post is positioned to support the operative leg at 90° of flexion during graft harvest and during preparation of the intercondylar notch. The more proximal foot post is adjusted to position the knee at a minimum of 120° of flexion. The two foot posts allow the leg to be positioned during the surgery without requiring an assistant to hold the leg (Fig. 19.2). The ability to hold the leg in maximal flexion during drilling of

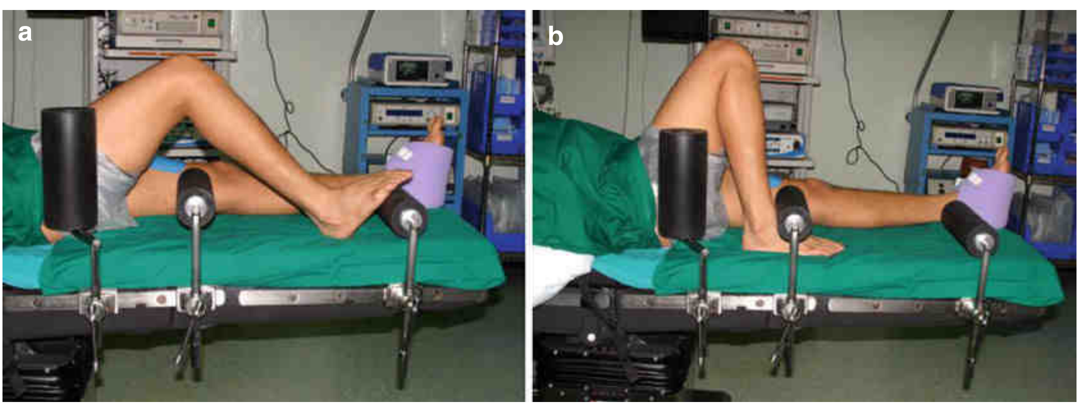

Fig. 19.2 (**a**) Distal foot post is adjusted to position the knee at 90° of knee flexion during graft harvest and preparation of the intercondylar notch. (**b**) Proximal foot rest is adjusted to maintain the knee in hyperflexion during drilling of the ACL femoral tunnel

the ACL femoral tunnel through an AM or AAM portal is essential to avoid a “blowout” of the posterior wall of the ACL femoral tunnel, to achieve an acceptable femoral tunnel length, to prevent bending of the femoral guide pin, and to protect the peroneal nerve.

19.4 Portal Placement

Proper placement of the arthroscopic portals is critical to the success of the procedure. Anatomic ACL femoral tunnel placement is facilitated by using three arthroscopic portals and drilling the femoral tunnel through an accessory anteromedial portal [3, 12, 39–41] (Fig. 19.3):

- The anterolateral (AL) portal—used as the primary viewing portal when performing diagnostic arthroscopy and meniscal surgery

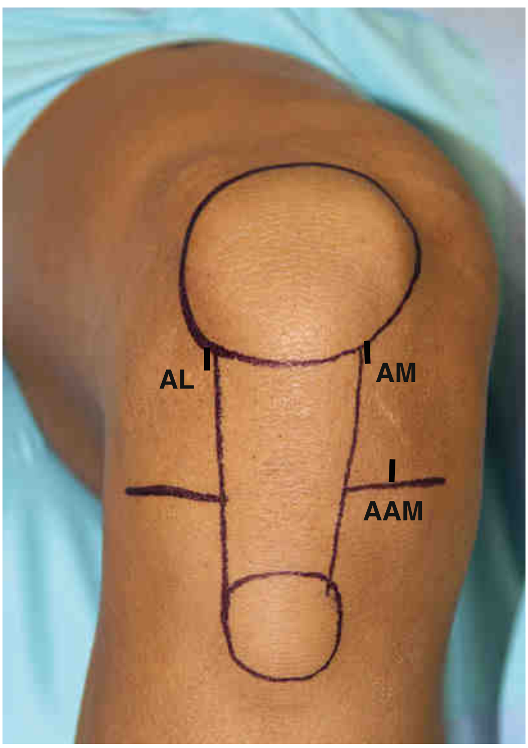

Fig. 19.3 Three arthroscopic portals and their relationship to the inferior pole of the patella, medial and lateral borders of the patellar tendon, and the medial and lateral joint lines (*marked*). *AL* high anterolateral portal, *AM* high anteromedial portal, *AAM* low accessory anteromedial portal

- The anteromedial (AM) portal—used as the primary viewing portal for identification of the ACL femoral attachment site
- The accessory anteromedial portal (AAM)—used as a working portal to insert instrumentation into the notch and for drilling the ACL femoral tunnel

The use of three portals offers 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 [41, 42].

19.4.1 Establish the Anterolateral Portal

A high AL portal is created 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, which minimizes interference of the visual field in the intercondylar notch when the knee is positioned in hyperflexion. A high AL portal also provides a better, “look down” view of the ACL tibial attachment site.

19.4.2 Establish the Anteromedial Portal

Creating the AM portal at the correct height above the medial joint line is extremely important. 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 the preparation of the intercondylar notch and during drilling of the ACL femoral tunnel. A 30° arthroscope is introduced into the knee joint through the AL portal and a diagnostic arthroscopy is performed. The knee is flexed to between 70° and 90° and the AM portal created under direct visualization using an 18-gauge spinal needle. The spinal needle is introduced into the knee joint as close as possible to the medial border of the patellar tendon and directed toward the roof of the intercondylar notch. The height of the spinal needle above the medial joint line is adjusted as needed to ensure that it comes to lie parallel to the roof of the intercondylar notch. Typically, the spinal needle is located at the height of the interior pole of the patella or slightly higher. Placing the spinal needle at this level ensures adequate spatial separation between the AM and the AAM portal which is created later and also results in the AM portal being positioned 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 low above the medial joint line will result in the arthroscope passing through the fat pad and the fat pad being dragged into the visual field by the sheath of the arthroscope. Placing the AM portal too low above the medial joint line will also result in instrument crowding when the AM and AAM portals are used simultaneously to view the ACL femoral attachment site and during drilling of the ACL femoral tunnel. A motored shaver is inserted into the knee joint through the AM portal, and the ligamentum mucosum resected. This step will release the fat pad and expose the intercondylar notch. Any necessary meniscal or chondral surgery can be carried out at this point.

19.4.3 Establish 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 aperture of the femoral tunnel. Positioning the AAM portal more medially results in a more perpendicular orientation of the 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 [41, 42] (Fig. 19.4). However, placing the AAM portal too medially can result in damage to the medial femoral condyle when drilling the ACL femoral tunnel through the AAM portal.

Moving the AAM portal more laterally, toward the medial border of the patellar ligament, orients the drill bit 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 [41, 42] (Fig. 19.5).

