

Intra-articular landmarks for anterior cruciate ligament reconstructions: a review

Although many factors influence outcome following anterior cruciate ligament reconstruction, recurrent instability is frequently linked to technical errors, most commonly tunnel malposition. Numerous anatomic landmarks have been described in order to aid in accurate tunnel placement. This article will review and summarize the current literature regarding intra-articular landmarks and their use in anterior cruciate ligament reconstruction.

KEYWORDS: anterior cruciate ligament ■ anteromedial bundle ■ lateral bifurcate ridge ■ medial tibial spine ■ posterolateral bundle ■ Resident's ridge ■ retro-eminence ridge

The anterior cruciate ligament (ACL) is one of the most important stabilizers of the knee joint. It resists anterior tibial translation and serves as a secondary restraint to internal tibial rotation [1–3]. ACL deficiency frequently leads to symptomatic knee instability, and is associated with both short- and long-term consequences, including meniscal and articular cartilage lesions and progressive osteoarthritic changes [4–6]. ACL rupture is generally treated either operatively or nonoperatively depending on the patient's symptoms, age, activity level and functional demands [7–9]. Arthroscopically assisted reconstruction techniques are frequently utilized in the surgical management of ACL ruptures. Numerous techniques have been described and there is currently no consensus as to which methods yield the best functional outcome, patient satisfaction and long-term results.

Currently, there is great interest in reproducing the native anatomy when reconstructing the ACL [10,11]. There is debate regarding the need for double-bundle reconstruction. Double-bundle reconstructions have been shown to improve rotational stability *in vitro* [12,13], but improved clinical outcomes have not been demonstrated [14,15]. With all techniques, the ultimate goal in ACL reconstructive surgery is to restore the translational and rotational kinematics of the native knee. Whether single- or double-bundle ACL reconstruction is performed, adherence to the anatomic reconstruction concept seems to be an important factor in achieving this goal [16].

Numerous factors affect outcome following ACL reconstruction, but the most common cause of revision ACL reconstruction is recurrent symptomatic instability [17]. Technical errors are

the most frequent cause of recurrent instability, with tunnel malpositioning noted to be the most common error [17,18]. On the femur, tunnels are often too anterior, leading to impingement in the notch and a loss of extension. Placement of the femoral tunnel too far posterior can lead to graft laxity in flexion or excessive tension in extension. Placement of the femoral tunnel vertically in the notch may lead to decreased rotational control and a persistent pivot-shift in some cases [17]. On the tibia, the tunnel may be too far posterior, leading to a vertical graft that poorly controls anterior translation, or too far anterior, leading to impingement of the graft in the notch during extension [19]. In order to achieve a successful long-term outcome, the surgeon must consider the native ACL anatomy during ACL reconstruction.

The aim of this article is to present the current knowledge of the native attachment sites of the ACL and the intra-articular landmarks for ACL reconstruction.

The anatomy & function of the ACL

The ACL is an intra-articular but extrasynovial ligament. Proximally, its origin is on the posteromedial aspect of the lateral femoral condyle. It follows an oblique course inferomedially until it reaches its insertion site on the tibia, the anterior intercondylar fossa.

The ACL is frequently described as consisting of two functional bundles: the anteromedial (AM) bundle and the posterolateral (PL) bundle [20]. They are named according to their relative insertion sites onto the tibia. There is, however, conflicting evidence regarding the number of bundles that constitute the ligament. Odensten and Gillquist reported that it was not possible

Elcil Kaya Bicer¹,
Robert A Magnussen²,
Matthias Jacob²,
Sebastien Lustig²,
Elvire Servien²
& Philippe Neyret[†]

¹Specialist of Orthopedic Surgery & Traumatology, Ipekyolu Public Hospital, Van, Turkey

²Specialist of Orthopedic Surgery & Traumatology, Centre Albert Trillat, Groupe Hospitalier Nord, Hospices Civils de Lyon, Lyon-Caluire, France

[†]Author for correspondence: Centre Albert Trillat, Groupe Hospitalier Nord, Hospices Civils de Lyon, Lyon-Caluire, France
philippe.neyret@chu-lyon.fr

to demonstrate separate bundles of the ACL in histologic sections [21], while some authors have described a third, intermediate bundle [22,23]. However, based on the findings of numerous cadaveric and fetal dissections, the majority of authors agree on the presence of two functional bundles [2,24–29].

The division of the ligament into functional bundles implies that each bundle is unique with respect to its tensioning pattern throughout the range of motion of the knee. In extension, the AM and PL bundles are parallel and both are relatively taut (FIGURE 1A) [20]. With knee flexion, a change in the spatial orientation of the bundles is observed. The AM bundle remains taut and crosses over the PL bundle, which relaxes with knee flexion (FIGURE 1B) [2,20]. *In situ* biomechanical studies have demonstrated that when resisting anterior tibial translation, the forces carried by the PL bundle significantly increased as the knee was extended, whereas the AM bundle was exposed to an almost constant force at all degrees of flexion. When resisting internal tibial rotation, the force transmitted by the AM bundle both in 15 and 30° of flexion was found to be higher than that of the PL bundle. These findings suggest that both of the bundles participate in the maintenance of the anteroposterior and rotational knee stability [2,30,31].

The size of the ACL is variable. Measurement of the intra-articular length of ACL in cadaveric studies revealed that it had a range between 22 and 41 mm, with a mean length of 32 mm [23]. The ligament is broadest near its attachment sites and narrower in its mid-substance [20]. The AM bundle is longer than the PL bundle, but the lengths and widths of the bundles are varied, subject to different degrees of flexion [2].

