17 Anatomy of the ACL Insertions: Arthroscopic Identification of the Attachments

Jorge Chahla and Robert F. LaPrade

17.1 Relevant Femoral Bony Landmarks

Bony landmarks on the lateral femoral condyle, including the lateral intercondylar ridge (LIR), bifurcate ridge (BR), femoral notch roof, over-the-top position (OTP), and the posterior notch outlet, have been described as consistent landmarks for determining anteromedial (AM) and posterolateral (PL) ACL bundle tunnel placement [1]. For the purpose of description of the landmarks, proximal/distal will be considered cephalic/caudal respectively and anterior/posterior will be ventral/dorsal respectively.

Identification of the LIR and BR has been reported to be an accurate and reliable method to locate the native ACL femoral insertion site [2] (Fig. 17.1). The LIR (commonly known as the "resident's ridge" as described by Clancy [3]) is particularly useful because it serves as the anterior margin of both the individual bundles and the overall ACL femoral attachment. It has shown to be consistent in all specimens in cadaveric and arthroscopic studies [1, 4–6]. Moreover, the LIR is usually identifiable arthroscopically, whereas the BR, which separates the AM and PL bundle femoral attachments, is more subtle, difficult to locate, and may not always be apparent during arthroscopic surgery [1]. Of note, the BR represents a delicate change of slope resembling a ledge rather than a convex ridge. Identification of the BR may be difficult arthroscopically, especially when using motorized shavers or curettes to clean off the lateral femoral wall. When the BR is visible and palpable, it has the potential to serve as a useful surgical landmark, especially for single- and double-bundle ACL reconstructions.

Landmarks from the distal and posterior articular cartilage margins, the proximal point, and the posterior point can also serve as references to guide ACL femoral reconstruction tunnel placement [1]. In particular, the perpendicular intersection of a line extending proximally from the distal articular cartilage margin and a line extending anteriorly from the posterior articular cartilage margin may be useful for locating the center of the ACL attachment [1]. For the reasons mentioned above, a patient's native anatomy should be carefully preserved by dissection (with mechanized shavers or thermal devices) of the anatomical insertions in order to leave more intact landmarks to guide tunnel placement.

17.2 Femoral Footprint Morphology and Location

The femoral insertion site of the ACL is described as either circular or oval shaped and similar in size between the two bundles (AM and PL). The areas of the entire ACL insertions are 113 ± 27 mm^2 and 136 ± 33 mm^2 for the femur and tibia, respec-

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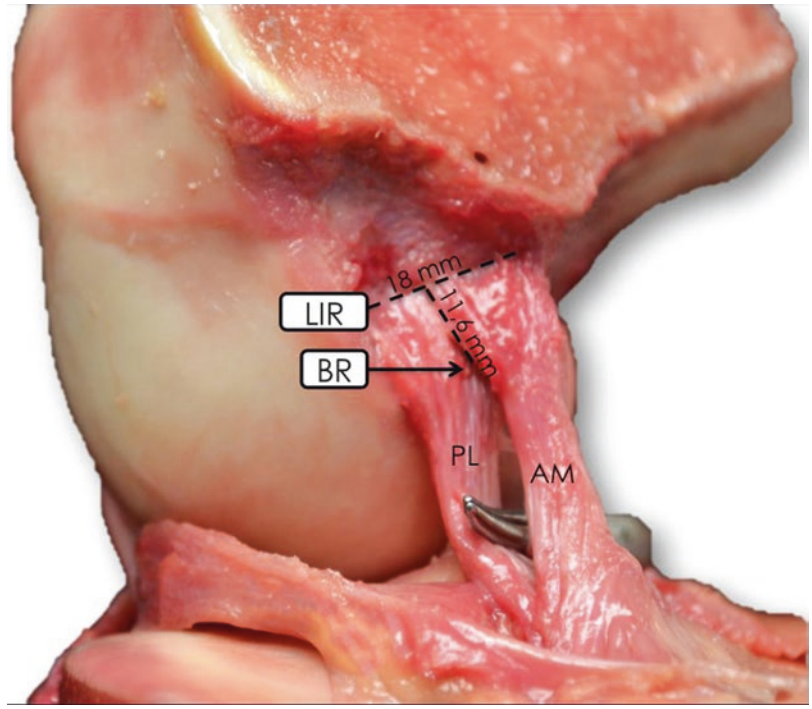