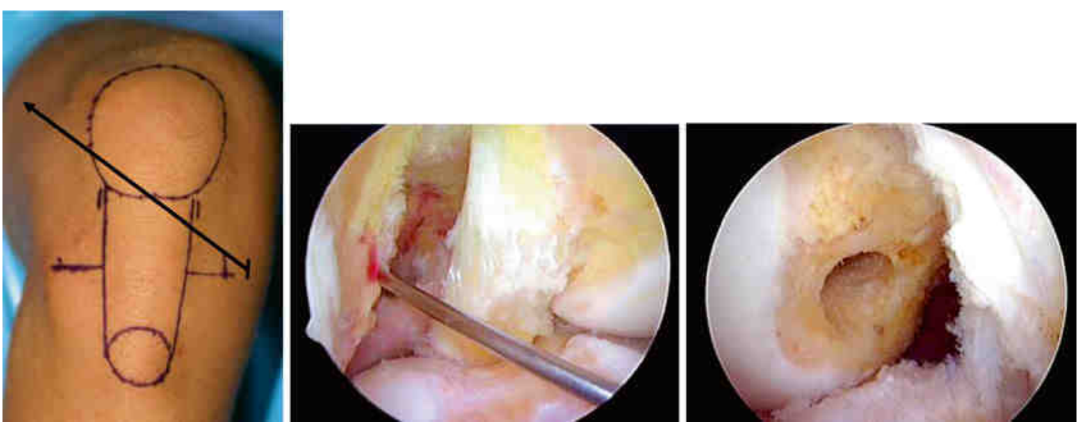

Fig. 19.4 Medial placement of the AAM portal results in a more perpendicular orientation of the spinal needle relative to the lateral wall of the notch. This orientation will produce a more circularly shaped aperture of the ACL femoral tunnel and a shorter femoral tunnel length

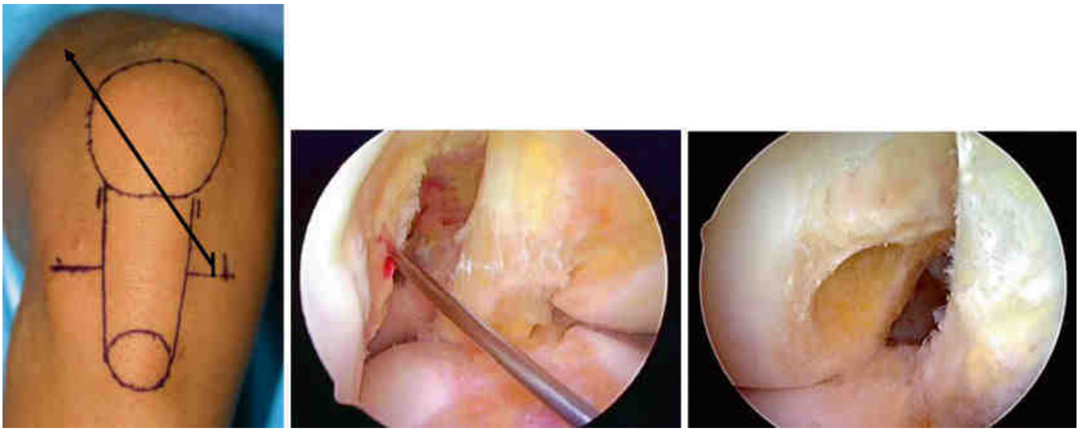

Fig. 19.5 A more lateral placement of the AAM portal results in a more oblique orientation of the spinal needle relative to the lateral wall of the notch. This orientation will result in a more elliptically shaped aperture of the ACL femoral tunnel and a longer femoral tunnel length

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, the required length of the femoral tunnel is in the range of 20–25 mm, which will allow a 20-mm bone block to be fully inserted into the femoral socket. In this situation, the AAM portal can be positioned more medially. When performing hamstring ACL reconstructions using a cortical suspensory femoral fixation technique, it is desirable to achieve a femoral tunnel length of around 40 mm, with the minimum tunnel length being around 35 mm. These femoral tunnel lengths allow for 20–25 mm of the hamstring tendon graft to be inserted into the ACL femoral socket when a 15-mm polyester loop is selected for the cortical suspensory implant.

An 18-gauge spinal needle is used to locate 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. The 30° arthroscope is rotated medially to determine if the spinal needle is positioned too close to the medial femoral condyle and the position adjusted accordingly. The AAM portal is created using a #11 knife blade, with the cutting edge of the blade oriented away from the anterior horn of the medial meniscus. The AAM portal is dilated by inserting the tips of the Metzenbaum scissors or a small clamp into the knee joint through the AAM portal incision and spreading the tips of the instrument in-line with the direction of the portal. This step will ease future instrument passage through the AAM portal.

19.5 Intercondylar Notch Preparation

The intercondylar notch is viewed through the AL portal and remnants of the torn ACL are resected using a basket punch and motorized shaver blade inserted into the knee joint through the AM portal. Some of the native ACL tissue is preserved at the femoral and tibial attachment sites to aid with later placement of the ACL femoral and tibial tunnels. To enhance biological healing and proprioception and to provide additional biomechanical support to the ACL replacement graft, an attempt should be made to preserve large ACL remnants with intact fiber connections from the femur to the tibia. The vertical fibers of lateral border of the posterior cruciate ligament (PCL) in the center of the notch should be identified and visualized by resecting some of the fat tissue surrounding the PCL with a motorized shaver blade. The distance from the lateral border of the PCL to the lateral wall of the intercondylar notch can be measured with an ACL ruler to ensure there is adequate space for