The femoral attachment site

The ACL originates from the posteromedial aspect of the lateral femoral condyle. The orientation of the origins of the AM and PL bundles relative to each other is dependent on the degree of knee flexion. From an anatomic point of view, the femoral origins are generally described with the knee in extension; however, the arthroscopic view is not compatible with the anatomic descriptions since the knee must be flexed to visualize the femoral origin arthroscopically. In full extension, the origin of the AM bundle is located at the proximal portion of the entire ACL footprint and the origin of the PL bundle is located posterior and distal to the origin of the AM bundle (FIGURE 2A). With knee flexion, the longitudinal axis of the ACL attachment becomes more horizontal and the

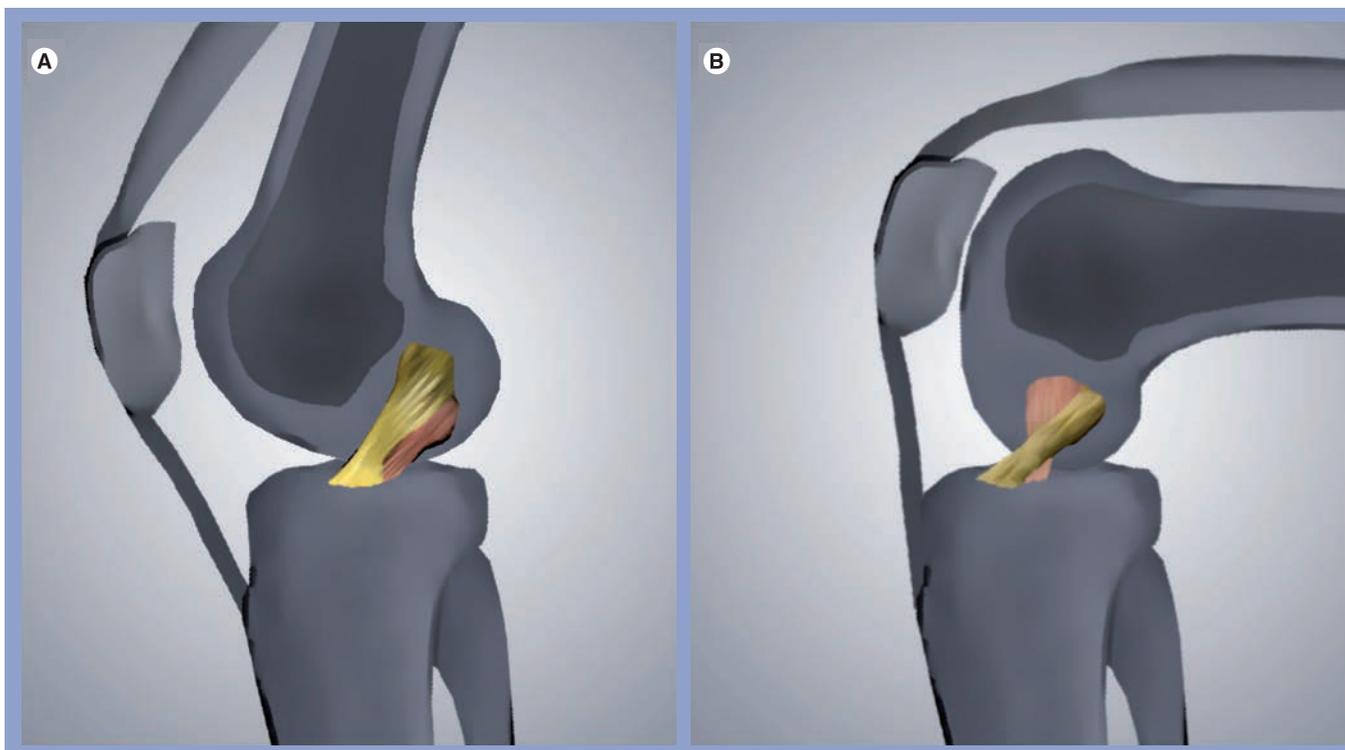


Figure 1. Anteromedial (light gray) and posterolateral (dark gray) bundles of the anterior cruciate ligament in a right knee. The bundles are parallel and taut in extension (A), while in flexion the anteromedial bundle remains taut and crosses over the posterolateral bundle (B).