Fig. 17.1 Lateral view of a hemi-sectioned right knee illustrating relevant femoral bony landmarks. The lateral intercondylar ridge (*LIR*) represents the most anterior femoral attachment for both bundles (18 mm average length) and the subtler bifurcate ridge (*BR*), which extends from the LIR to the posterior cartilage (11.6 mm average length)

tively [7]. Hensler et al. [8] reported that only 61% of the femoral insertion is reconstructed with standard tunnel reaming. The overall ACL attachment center is 6.1 mm posterior to the lateral intercondylar ridge, 1.7 mm proximal to the bifurcate ridge, 14.7 mm proximal to the distal cartilage margin, and 8.5 mm anterior to the posterior cartilage margin [1]. The footprint of the AM bundle is approximately 52% of the total femoral ACL insertion area, and that of the PL bundle is approximately 48% [9]. The AM bundle femoral attachment center is 7.1 mm posterior to the lateral intercondylar ridge, 4.8 mm proximal to the bifurcate ridge, 18.6 mm proximal to the distal cartilage margin, and 11.7 mm anterodistal to the proximal point. The PL bundle attachment center is 3.6 mm posterior to the LIR, 5.2 mm distal to the bifurcate ridge, 10.7 mm proximal to the distal cartilage margin, and 5.7 mm anterior to the posterior cartilage margin [1]. Slight ACL size variations may exist depending on the age, gender, or size of the specimen under study.

The AM and PL bundle attachments appear differently as the knee flexion angle changes (Fig. 17.2). Therefore, the knee flexion angle has been assumed to be the most powerful and modifiable factor influencing the arthroscopic view [10].

17.3 Relevant Tibial Bony and Soft Tissue Landmarks

Specific bony landmarks assessed for the ACL tibial attachment include the lateral and medial tibial eminences, the medial and lateral tibial plateau articular cartilage borders, the ACL ridge, the ACL tubercle, the anterolateral fossa, and the retroeminence ridge [1]. Relevant soft tissue landmarks are the anterior horn of the lateral meniscus and the anterior intermeniscal ligament (AIL).

The *anterolateral fossa* is a bony depression immediately medial to the lateral tibial plateau articular cartilage border and anterior to the lateral tibial eminence, which corresponds to the attachment of the anterior horn of the lateral meniscus. The *ACL ridge* is an anterior bony elevation that courses between the anterolateral fossa and the medial tibial plateau articular cartilage border. The *ACL tubercle* defines the lateral-most aspect of the ACL ridge. The ACL ridge and tubercle serves as a landmark for the anterior-most border of the ACL tibial attachment. The retroeminence ridge ("over-the-back" ridge) is a transverse ridge located at the apex of the posterior slope of the tibial plateau in close relationship with the anterosuperior aspect of the PCL tibial attachment [1].

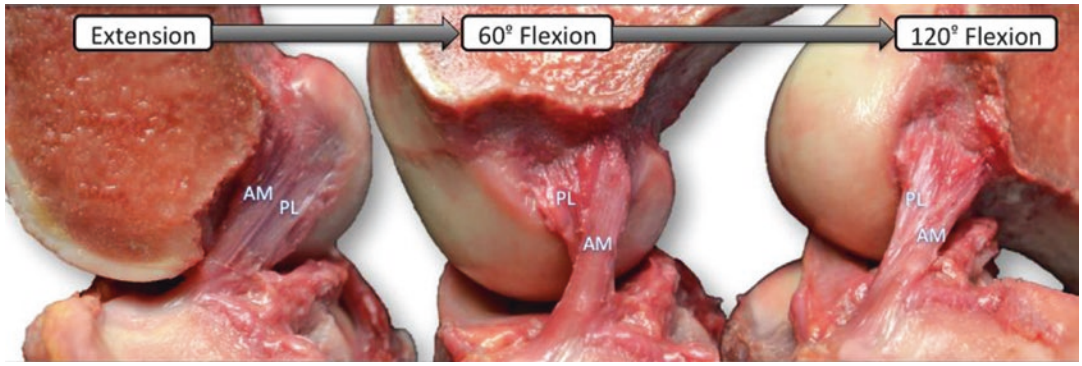

Fig. 17.2 Lateral view of a hemi-sectioned right knee demonstrating changes in bundles and femoral insertion sites with progressive knee flexion (extension, 60° of flexion and 120° flexion). This relationship is essential to understand for the arthroscopist in order to perform an anatomical reconstruction