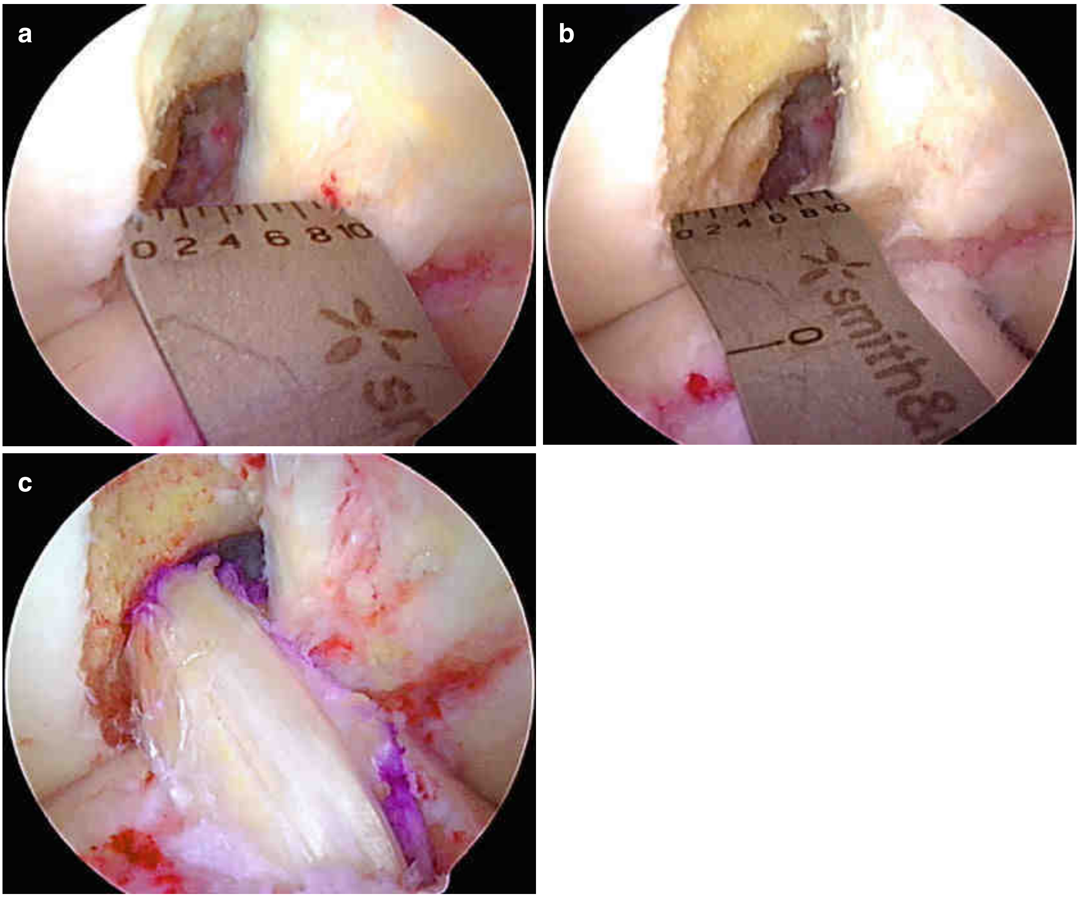

Fig. 19.6 (**a**) Chronic ACL-deficient knee with narrow notch width. The distance between the lateral border of the ACL and lateral wall of the notch measures 5 mm in this case. (**b**) A wallplasty was performed *after* drilling the ACL femoral tunnel. Note that the space between the deep part of the lateral wall of the notch at the site of the ACL femoral tunnel and the lateral border of the PCL was not changed. The distance between the lateral border of the PCL and the lateral wall of the notch was widened to 10 mm to accommodate an 8.5-mm, 5-stranded hamstring tendon graft. (**c**) 5-stranded, 8.5-mm hamstring tendon ACL graft. There is no lateral wall or PCL impingement

the ACL replacement graft (Fig. 19.6). In the case of large ACL grafts or small notch widths, a limited wallplasty may be required. However, the wallplasty should be performed after the ACL femoral tunnel is drilled to avoid removing remnants of the native ACL and the underlying bony landmarks which are valuable aids to help with placement of the ACL femoral tunnel. If a wallplasty is required, it is important to remove bone only at the shallow area of the notch and avoid removing bone in the area of the ACL femoral bone tunnel. Removing bone around the ACL femoral tunnel may lateralize the position of the tunnel, changing the axis of rotation of the ACL replacement graft.

The view of the intercondylar notch and the ACL femoral attachment site changes significantly depending on the arthroscopic portal utilized [3, 12, 39, 40]. 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 (Fig. 19.7). 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

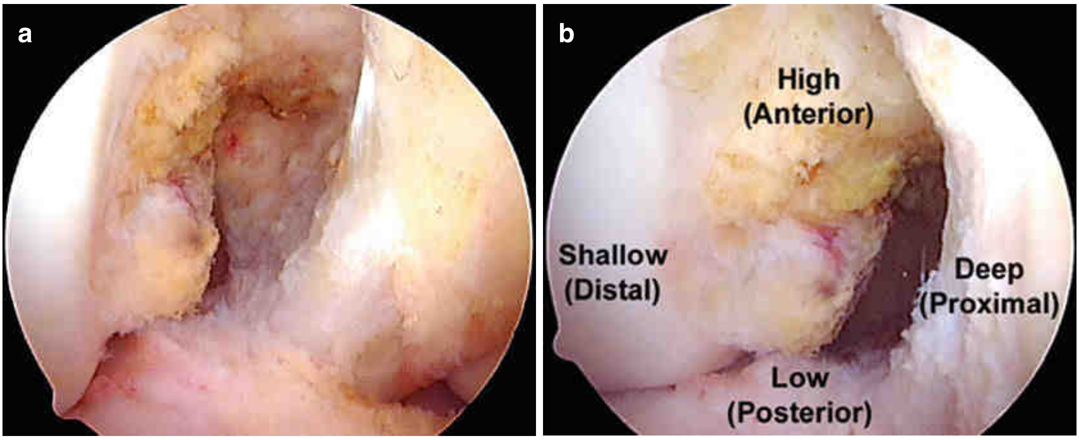

Fig. 19.7 (**a**) Right knee at 90°. View through the AL portal. This view provides a tangential view of the ACL femoral attachment site. (**b**) AM portal view at 90° of flexion. The native ACL femoral footprint is seen along the lower third of the lateral wall of the notch. In the arthroscopic terminology, directions along the lateral wall of the intercondylar notch are referred to as high or superior, low or inferior, and shallow and deep. The directions using the corresponding anatomic description (shown in parenthesis) which references the knee in the extended position are anterior, posterior, distal, and proximal [3, 14]

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 tissue and underlying bony landmarks.

The arthroscope is switched to the AM portal and the knee positioned at 90° of flexion to identify the ACL femoral attachment site. Identification of the ACL femoral attachment can be facilitated by maintaining 90° of flexion and placing the knee in the figure-four position. This position will open the lateral compartment and elevate the femur off the tibia and the lateral meniscus providing a superior view of the inferior articular cartilage border which is an anatomic landmark for the lower border of the native ACL attachment site. Placing the knee in the figure-four position also protects the posterior horn of the lateral meniscus during drilling of the ACL femoral tunnel (Fig. 19.8).

19.6 Identification of the Center of the ACL Femoral Attachment Site

Although the clockface reference method has often been used to specify the location of the ACL femoral tunnel, the clockface reference method has several shortcomings: it ignores the depth of the intercondylar 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 [3, 12]. Due to the above limitations, the clockface reference is not an accurate method to specify or locate ACL femoral tunnel position. ACL femoral tunnel position is more accurately located and specified using the following methods:

19.6.1 Native ACL Footprint

In most situations, there are remnants of the native ACL present to aid with anatomic ACL femoral tunnel placement (Fig. 19.9).

To use the native ACL footprint method, view the lateral wall of the notch with the 30° arthroscope positioned in the AM portal. Insert a 90° thermal probe through the AAM portal and mark the borders of the ACL femoral attachment site. Next, insert an angled microfracture awl through the AAM portal and mark the center of the ACL femoral attachment site. This "eyeball" technique is fairly accurate for estimating high-low positions. However, due to the visual distortion

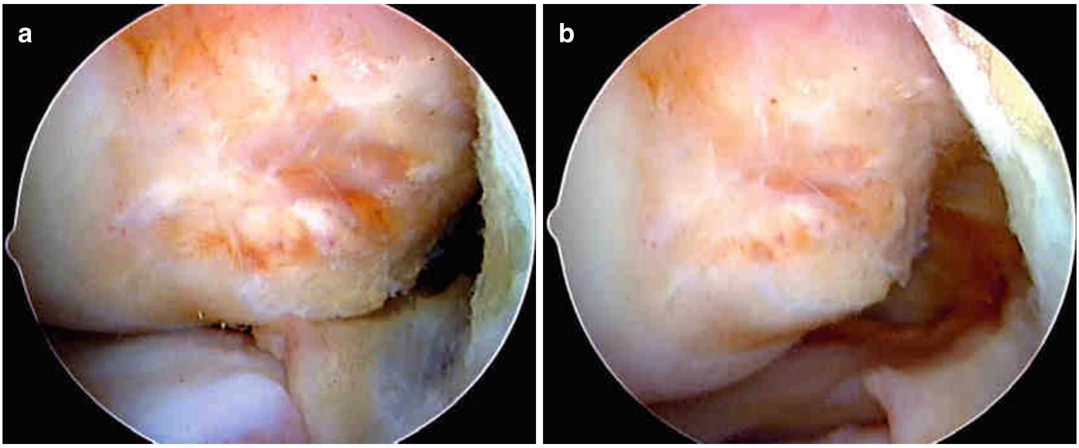

Fig. 19.8 Right knee. (**a**) View of the ACL femoral attachment site through the AM portal with the knee at 90° of flexion. Remnants of the native ACL are seen lying inferior to the lateral intercondylar ridge. (**b**) View of the ACL femoral attachment site through the AM portal with the knee at 90° in the figure-four position. The lateral compartment is opened and the femur elevated from the lateral meniscus. This position provides a better view of the inferior and deep aspects of the ACL femoral attachment site