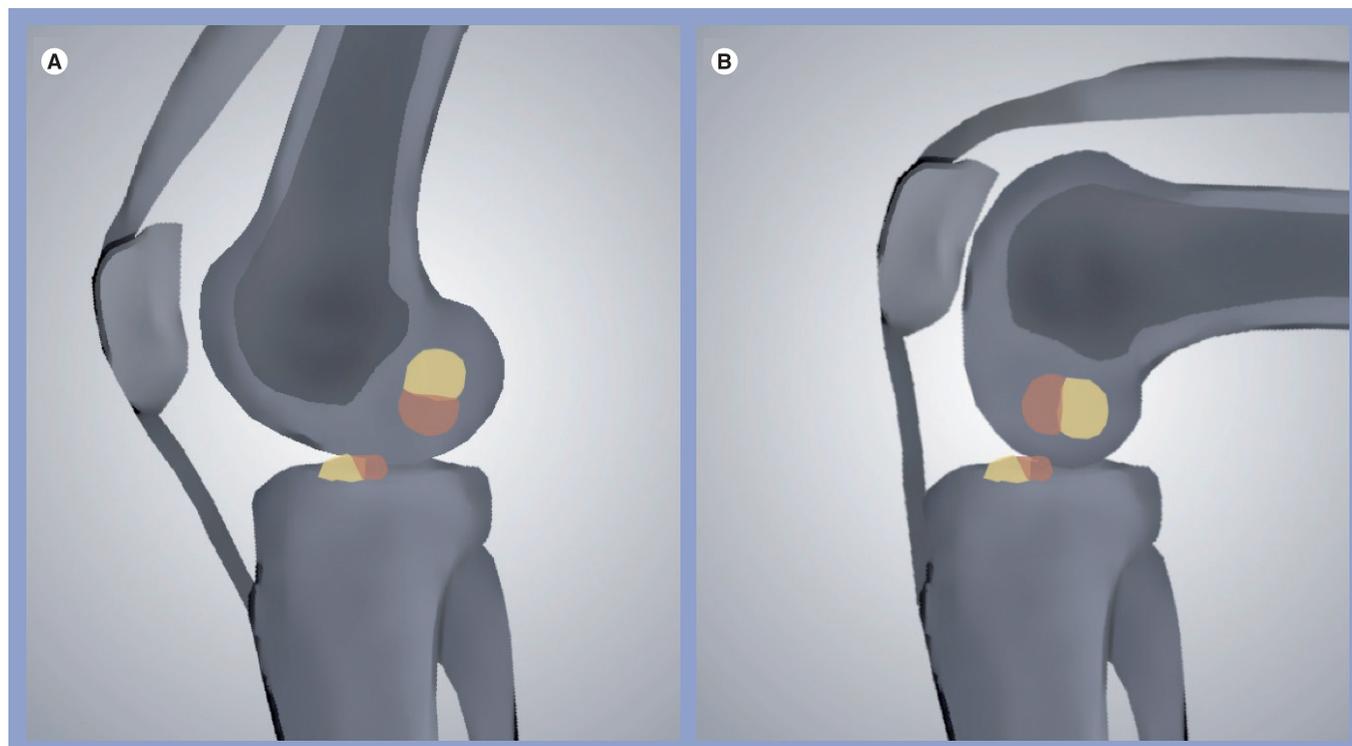


Figure 2. Femoral and tibial attachments of the anteromedial (light gray) and posterolateral (dark gray) bundles of the anterior cruciate ligament in a right knee. Note the change in orientation of the femoral attachment sites relative to the tibia when the knee moves from extension (A) to flexion (B).

PL origin is located anterior and inferior relative to the AM origin when viewed arthroscopically (FIGURE 2B) [11].

Numerous cadaveric and radiologic studies have been performed to describe the localization of the attachment sites of the ACL with respect to anatomic references [2,20,25,26,29,32–34]. Concerning the femoral origin, the most prominent bony landmark is the Resident's ridge (also known as the lateral intercondylar ridge). The Resident's ridge is a thick bony ridge on the medial wall of the lateral femoral condyle (FIGURE 3A), which extends from a posterior–superior to anterior–inferior direction from an arthroscopic point of view (FIGURE 3B). It constitutes the anterosuperior border of the femoral ACL attachment area, meaning that the ACL does not possess any fibers that attach anterosuperior to this ridge. The Resident's ridge extends along the entire length of the femoral origin. Histologic analysis of fetuses ranging from 19 to 22 weeks of gestation has demonstrated the presence of the Resident's ridge [27]. A recent cadaveric study conducted by Purnell *et al.*, which utilized high-resolution volume rendering computed tomography to describe the anatomy of the ACL, demonstrated that the Resident's ridge was present in all knees studied. The angle between the ridge and the axis

of the femoral diaphysis in the sagittal plane was $34.9 \pm 3.7^\circ$ and the length of this ridge was measured as 15.5 ± 1.5 mm [35].

In a clinical study, Shino *et al.* investigated the utility of Resident's ridge as an arthroscopic landmark for anatomical femoral tunnel for ACL graft [36]. It was shown that arthroscopic identification of the Resident's ridge was possible without performing bony notchplasty, even in patients with chronic ACL insufficiency. The arthroscopically measured distance between the midpoint of this ridge and the posterior articular margin was 7–10 mm. Postoperative evaluation of these patients with 3D computed tomography demonstrated that the mean length of the Resident's ridge was 18.8 ± 1.4 mm. The average maximum distance measured between the ridge and the posterior margin of the medial wall of the lateral femoral condyle was 9.3 ± 0.8 mm, and the angle between the ridge and the axis of distal femoral diaphysis in the sagittal plane was $31.1 \pm 2.0^\circ$. They concluded that the Resident's ridge could be used as an intraoperative landmark for proper femoral tunnel placement [36]. Radiographic location of the Resident's ridge was described by Farrow *et al.* with the aim of providing a method to confirm the femoral tunnel position intraoperatively in difficult cases and also to assess the tunnel position