17.4 Tibial Footprint Morphology and Location

Harner et al. [7] reported that the tibial insertion of the ACL is 120% of the area of the femoral insertion site. Kopf et al. [11] showed that with standard drilling, only 57% of the native tibial insertion is reproduced. The tibial insertion site of the ACL has been described as having a duck-foot shape [5]. The division between the attachments of the AM and PL bundles on the tibia is obliquely oriented and courses in a posteromedial-to-anterolateral direction, with an average distance between the bundle centers of 10.1 mm. The distinctive contour of this division imparts a convex, comma-shaped appearance to the AM bundle footprint, enveloping the medial convex contour of the PL bundle [1]. The ACL center is 10.5 mm posterior to the ACL ridge, 13 mm anterior to the retroeminence ridge, and 7.5 mm medial (and slightly anterior [7]) to the anterior horn of the lateral meniscus [1] (Figs. 17.3 and 17.4).

Fibrous connections extending from the anterior horn of the lateral meniscus attachment to the ACL bundles are constant (the anterior aspect of the anterior horn of the lateral meniscus attachment is aligned with the AM bundle, whereas the posterior aspect fibrous attachments are aligned with the PL bundle) [1] (Fig. 17.5).

In regard to the tibial eminences, no ACL insertion is located posterior to the lateral tibial eminence [7]. The medial tibial eminence has less variability, having a constant relationship with the center of the ACL and its bundles [7]. Harner [7] reported the AIL as a reliable landmark (center of

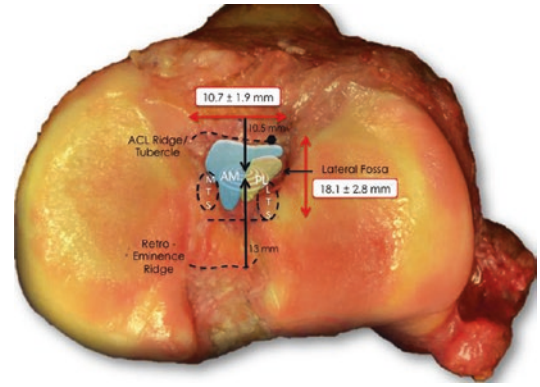

Fig. 17.3 Superior view of a right tibia depicting distances between the most reliable tibial bony landmarks. The average distance of the tibial footprint is indicated with their respective standard deviations. An important anatomic fact is that none of the ACL tibial insertion is posterior to the lateral eminence

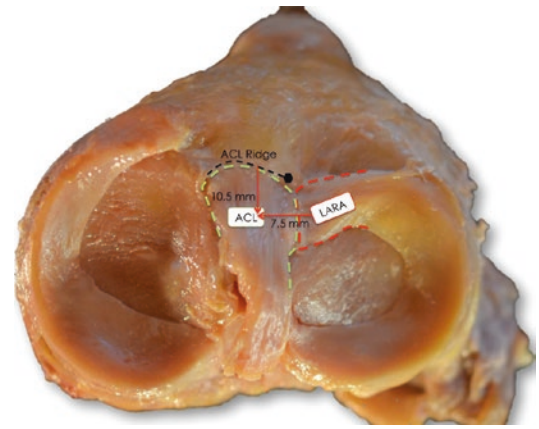

Fig. 17.4 Superior (axial) view of a right tibia showing the relationship between the lateral meniscus anterior root attachment (*LARA*) and the ACL

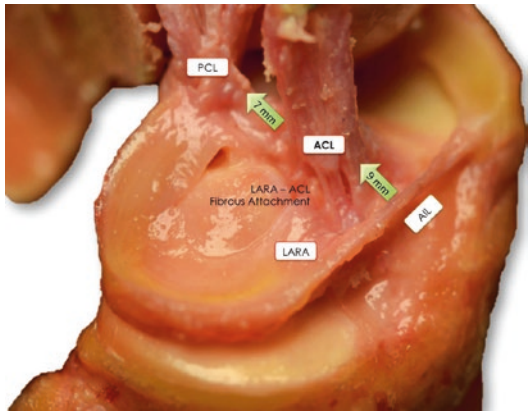

Fig. 17.5 Superolateral view of a right tibia demonstrating the most widely used soft tissue landmarks. From anterior to posterior, the relationship between soft tissue landmarks is illustrated. Note the fibrous tissue connecting the anterolateral root (*LARA*) to the ACL

the tibial ACL attachment is 9.1 ± 1.5 mm posterior to the posterior edge of the AIL) [7]. However, a recent study by Kongcharoensombat [12] reported that the AIL coincides with the anterior edge of the ACL tibial footprint in the sagittal plane.