Fig. 19.9 AM portal view at 90° of flexion. The native ACL femoral footprint is clearly seen

associated with the use of a 30° arthroscope, using visual cues to locate the center of the ACL femoral attachment site tends to position the tip of the microfracture awl more shallow than the true center of the ACL femoral attachment site. The true center of the ACL attachment site can be more accurately located using an ACL ruler inserted through the AL portal oriented along the long axis of the ACL attachment site. To achieve the correct axis of measurement, the knee is flexed to 110–120° which orients the long axis of the ACL femoral attachment site parallel to the tibial plateau. The length of the ACL femoral footprint is measured from the deep (proximal) border to the shallow (distal) border along its long axis and the midpoint located and marked by inserting an angled microfracture awl through the AAM portal (Fig. 19.10).

19.6.2 Lateral Intercondylar and Bifurcate Ridges

When there are no remnants of the native ACL present, the underlying bony morphology of the ACL femoral attachment site can provide useful anatomic landmarks to assist with anatomic ACL femoral tunnel placement. The lateral

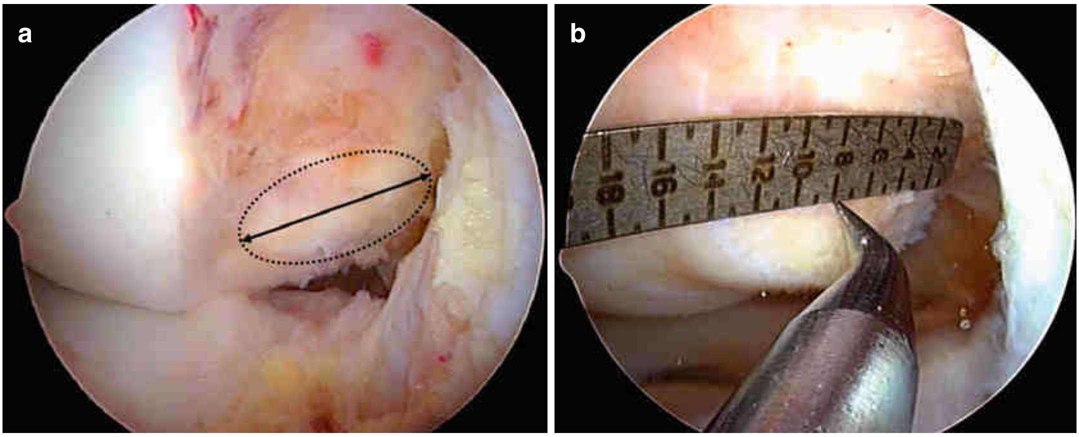

Fig. 19.10 (**a**) AM portal view at 90° of flexion. The margin of the native ACL footprint is outlined by the *dotted ellipse*. The knee is flexed to 110° and the length of the ACL femoral attachment site is measured along its long axis (*black line*). (**b**) The ACL ruler is inserted through the AL portal and an angled microfracture awl inserted 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

intercondylar ridge, when present, is an important anatomic landmark to aid the knee surgeon with anatomic ACL femoral tunnel placement since the native ACL *always* attaches inferior to this ridge [3, 20, 22–24, 26–28]. The lateral intercondylar ridge, therefore, marks the upper limit of the superior border of the ACL femoral attachment site. 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 [3, 12, 13, 20, 24, 26, 29] (Fig. 19.11). 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.

Fig. 19.11 View through the AM portal at 90° of flexion. The lateral intercondylar and bifurcate ridges are clearly seen

The arthroscope is placed in the AM portal and a 90° thermal probe or motorized shaver blade is inserted into the knee joint through the AAM portal and used to remove soft tissue along the lower third of the lateral wall of the notch. The knee is positioned at 90° of flexion and the border of the inferior (posterior) articular cartilage identified. As mentioned earlier, the inferior articular cartilage border is best visualized by placing the knee in the figure-four position. The lateral intercondylar ridge is most easily identified by starting the dissection at the inferior articular cartilage border and working in the superior (high) direction along the lateral wall of the notch. A distinct endpoint is often encountered as the tip of the thermal probe contacts the ridge. The center of the ACL femoral attachment site in the high-low direction is midway between the lateral intercondylar ridge or the superior border of the ACL footprint and the inferior articular cartilage border (Fig. 19.12). Based on anatomic studies, this distance is in the range of 7.3–8.6 mm [8, 21, 23, 28]. According to Ziegler

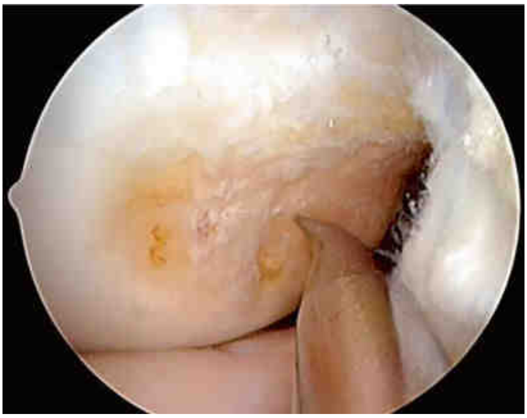

Fig. 19.12 AM portal view at 90°. The tip of the angled microfracture awl is located at the center of the ACL femoral attachment site, 2 mm deep (proximal) to the lateral bifurcate ridge, and halfway between the lateral intercondylar ridge and the inferior (posterior) articular cartilage border

et al., the center of the ACL femoral tunnel in the shallow-deep (proximal-distal) direction is 1.7 mm deep (proximal) to the lateral bifurcate ridge [26]. When the lateral bifurcate ridge is not present or visualized, the shallow-deep position of the ACL femoral tunnel can be determined using an ACL ruler as described below.

19.6.3 ACL Ruler

Use of an ACL ruler allows the knee 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. This technique is particularly useful for revision ACL reconstructive surgery where there are usually no remnants of the native ACL present and the bony landmarks may have been destroyed by prior notchplasty or the previous ACL femoral bone tunnel. The knee is placed at 90° of flexion and the ACL femoral attachment site viewed through the AM portal using a 30° arthroscope. The malleable ACL ruler is bent at approximately a 45° angle at the 24-mm mark to allow it to lie flat along the lateral wall of the notch. The ACL ruler is inserted into the intercondylar notch through either the AL or the AAM portal (Fig. 19.13). Inserting the ruler through the AL portal allows an angled microfracture awl to be inserted through the AAM portal, making it possible for the surgeon 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 difficult to position the ACL ruler lower down the lateral wall of the notch at the location of the lateral intercondylar ridge. This limitation can often be overcome by flexing the knee to 120° and or placing the knee in the figure-four position. If these maneuvers are unsuccessful, then the ruler should be inserted into the notch through the AAM portal. The lower position of the AAM portal allows the ruler to be easily positioned along the ACL femoral attachment site.