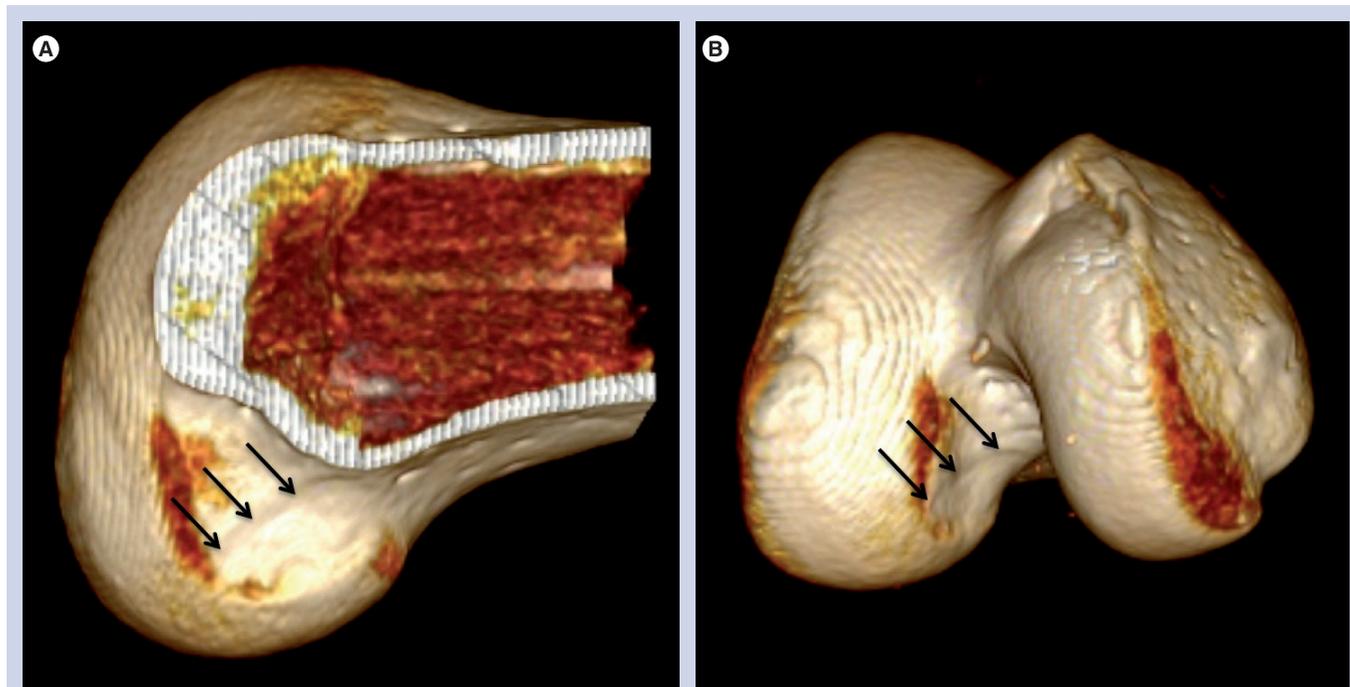


Figure 3. A 3D computed tomography reconstruction of the distal femur in a right knee. (A) In a medial view with the medial femoral condyle removed, the Resident's ridge (arrows) is visible on the medial wall of the lateral femoral condyle. **(B)** The orientation of the Resident's ridge (arrows) from a simulated arthroscopic view via the anteromedial portal.

postoperatively in patients with unsatisfactory outcomes [37]. The bone posteroinferior to the Resident's ridge is generally less dense on the lateral radiograph.

The femoral attachment site of the ACL follows the contour of the articular cartilage of the posteromedial part of the lateral femoral condyle, which can be used as another landmark for tunnel placement (FIGURE 4). Colombet *et al.* and Purnell *et al.* measured the distance from the posterior articular margin to the posterior extent of the ACL as 2.5 ± 1.1 mm and 3.5 ± 0.9 mm, respectively [25,35]. The distance from the inferior articular margin of the lateral femoral condyle to the edge of the femoral footprint of the ACL was measured as 3.0 ± 0.9 mm [35]. The posterosuperior border of the ACL footprint lacks a bony landmark. The ACL insertion extends up the lateral wall toward the roof of the intercondylar notch, but none of its fibers attach medial to the center of the roof [35].

The locations of AM and PL bundle insertions on the lateral wall of the intercondylar notch with respect to anatomic landmarks have also been described. The distance from the center of the AM bundle to the posterior articular margin was measured as 5–6 mm by Peterson and Zantop, and 6.3 ± 0.6 mm by Mochizuki *et al.* [2,33]. The distance from the center of the PL bundle to the posterior margin has been

reported to be 8.6 ± 0.6 mm [33], while the distance to the inferior margin was measured as 4–5 mm [2].

Fetal, cadaveric and arthroscopic studies by Ferreti *et al.* demonstrated the existence of another ridge between the AM and PL bundles, which was named the lateral bifurcate ridge [26,27]. However, it was noted that this ridge was not found in every case and was present only in the anterior portion of the femoral footprint. 3D computed tomography scans showed that the attachment site of the AM bundle was concave and the attachment site of the PL was relatively flat [26].

The tibial attachment site

The ACL inserts into the anterior intercondylar fossa on the tibial plateau. The shape of the tibial insertion has been described as oval or triangular [2,21,28]. The tibial insertion site is the broadest part of the ligament as its fibers splay and attach in a manner that has been said to resemble the foot of a duck [28]. The fibers of the ACL insert anterior to the intercondylar eminence and lateral to the medial tibial spine (FIGURE 5). None of its fibers attach to the tibial spines themselves. Anteriorly, ACL fibers pass beneath the inter-meniscal ligament and some fibers blend with the anterior horn of the lateral meniscus [35].

The most commonly described soft tissue landmarks for ACL reconstruction are the posterior cruciate ligament (PCL) and the posterior border of the root of the anterior horn of the lateral meniscus, both of which are easily identified arthroscopically. Morgan *et al.* demonstrated that irrespective of knee size, the distance from the most anterior fibers of the PCL to the center of the ACL attachment was 7 mm in a knee flexed 90° [38]. In another cadaveric study conducted by Hutchinson *et al.*, a similar distance was measured (10.4 ± 2.4 mm) and it was again noted that this distance was not correlated with knee size [39]. Measurement of the distance from the posterior border of the ACL footprint to the anterior fibers of the PCL yielded inconsistent results. The root of the anterior horn of the lateral meniscus is located just anterior to the AM aspect of the ACL's tibial attachment area (FIGURE 6) [11]. The center of the ACL insertion has

been measured to be 4.9 ± 1.9 mm posterior to the posterior border of the anterior root of the lateral meniscus [39].

Numerous osseous landmarks have been described to localize the ACL tibial insertion. Its location has been described relative to the anterior and posterior borders of the tibial plateau in several studies. Using tibial plateau specimens obtained during arthroplasty, Tállay *et al.* showed that the anterior fibers of the ACL were 12.9 ± 2.8 mm posterior to the anterior tibial border [40]. In a cadaveric study by Colombet *et al.* this distance was measured as 13.1 ± 1.6 mm [25]. The attachment of the most posterior fibers of the ACL have been reported as being 12.4 ± 2.4 mm anterior to the posterior border of the tibial plateau [39], while the center of the ACL attachment has been measured to be 35 ± 5 mm anterior to the posterior margin of the plateau [32].