The posterior cruciate ligament (PCL) has historically been used as a landmark (ACL tibial attachment is approximately 7 mm anterior) [7, 13]. However, the utility of this landmark depends on which aspect of the PCL is used as a reference, if the PCL is injured, and whether the tibia is anteriorly subluxed on the femur. It is now recognized that tibial tunnel positioning based on the PCL is located too posterior to the native ACL tibial attachment. Thus, the anterior root of the lateral meniscus and the retroeminence ridge are more reliable landmarks for referencing the ACL tibial attachment site [1].

17.5 Positioning and Essential Arthroscopic Landmarks

Several cadaveric and clinical studies have assessed ACL tunnel positioning [14–17]. However, 10–40% of tunnel placements in ACL reconstructions are reportedly malpositioned [10], comprising the main reason (52%) for ACL revision surgery [18]. The high rate of tunnel misplacement can be attributed to the position of the portals, the degree of flexion during identification of the footprints, anatomical variation [10], or arthroscopic image distortion [19, 20]. Hoshino [19] reported that the knee should be positioned at 90° when determining graft placement because the accuracy of the footprint placement could be reproduced more accurately than in a hyperflexion state. Moreover, there was a tendency of distal misplacement of the tunnels with the knee at 110° [10]. Conversely, surgeons can identify osseous landmarks more easily with a more flexed position (110–120°) as the lateral femoral condyle acquires a lower and shallower position in the arthroscopic view [19, 21]. Some surgeons prefer a more flexed position [22, 23] because that has less risk of blowing out the posterior wall of the lateral femoral condyle, making a tunnel with insufficient length or damage to the lateral structures [24]. Therefore, we recommend 90° of knee flexion to choose tunnel position and flexion of 110° or more for improved consistency in tunnel creation in order to prevent cortex fracture and also to maximize tunnel length.

Another risk factor for tunnel malpositioning is the image distortion since peripheral regions may be altered, especially when viewing angle is not straight [19]. Therefore, when reaming the femoral tunnel, initial visualization through the anteromedial portal is preferred [19, 21].

The most accurate anatomic landmark for arthroscopic ACL reconstruction is the native ACL remnant [6, 9, 25]. However, in a chronic setting or in a revision surgery, this may not be visible [9]. Therefore, for the femoral tunnels, the OTP and the LIR remain the most reliable osseous landmarks and are the senior author's (RFL) preferred method. For this purpose, a 7 mm offset guide can be utilized to place the tunnel anterior to the posterior margin of the femoral condyle [13]. A motorized burr or an awl can be used to demarcate the desired area. With regard to the lateral femoral condyle clock face position, it differs among surgeons [9, 26, 27] and has not shown to be a reliable method.

For identifying the tibial ACL attachment, the remnant fibers should be left intact in order to have a reliable landmark of the previous ACL insertion site. For cases in which the ACL tibial stump is not visible, placing a tibial single-bundle tunnel medial to the midpoint of the anterior horn of the lateral meniscus attachment may be a useful arthroscopic landmark for single-bundle ACL reconstructions (Fig. 17.6).

Lastly, careful attention must be paid in order to preserve the meniscal root insertions because