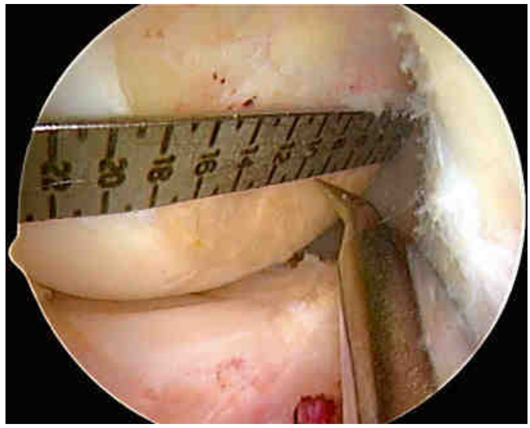

Fig. 19.13 (**a**) View through the AM portal at 90° of flexion. The ACL ruler has been bent to lie flat along the lateral wall of the intercondylar notch. The ruler is inserted through the AL portal and the lower edge is positioned to lie parallel to the wall of the notch just below the lateral intercondylar ridge. In this case, the distance from the deep to shallow articular cartilage margin measures 19 mm. The tip of the microfracture awl is positioned at the 9-mm mark which is 0.5 mm deeper than the calculated 50 % distance (9.5 mm)

In the situation where there are no remnants of the native ACL present, position the lower edge of the ruler parallel to and just above the lateral intercondylar ridge. This approach allows the entire ACL femoral attachment site to be visualized which aids in determining the high-low position of the ACL femoral tunnel. Alternatively, the upper edge of the ruler can be positioned parallel to and just below the lateral intercondylar ridge. Insert the ruler along the lateral wall of the notch until the tip is positioned at the deep (proximal) border of the articular cartilage. This point represents the zero reference point for the ruler. Note that this position is different than the commonly referenced “over-the-top” position which lies higher and deeper in the notch. It is important to resect enough soft tissue from the lateral sidewall of the notch to clearly visualize this point. It is helpful to place the tip of an angled microfracture awl at this location and slide the ruler into the notch until tip of the ruler contacts the tip of the microfracture awl. This step will accurately align the ruler at the correct starting point. The length of the sidewall of the notch is measured to the point where the ACL ruler touches the shallow margin of the articular cartilage (Fig. 19.13).

Insert an angled microfracture awl through the AAM portal and use it to mark the location of the ACL femoral tunnel. The center of the ACL femoral tunnel should be located at a shallow-deep position that is 45–50 % of the measured distance from the deep (proximal) articular cartilage border to the shallow articular cartilage border. This point has been validated by Bird et al. as a close approximation to the center of the ACL femoral attachment site [43]. Anatomic studies have revealed that the high-low position of the center of the ACL femoral attachment site is located 7.3–8.6 mm above the inferior articular cartilage border [21, 28, 44]. This position can be achieved by positioning the tip of the microfracture awl midway between the lateral intercondylar ridge or the superior border of the ACL footprint and the inferior (posterior) articular cartilage border.

Note that it is important to avoid positioning the ACL femoral tunnel too shallow in the notch as this will result in the ACL replacement graft experiencing higher forces in extension. The zero starting point of the ruler must be accurately identified and if in doubt the 50 % measured distance reduced by 1–2 mm to avoid positioning the ACL graft too shallow in the notch. Figure 19.14 demonstrates the anatomy of the ACL femoral attachment.

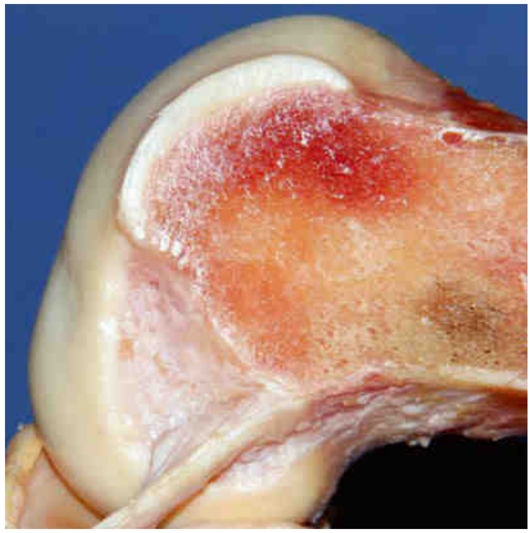

Fig. 19.14 Right knee, human cadaver. The medial femoral condyle has been removed, allowing the ACL femoral attachment site to be visualized. The lateral intercondylar ridge is clearly seen. Note that the shallow fibers of the native ACL do not completely extend to the shallow articular cartilage margin

19.7 Use of Intraoperative Fluoroscopy

At the present time, interoperative fluoroscopy is the most accurate method to determine and evaluate ACL femoral tunnel placement [45–47]. Fluoroscopy gives the surgeon the ability to precisely measure and if needed change the ACL femoral tunnel position during the surgical procedure. Fluoroscopy is especially valuable in revision cases where there are usually no remnants of the native ACL present and the bony anatomy of the ACL femoral attachment site has been altered or destroyed by prior notchplasty and the previous ACL femoral tunnel. Fluoroscopy is also extremely helpful when attempting to preserve remnants of the torn ACL or performing an augmentation technique for a partial ACL tear. In these situations, identification of the lateral intercondylar and bifurcate ridges is not feasible as this would require resection of intact ACL fibers to expose the lateral wall of the notch. The ruler technique is also not possible since the intact ACL fibers prevent accurate positioning of the ruler along the lateral wall

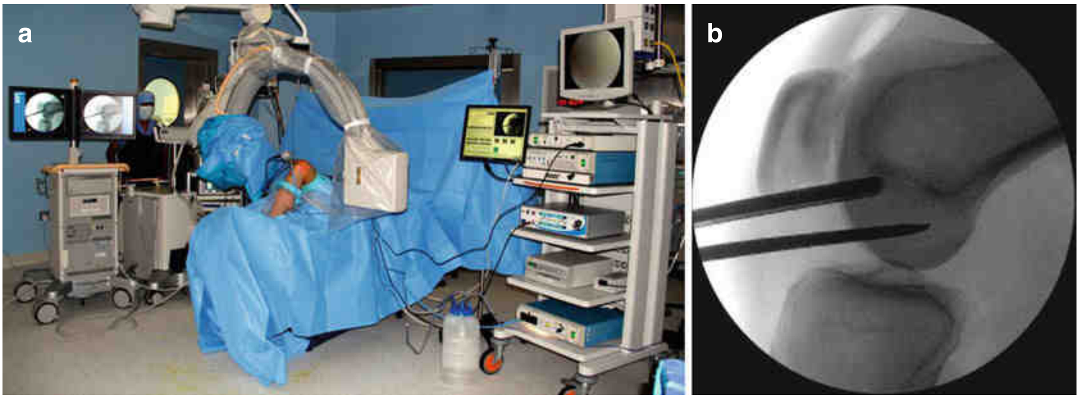

Fig. 19.15 (**a**) Intraoperative fluoroscopy. (**b**) The angled microfracture awl is positioned at the center of the ACL femoral attachment site

of the notch. Using fluoroscopy, the proper placement of the ACL femoral tunnel can be easily accomplished without the need to rely on remnants of the native ACL, measurements along the lateral wall of the notch, or the bony anatomy of the ACL femoral attachment site.