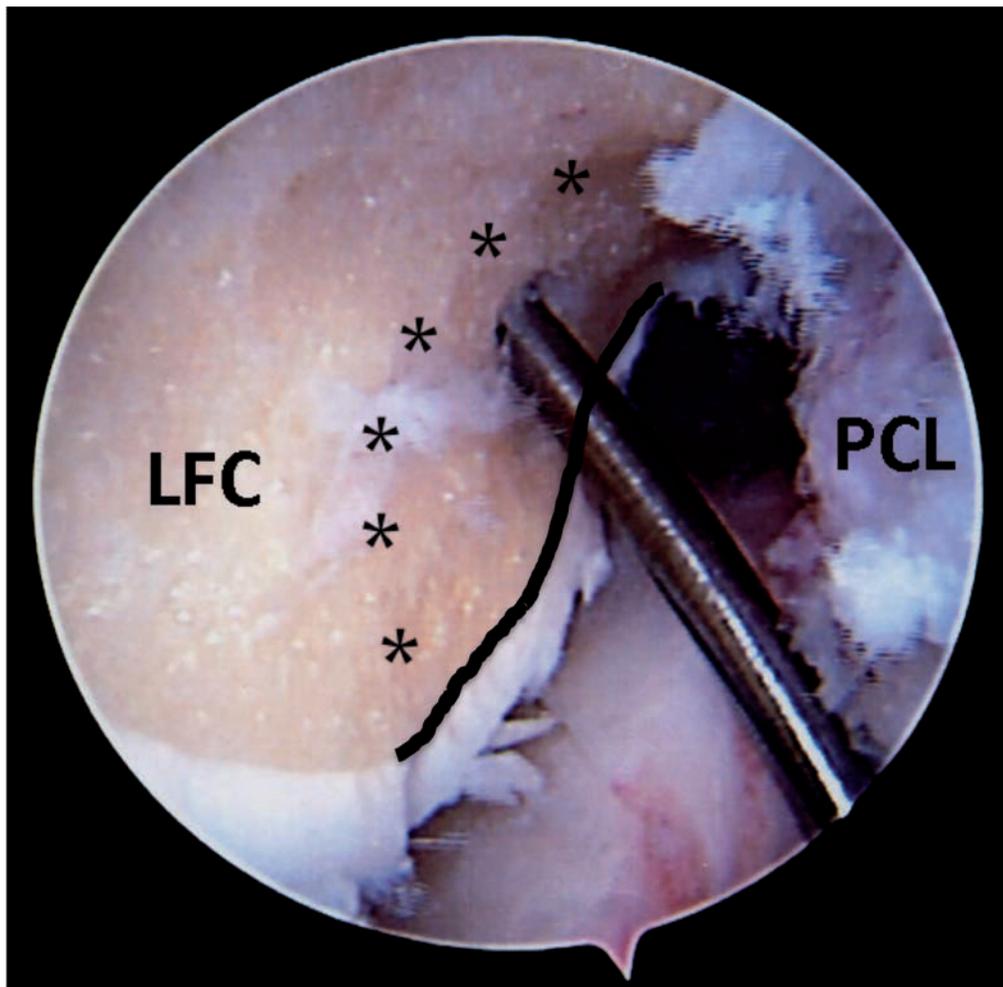


Figure 4. An arthroscopic view of the femoral attachment site of the anterior cruciate ligament in a right knee. Soft tissue has been cleared from the medial wall of the lateral femoral condyle. The native anterior cruciate ligament attachment site is anterosuperior to the posterior articular margin (marked with a black line) and posteroinferior to the Resident's ridge (marked with *). LFC: Lateral femoral condyle; PCL: Posterior cruciate ligament.

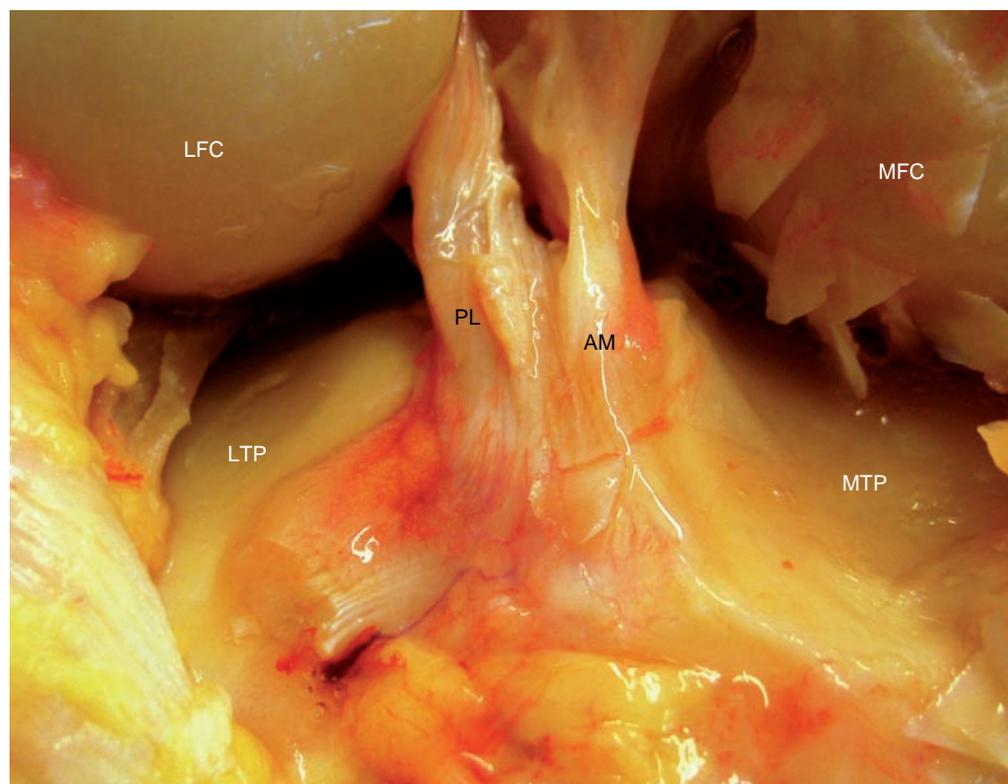


Figure 5. Anterior view of the tibial attachment site of the anterior cruciate ligament in a cadaveric right knee. The anterior cruciate ligament inserts anterior to the intercondylar eminence lateral to the medial tibial spine.

AM: Anteromedial; LFC: Lateral femoral condyles; LTP: Lateral tibial plateau; MFC: Medial femoral condyles; MTP: Medial tibial plateau; PL: Posterolateral.

The medial tibial spine is easily identified arthroscopically and is a frequently cited landmark for ACL reconstruction. The distance from the medial tibial spine to the posterior fibers of the ACL was measured to be 8.8 ± 2.0 mm [39]; however, it has been determined that the distance from insertion to the medial spine is dependent on the size of the tibial plateau [32].