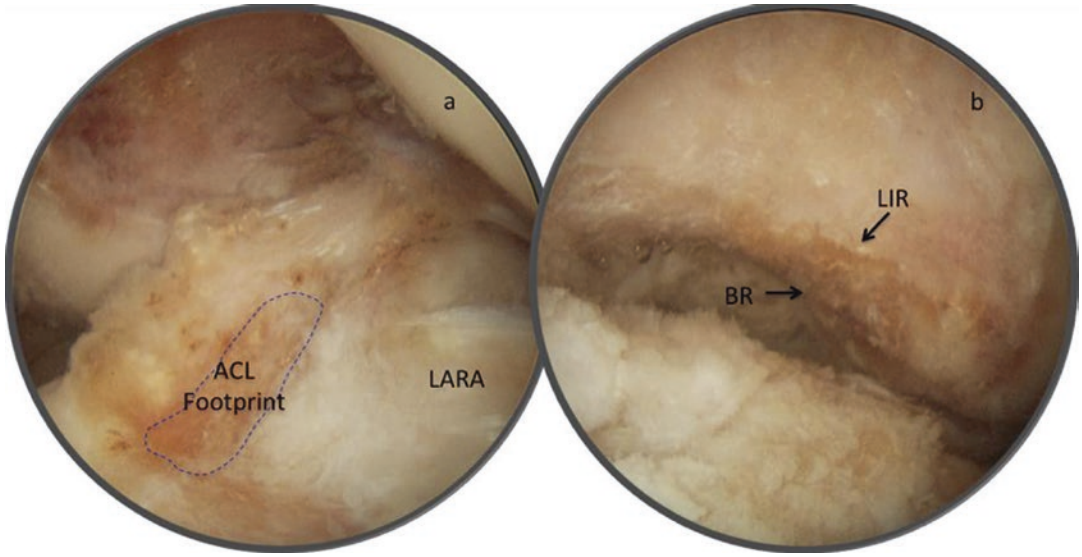

Fig. 17.6 Arthroscopic images of a left knee demonstrating (**a**) the tibial footprint of the ACL and its relationship to the lateral meniscus anterior root attachment (*LARA*) and (**b**) the external femoral condyle in 110° of flexion depicting the lateral intercondylar ridge (*LIR*) and the bifurcate ridge (*BR*)

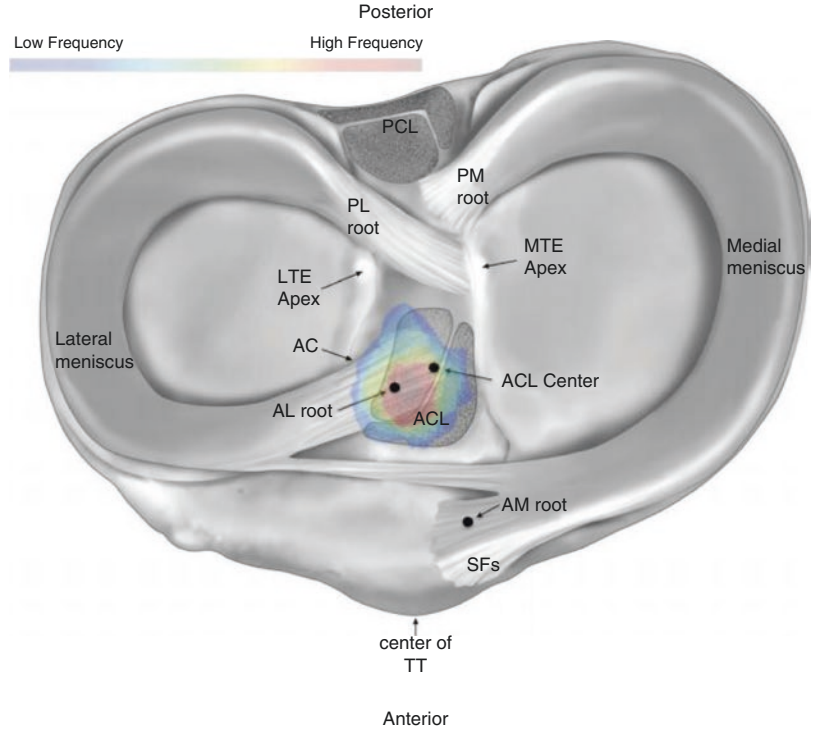

Fig. 17.7 A diagrammatic representation of the danger zone created using the quantified overlap of the anterolateral (*AL*) meniscal root with the anterior cruciate ligament (*ACL*) superimposed over a qualitative illustration of the tibial plateau (right knee). High frequencies represent areas in which the ACL and AL root were found to overlap in all 12 tested specimens (Reproduced with permission from LaPrade et al. [33])

iatrogenic anterior medial meniscus root [28–30] and posterior lateral meniscus root [31] avulsion can occur due to malposition of the tibial tunnel(s) during ACL reconstruction. Anatomic and biomechanical studies have reported that the attachment fibers of the anterolateral meniscal root course deep to a significant portion of the ACL's tibial attachment fibers [32, 33], and therefore, even an anatomically placed tibial tunnel can disrupt the AL root attachment. AM root attachment was not significantly affected by anatomical ACL tunnel placement in a biomechanical study [30] (Fig. 17.7).

Key Points for a Successful ACL Tunnel Placement

1. Extensive knowledge of the anatomy and relationship with surrounding structures can reduce the risk of tunnel misplacement in ACL reconstruction. Extreme caution should be taken not to damage meniscal roots.
2. Viewing arthroscopic portal should be chosen based on the structure needed to observe (AM portal for lateral femoral wall) in order to diminish optical distortion.
3. Ninety degrees of knee flexion should be maintained when determining graft placement since accuracy of the footprint could be reproduced more accurately. Hyperflexion of the knee is recommended when reaming the femoral tunnels in order to avoid lateral structure damage.

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