The knee is positioned at 90° of flexion and an angled microfracture awl is 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 (Fig. 19.15a). A true lateral radiograph is one in which the inferior (posterior) and deep (proximal) borders of the medial and lateral femoral condyles overlap (Fig. 19.15b). Due to the size difference between the medial and lateral femoral condyles, it is often difficult to achieve a perfect overlap of the shallow (distal) borders of both condyles. However, it is not necessary to achieve a perfect overlap of the distal condylar borders to obtain reliable information.

The grid system described by Bernard and Hertel is used to locate the center of the ACL femoral attachment site [45]. This method is easy to use, is reproducible, and has been shown to be independent of the knee size, shape, and the distance between the x-ray tube and the patient. The Bernard-Hertel grid is drawn in the following way:

1. 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 the intersection of the tangent line and the deep border of the lateral femoral condyle. The lateral femoral condyle can be identified by an indentation at the distal margin (Grant's notch) and the fact that the medial femoral condyle extends more distal.
2. 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 (Fig. 19.16).

The Bernard-Hertel grid has been used to locate the centers of the PL and AM bundle in human cadaveric specimens [19, 25, 28, 38, 44, 45, 48–50]. A summary of these studies is shown in Table 19.1.

Using data from these studies, a weighted average position for the center of the ACL femoral attachment site can be calculated. This calculation reveals that the center of the ACL femoral attachment site is located at a point which is 27 % along Blumensaat's line and 34 % of the height of the intercondylar notch (Fig. 19.17).

Commercially available software (Smith & Nephew ACUFEX Director Application Anatomic Guide) can be used to plot the Bernard and Hertel grid from the intraoperative c-arm image

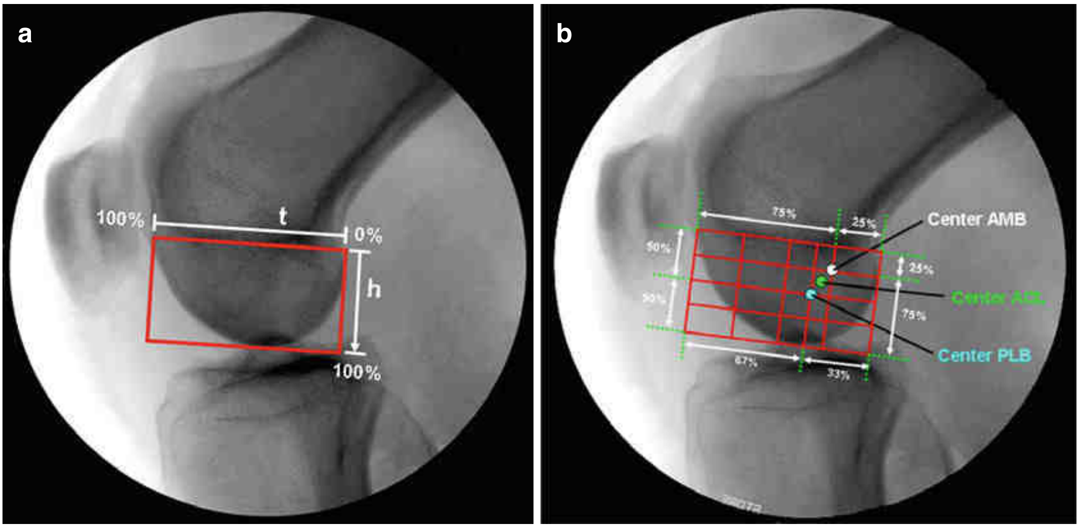

Fig. 19.16 (**a**) Bernard-Hertel grid method, (t) represents measurement along Blumensaat's line and (h) the height of the intercondylar notch. (**b**) The centers of the AM and PL bundles are shown according to the data of Columbet et al. [19]. In this study, the center of the AM bundle was found to 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)

Table 19.1 Published anatomic studies using the Bernard-Hertel grid to locate the centers of the AMB and PLB

Summary of radiographic grid measurements						
Study	AMB depth	PLB depth	Av 50 % depth	AMB height	PLB height	Av 50 % height
Bernard-Hertel (1997) [45], $n=10$			24.8			28.5
Yamamoto (2004) [38], $n=10$	25	29	27	16	42	29
Colombet (2006) [19], $n=7$	26.4	32.3	29.4	25.3	47.6	36.5
Zantop (2008) [28], $n=20$	18.5	29.3	23.9	22.3	53.6	38.0
Tsukada (2008) [25], $n=36$	25.9	34.8	30.4	17.8	42.1	30.0
Lorenz (2009) [50], $n=12$	21	27	24	22	45	34
Forsythe (2010) [48], $n=8$	21.7	35.1	28.4	33.2	55.3	44.3
Pietrini (2011) [44], $n=12$	21.6	28.9	25.3	14.6	42.3	28.5
Iriuchishima (2010) [49], $n=15$	15	32	23.5	26	52	39
Weighted averages	22.0	31.6	26.7	21.0	46.8	33.5

(Fig. 19.18). Alternatively, the images can be saved to an image capture unit and the grid applied later as a quality control check. The microfracture awl position is adjusted under arthroscopic and fluoroscopic guidance until the desired position is obtained.

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 ACL femoral tunnel placement. ACL femoral offset aimers can constrain the location of the femoral guide pin and can lead to nonanatomic 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.

19.8 Drilling the ACL Femoral Tunnel

The 30° arthroscope is placed in the AM portal and the angled microfracture awl inserted into the notch through the AAM portal. The tip of the

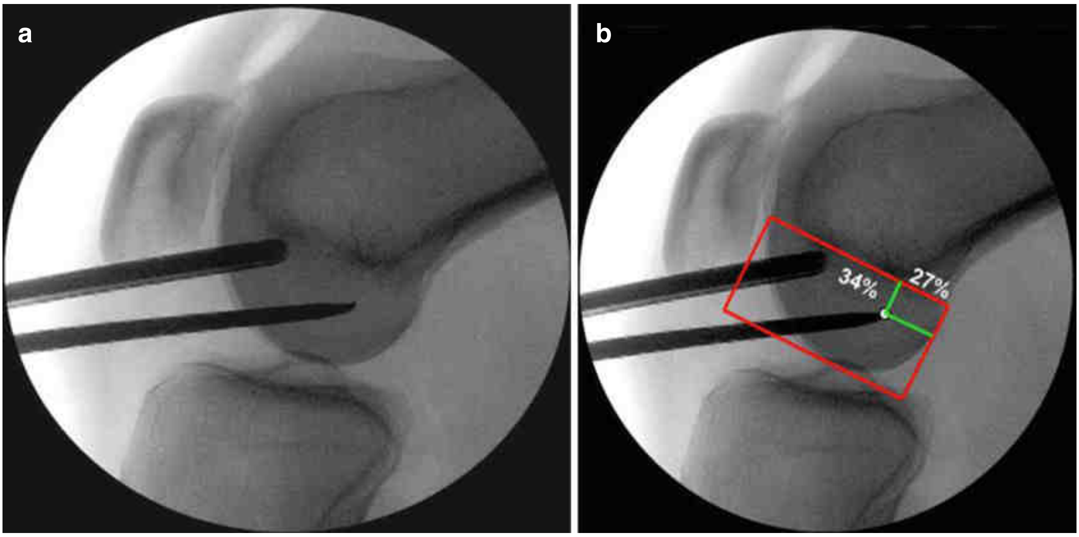

Fig. 19.17 (**a**) Intraoperative fluoroscopic image. (**b**) Bernard-Hertel grid. The tip of the angled microfracture awl is located at the 27 %/34 % location, which represents the center of the ACL femoral attachment site based on the calculated weighted average from published anatomic studies [19, 25, 28, 38, 44, 45, 48–50]