The retro-eminence ridge runs transversely between the medial and lateral tibial spines, and has also been suggested as a landmark for ACL tibial tunnel placement. Hutchinson *et al.* declared that in a 90°-flexed knee, the anterior fibers of the PCL approximated this ridge [39]. They suggested that use of this ridge as a landmark is equivalent to using the anterior border of the PCL and reported the distance from the retro-eminence ridge to the posterior border of the ACL attachment area to be 6.7 ± 1.2 mm [32]. Purnell *et al.* noted that the most posterior ACL fibers were inserted just anterior to this ridge. They measured the distance from the ridge to the anterior border of the ACL footprint and found it to be 10.7 ± 1.3 mm [35]. A similar distance of 10.3 ± 1.9 mm was noted by Colombet *et al.* [19]. The distance from the retro-eminence

ridge to the attachment center of the ACL was measured in another study and found to be to be 15 ± 2 mm [40].

Thus, there are numerous landmarks to consider when placing the ACL tibial tunnel. Hutchinson *et al.* stated that PCL-based landmarks were the most reproducible guides [39]; however, other authors have noted that changes in apparent PCL position at various degrees of flexion may limit the utility of this system [11,25]. The anterior and posterior borders of the tibial plateau cannot be visualized arthroscopically and their use as a landmark required intraoperative fluoroscopy [25]. Additionally, their use as a landmark has been associated with a higher intraobserver error than measurements relative to the retro-eminence ridge [25]. Colombet *et al.* and Edwards *et al.* agreed that the measurements with respect to the retro-eminence ridge were the most reproducible and reliable measurements [25,32].

As mentioned before, the AM and PL bundles were named according to their insertion sites at the ACL footprint. However, their tibial insertion has been noted to have considerable variability [25,40]. The findings of the study

conducted by Tállay *et al.* showed that the insertion of the AM bundle could range from directly anterior to directly medial to the insertion of the PL bundle [40]. The distance between the centers of the bundles was measured as 9.3 ± 1.8 mm by Tállay *et al.* and 8.4 ± 0.6 mm by Colombet *et al.* [25,40].

The location of the tibial attachment sites of the two bundles with respect to the aforementioned anatomic landmarks has also been studied. Zantop *et al.* defined the localization of each bundle relative to the anterior horn of the lateral meniscus, and concluded that the center of attachment of the AM bundle was 2.7 mm posterior and 5.2 mm medial to the anterior horn [41]. The same measurements for the center of the PL bundle were 11.2 and 4.1 mm, respectively [41].

Tállay *et al.* measured the centers of the AM and PL bundles, which were 17.2 ± 4.1 and 25.6 ± 4.8 mm posterior to the anterior border of the tibial plateau [40], but these distances have been shown to vary, based on the size of the plateau [32]. The distances from the medial tibial spine to the centers of attachment sites of the AM and PL bundles were shown to be 5 ± 1 and 4 ± 1 mm, respectively, which were not related to the knee size [32]. These results were

not reproduced in a study of Luites *et al.*, which showed these distances to be 3.0 ± 1.6 mm for the AM bundle and 7.2 ± 1.8 mm for the PL bundle [29]. These differences likely reflect morphologic variation at the tibial attachment site.

The distance from the retro-eminence ridge to the attachment center of the PL bundle was found to be 10 ± 1 mm and that of the AM bundle was found to be 17 ± 2 mm [32]. These findings were related to the anteroposterior depth of the tibial plateau.

Conclusion

Although many factors affect outcome following ACL reconstruction, improper tunnel placement is the most common cause of recurrent instability requiring reoperation. Numerous soft tissue and osseous landmarks are available to aid surgeons achieving proper tunnel placement. The Resident's ridge and posteromedial articular margin are consistent femoral landmarks, while the retro-eminence ridge is likely the most reproducible tibial landmark.

Future perspective

The ACL is an extensively studied topic and understanding of the anatomy, biology and clinical results of ACL reconstruction are constantly

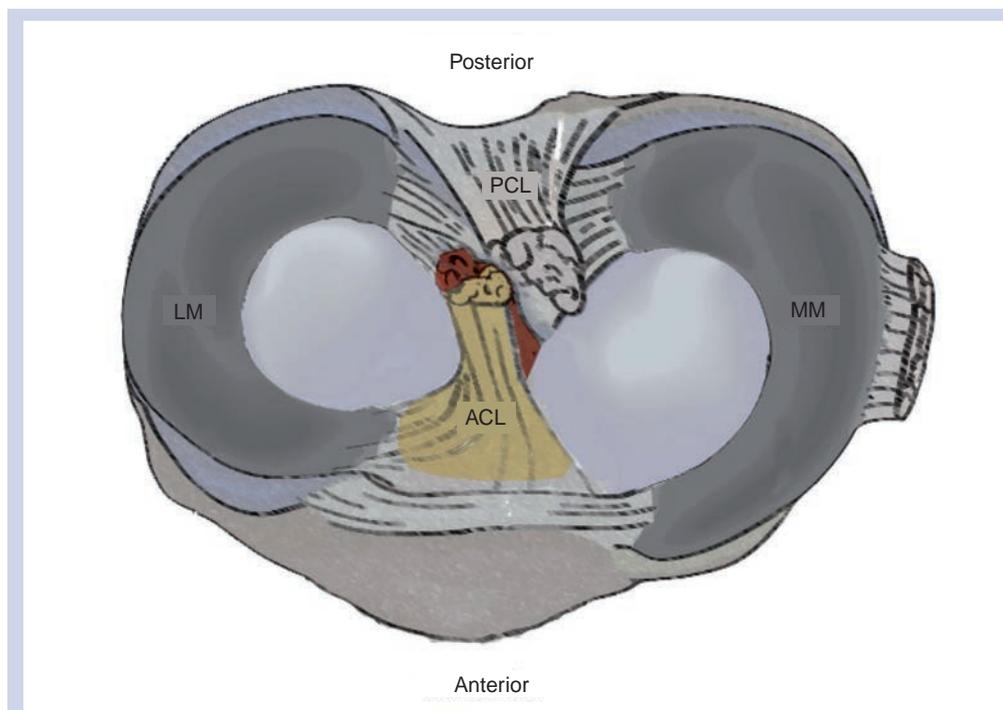


Figure 6. Superior view of the tibial plateau of a right knee demonstrates the location of the anterior cruciate ligament tibial insertion relative to the root of the anterior horn of the lateral meniscus. The PCL and MM are also labeled.