angled microfracture awl is positioned at the center of the ACL femoral attachment and the knee slowly flexed to a minimum of 120°. Flexion above 120° is often helpful in achieving longer femoral tunnel lengths. The knee is stabilized in hyperflexion by locking the foot of the operative leg under the most proximal foot post. One criticism about viewing the ACL femoral attachment site through the AM portal is that the view is compromised by the need to work in the notch with the knee flexed to 120° or higher. Due to the rotation of the ACL femoral attachment site that occurs when the knee is flexed beyond 90°, it is our experience that an excellent view of the ACL femoral attachment site, particularly the inferior and deep aspects, can be obtained (Fig. 19.19). As a result, we have not found it necessary to use a 70° arthroscope or switch the arthroscope to the AL portal.

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. One solution to maintain adequate joint distension and visualization while working in the notch with the knee in hyperflexion is to increase the pump fluid pressure up to 120 mm Hg. The pump pressure is decreased back to the normal setting after drilling the ACL femoral tunnel and the knee has been extended back to 90°. If increasing the fluid pressure does not solve the problem and the fat pad still limits visualization, limited resection of the fat pad should be performed using a motorized shaver blade inserted through the AAM or AL portal.

The microfracture awl is removed from the knee and a 0° ACL femoral offset aimer inserted in the notch through the AAM. The offset femoral aimer is advanced to the site of the mark left by the microfracture awl. If there is an inadequate view of the ACL femoral attachment site or loss of the microfracture awl occurs, the knee is brought back to the 90° position and further soft tissue resected using a motorized shaver blade. A drill-tip-graduated guide pin is passed into the notch through the 0° ACL offset femoral aimer and placed into the divot mark left by the microfracture awl. The drill-tip guide pin is tapped into the bone using a small mallet. Keeping the tip of the drill-tip guide pin in the divot, the handle of the 0° offset aimer is slowly moved in a lateral direction, and the guide pin is

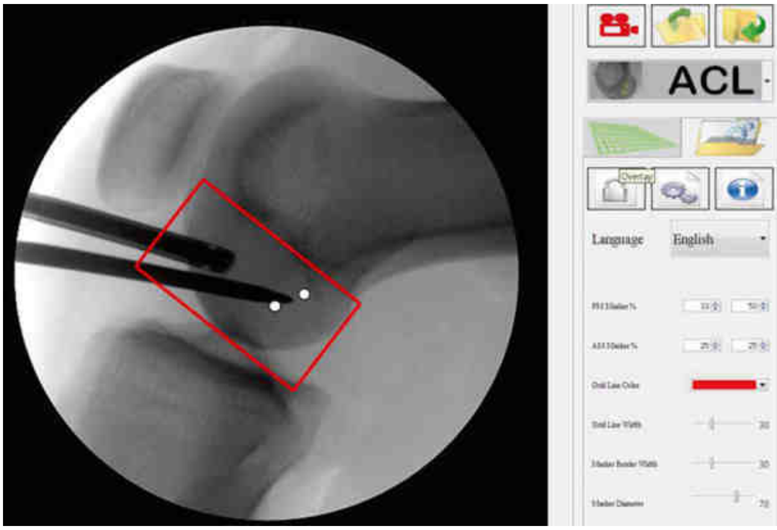

Fig. 19.18 The Smith & Nephew ACUFEX Director Application Anatomic Guide software was used to plot the location of the AM and PL bundles (*white circles*) based on the data of Columbet et al. [19]. The software also allows other data for the centers of the AM and PM bundles to be selected. In this example, the tip of the microfracture awl is positioned halfway between the centers 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

Fig. 19.19 View through the AAM portal with the knee in hyperflexion. The inferior and deep (proximal) aspects of the ACL femoral attachment site are well visualized. The ACL femoral tunnel position has been previously marked with a microfracture awl using the ACL ruler method. The marked location can be clearly seen to lie at the center of the ACL attachment site

tapped into the attachment site until the drill-tip part of the 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 (Fig. 19.20). 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 [42]. Slowly drill the drill-tip-graduated guide pin through the lateral femoral condyle until the resistance of the lateral femoral cortex is encountered. 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 less than desired, it is often 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.

Depending on the intended graft fixation method, final drilling of the femoral tunnel is variable but essentially involves using a drill bit which is sized to the measured diameter of the ACL replacement graft. When using a cortical suspensory fixation technique such as the

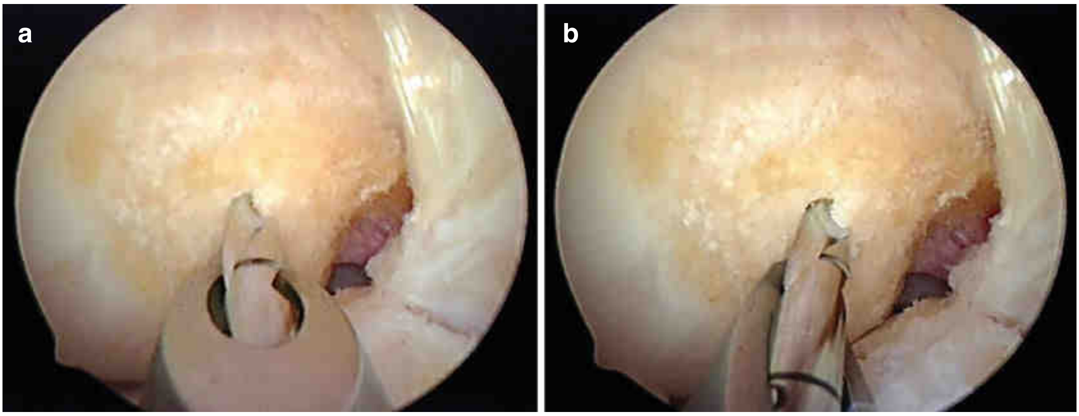

Fig. 19.20 AM portal view in hyperflexion. (**a**) The femoral drill-tip guide pin is oriented perpendicular to ACL femoral attachment site. This guide pin orientation will result in a short femoral tunnel length and a more circular shape of the ACL femoral tunnel aperture. (**b**) The 0° offset aimer has been angled laterally which results in the guide pin being oriented more obliquely to ACL femoral attachment site. 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

ENDOBUTTON CL (Smith & Nephew, London, UK), it is necessary to drill a 4.5-mm tunnel through the lateral cortex of the femur. The 4.5-mm ENDOBUTTON drill bit can be used to measure the tunnel length by hooking the 10-mm drill portion on the lateral cortex and subtracting this distance from the measured length noted arthroscopically. Alternatively, the femoral tunnel length is measured using a depth gauge. During drilling of the ACL femoral tunnel, fluid flow and visualization in the notch can be facilitated by inserting 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.

The 4.5-mm ENDOBUTTON (or equivalent) drill bit is removed from the knee joint and the appropriate size endoscopic reamer advanced over the guide pin to the ACL femoral attachment site (Fig. 19.21). The depth of the femoral socket is determined by the measured length of the femoral tunnel. For the ENDOBUTTON fixation device, the depth of the ACL femoral socket must equal the length of the ACL graft to be inserted into the socket plus an additional minimum distance of 6 mm, to allow the ENDOBUTTON to exit the femoral tunnel and flip on the lateral femoral cortex. When femoral fixation of the ACL graft is performed with an interference screw, the femoral socket can be drilled to the length of the bone block so that the desired length of graft can be inserted into the femoral socket. The reamer is removed from the knee joint and a number 2 polyester

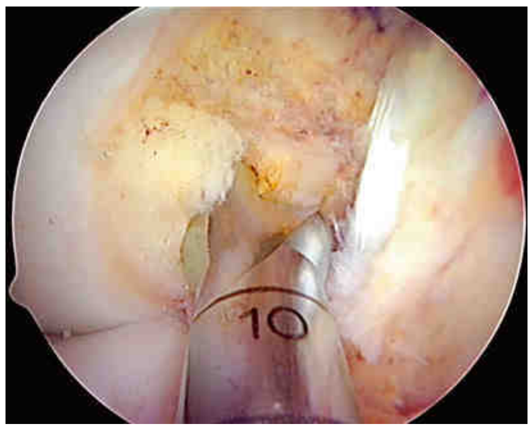

Fig. 19.21 AM portal view in hyperflexion. The endoscopic drill bit is inserted into the knee joint through the AAM portal. The ACL femoral footprint is clearly visible and the drill bit is seen to lie at the center of the ACL femoral attachment site

suture threaded through the eyelet of the guide pin. The free ends of the suture are pulled out through the lateral soft tissue, leaving the loop of the suture in the femoral socket.

19.9 Assessment of the Femoral Tunnel

A motorized shaver blade is inserted into the femoral tunnel through the AAM portal and used to remove bony debris from inside the femoral tunnel. The knee is positioned at 90° and the ACL femoral tunnel inspected. A minimum 2-mm wall should remain inferiorly (posterior) and the aperture of the tunnel should be elliptically shaped rather than circular, thereby more closely restoring the shape of the native ACL femoral attachment site and maximizing the femoral tunnel surface area (Fig. 19.22).

19.10 Alternatives and Variations to This Technique

The surgical technique described in this chapter has outlined several methods for creating an anatomic ACL femoral tunnel. The principal goal of all of these methods is to create an elliptically shaped ACL femoral tunnel at the center of the native ACL femoral attachment site. Alternative techniques for creating the ACL femoral tunnel include:

1. Instead of using two medial portals, the ACL femoral attachment site can be viewed through the AL portal and the femoral tunnel drilled through an AM or AAM portal. This technique may be advantageous in small knees where instrument crowding may occur when using two medial portals. The scope can be temporarily placed into the AM portal to fully evaluate the anatomy of the ACL attachment site and to locate the center of the ACL femoral attachment site. Once this has been accomplished, the arthroscope is moved back to the AL portal and the ACL femoral tunnel drilled through the AM or AAM portal.
2. The ACL femoral tunnel can be drilled using flexible reamers, in which case, it is not necessary to hyperflex the knee.
3. The ACL femoral tunnel can be drilled using an outside-in technique. In this situation, the exit point of the guide wire within the notch can still be determined by the methods described in this chapter.

Memory
The ACL femoral attachment site is defined by two bony ridges, the lateral intercondylar and the lateral bifurcate ridges. The lateral intercondylar ridge is an important

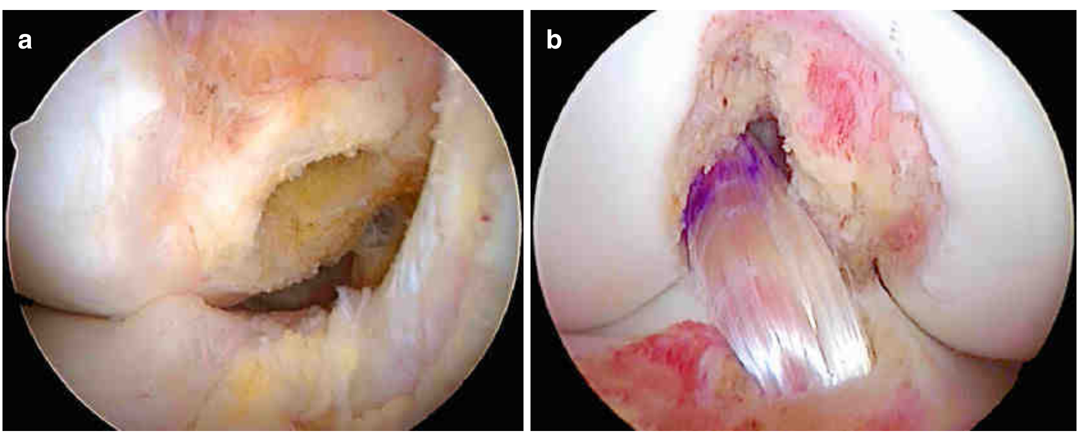

Fig. 19.22 (**a**) AM portal view at 90°. The elliptically shaped aperture of the ACL femoral tunnel is centered in the ACL femoral footprint. (**b**) 5-stranded hamstring ACL graft positioned at the center of native femoral and tibial attachment sites

anatomic landmark during surgery since the native ACL always attaches inferior (posterior) to it. The center of the ACL femoral attachment site is 1.7 mm deep (proximal) to the bifurcate ridge and 7.3–8.5 mm superior (anterior) to the inferior (posterior) articular cartilage border of the lateral femoral condyle. For anatomic single-bundle ACL reconstruction, the center of the ACL femoral attachment site is chosen as the location for the ACL femoral tunnel. This recommendation is based on biomechanical studies demonstrating that an ACL replacement graft placed at the center of the ACL femoral attachment site is more effective in controlling anterior tibial translation and the combined motions of anterior tibial translation and internal tibial rotation (simulated pivot shift test) compared to an "isometric" ACL femoral tunnel placement or femoral tunnel placements that have traditionally restored predominantly the anteromedial bundle fibers. The ACL femoral attachment site is best visualized by viewing the lateral wall of the intercondylar notch through the anteromedial portal. Anatomic placement of the ACL femoral tunnel is facilitated by drilling the femoral tunnel through an accessory anteromedial portal. Drilling the ACL femoral tunnel through the AAM portal allows acceptable femoral tunnel lengths to be obtained. The center of the ACL femoral attachment site can be located using the following methods: the native ACL footprint, the lateral intercondylar and bifurcate ridges, an ACL ruler, and intraoperative fluoroscopy.

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