ACL: Anterior cruciate ligament; LM: Lateral meniscus; MM: Medial meniscus; PCL: Posterior cruciate ligament.

evolving. While today's procedures attempt to restore the anatomy and thus function of the ruptured ligament, there are inherent limitations to this approach. Advances related to the biologic enhancement of intra-articular healing and ligament scaffolds may some day allow for primary repair of many acute ACL injuries, guaranteeing perfect anatomic tunnel positioning. In cases where repair is impossible, reconstruction techniques will continue to evolve. One could imagine studying the ACL attachment points of the uninjured contralateral knee and using these data to exactly reproduce the patient's native anatomy in the injury knee. There may be a role for intraoperative guidance systems in ACL

reconstruction as ideal tunnel location becomes more and more precisely defined. It is certain that discussion of anatomy will continue to be central to our understanding of ACL.

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Executive summary

The anatomy & function of the anterior cruciate ligament

- The anterior cruciate ligament (ACL) is an intra-articular, extrasynovial ligament, extending inferomedially from the posteromedial aspect of the lateral femoral condyle to the anterior intercondylar area of the tibia.
- The ACL has two functional bundles: the anteromedial (AM) bundle and the posterolateral (PL) bundle.
- The AM and PL bundles are named according to their relative orientation at their tibial insertions.
- Both the AM and the PL bundles participate in controlling anteroposterior and rotational knee stability.

The femoral attachment site

- In an extended knee, the origin of the AM bundle is located in the proximal portion of the ACL attachment, whereas the origin of the PL bundle lies posterior and inferior to the AM bundle.
- In a flexed knee, the origin of the PL bundle is relatively inferior and anterior.
- The borders of the femoral attachment site of the ACL are:
 - Resident's ridge: a bony landmark extending along the entire attachment site anteriorly.
 - Posterior and inferior condylar articular margin: the femoral attachment of the ACL follows the contours of the articular margin both posteriorly and inferiorly.
 - Superior border: there is not a bony landmark limiting its superior attachment sites. Some fibers of the ACL extend up to the roof of the notch.
 - The lateral bifurcate ridge: a bony landmark that separates the attachment sites of the AM and PL bundles.

The tibial attachment site

- Soft tissue landmarks:
 - The posterior cruciate ligament.
 - The anterior horn of the lateral meniscus. It is located anterior to the AM aspect of the ACL.
- Bony landmarks:
 - The retro-eminence ridge: the ACL inserts anterior to this ridge.
 - Medial tibial spine: the ACL inserts lateral to the medial tibial spine.
 - There is not a true bony landmark denoting the lateral margin of the ACL attachment area.
 - The anterior and posterior borders of the tibial plateau are also among the suggested bony landmarks, but it is not possible to place the tunnels with respect to these landmarks arthroscopically. Fluoroscopy must be used.
- The orientations of the tibial attachment sites of the AM and PL bundles are highly variable.

Conclusion

- While many factors affect long-term outcome following ACL reconstruction, the most common cause of recurrent instability requiring revision ACL reconstruction is technical error.
- Data suggest that proper placement of both femoral and tibial tunnels with respect to the attachment sites of the native ligament is important in achieving successful and long-lasting surgical outcomes.

Bibliography

Papers of special note have been highlighted as:

■ of interest

■ of considerable interest

- 1 Amis AA, Bull AM, Lie DT: Biomechanics of rotational instability and anatomic anterior cruciate ligament reconstruction. *Oper. Tech. Orthop.* 15, 29–35 (2005).
- 2 Petersen W, Zantop T: Anatomy of the anterior cruciate ligament with regard to its two bundles. *Clin. Orthop. Relat. Res.* 454, 35–47 (2007).
- **In this study, the anatomic descriptions of the attachment sites of the two bundles of the anterior cruciate ligament along with their functional contributions to the knee joint kinematics were reviewed extensively.**
- 3 Zantop T, Herbolt M, Raschke MJ, Fu FH, Petersen W: The role of the anteromedial and posterolateral bundles of the anterior cruciate ligament in anterior tibial translation and internal rotation. *Am. J. Sports Med.* 35(2), 223–227 (2007).
- 4 Louboutin H, Debarge R, Richou J *et al.*: Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. *Knee* 16(4), 239–244 (2009).
- 5 Oiestad BE, Engebretsen L, Storheim K, Risberg MA: Knee osteoarthritis after anterior cruciate ligament injury: a systematic review. *Am. J. Sports Med.* 37(7), 1434–1443 (2009).
- 6 Tayton E, Verma R, Higgins B, Gosal H: A correlation of time with meniscal tears in anterior cruciate ligament deficiency: stratifying the risk of surgical delay. *Knee Surg. Sports Traumatol. Arthrosc.* 17(1), 30–34 (2009).
- 7 Diekstatt P, Rauhut F: [Considerations for the indications for anterior cruciate ligament reconstruction. Results of conservative versus operative treatment]. *Unfallchirurg* 102(3), 173–181 (1999).
- 8 Spindler KP, Wright RW: Clinical practice. Anterior cruciate ligament tear. *N. Engl. J. Med.* 359(20), 2135–2142 (2008).
- 9 Swirtun LR, Eriksson K, Renstrom P: Who chooses anterior cruciate ligament reconstruction and why? A 2-year prospective study. *Scand. J. Med. Sci. Sports* 16(6), 441–446 (2006).
- 10 Musahl V, Plakseychuk A, VanScyoc A *et al.*: Varying femoral tunnels between the anatomical footprint and isometric positions: effect on kinematics of the anterior cruciate ligament-reconstructed knee. *Am. J. Sports Med.* 33(5), 712–718 (2005).
- **In this biomechanical cadaveric study, the ability of reconstruction with anatomic and isometric femoral tunnel placement to restore normal knee kinematics were compared.**
- 11 Zantop T, Petersen W, Sekiya JK, Musahl V, Fu FH: Anterior cruciate ligament anatomy and function relating to anatomical reconstruction. *Knee Surg. Sports Traumatol. Arthrosc.* 14(10), 982–992 (2006).
- 12 Gadikota HR, Seon JK, Kozanek M *et al.*: Biomechanical comparison of single-tunnel-double-bundle and single-bundle anterior cruciate ligament reconstructions. *Am. J. Sports Med.* 37(5), 962–969 (2009).
- 13 Tsai AG, Wijdicks CA, Walsh MP, Laprade RF: Comparative kinematic evaluation of all-inside single-bundle and double-bundle anterior cruciate ligament reconstruction: a biomechanical study. *Am. J. Sports Med.* 38(2), 263–272 (2010).
- 14 Ibrahim SA, Hamido F, Al Misfer AK, Mahgoob A, Ghafar SA, Alhran H: Anterior cruciate ligament reconstruction using autologous hamstring double bundle graft compared with single bundle procedures. *J. Bone Joint Surg. Br.* 91(10), 1310–1315 (2009).
- 15 Song EK, Oh LS, Gill TJ, Li G, Gadikota HR, Seon JK: Prospective comparative study of anterior cruciate ligament reconstruction using the double-bundle and single-bundle techniques. *Am. J. Sports Med.* 37(9), 1705–1711 (2009).
- 16 Giuliani JR, Kilcoyne KG, Rue JP: Anterior cruciate ligament anatomy: a review of the anteromedial and posterolateral bundles. *J. Knee Surg.* 22(2), 148–154 (2009).
- 17 Carson EW, Anisko EM, Restrepo C, Panariello RA, O'Brien SJ, Warren RF: Revision anterior cruciate ligament reconstruction: etiology of failures and clinical results. *J. Knee Surg.* 17(3), 127–132 (2004).
- 18 Johnson DL, Fu FH: Anterior cruciate ligament reconstruction: why do failures occur? *Instr. Course Lect.* 44, 391–406 (1995).
- 19 Howell SM, Clark JA: Tibial tunnel placement in anterior cruciate ligament reconstructions and graft impingement. *Clin. Orthop. Relat. Res.* 283, 187–195 (1992).
- 20 Duthon VB, Barea C, Abrassart S, Fasel JH, Fritschy D, Menetrey J: Anatomy of the anterior cruciate ligament. *Knee Surg. Sports Traumatol. Arthrosc.* 14(3), 204–213 (2006).
- 21 Odensten M, Gillquist J: Functional anatomy of the anterior cruciate ligament and a rationale for reconstruction. *J. Bone Joint Surg. Am.* 67(2), 257–262 (1985).
- 22 Norwood LA, Cross MJ: Anterior cruciate ligament: functional anatomy of its bundles in rotatory instabilities. *Am. J. Sports Med.* 7(1), 23–26 (1979).
- 23 Amis AA, Dawkins GP: Functional anatomy of the anterior cruciate ligament. Fibre bundle actions related to ligament replacements and injuries. *J. Bone Joint Surg. Br.* 73(2), 260–267 (1991).
- 24 Chhabra A, Starman JS, Ferretti M, Vidal AF, Zantop T, Fu FH: Anatomic, radiographic, biomechanical, and kinematic evaluation of the anterior cruciate ligament and its two functional bundles. *J. Bone Joint Surg. Am.* 88(Suppl. 4), 2–10 (2006).
- 25 Colombet P, Robinson J, Christel P *et al.*: Morphology of anterior cruciate ligament attachments for anatomic reconstruction: a cadaveric dissection and radiographic study. *Arthroscopy* 22(9), 984–992 (2006).
- **In this cadaveric study, the shape and positions of the femoral and tibial attachments of the bundles relative to bony landmarks were described. The retro-eminence ridge was regarded as an easily identifiable and accurate bony landmark that can be used clinically.**
- 26 Ferretti M, Ekdahl M, Shen W, Fu FH: Osseous landmarks of the femoral attachment of the anterior cruciate ligament: an anatomic study. *Arthroscopy* 23(11), 1218–1225 (2007).
- **Topographical anatomy of the femoral attachment site of the anterior cruciate ligament was described by performing examinations in human fetuses, cadaveric specimens and through arthroscopic evaluation in living patients.**
- 27 Ferretti M, Levicoff EA, Macpherson TA, Moreland MS, Cohen M, Fu FH: The fetal anterior cruciate ligament: an anatomic and histologic study. *Arthroscopy* 23(3), 278–283 (2007).
- 28 Harner CD, Baek GH, Vogrin TM, Carlin GJ, Kashiwaguchi S, Woo SL: Quantitative analysis of human cruciate ligament insertions. *Arthroscopy* 15(7), 741–749 (1999).
- 29 Luites JW, Wymenga AB, Blankevoort L, Kooloos JG: Description of the attachment geometry of the anteromedial and posterolateral bundles of the ACL from arthroscopic perspective for anatomical tunnel placement. *Knee Surg. Sports Traumatol. Arthrosc.* 15(12), 1422–1431 (2007).
- 30 Sakane M, Fox RJ, Woo SL, Livesay GA, Li G, Fu FH: *In situ* forces in the anterior cruciate ligament and its bundles in response to anterior tibial loads. *J. Orthop. Res.* 15(2), 285–293 (1997).
- 31 Wu JL, Seon JK, Gadikota HR *et al.*: *In situ* forces in the anteromedial and posterolateral bundles of the anterior cruciate ligament under simulated functional loading conditions. *Am. J. Sports Med.* 38(3), 558–563 (2010).

- 32 Edwards A, Bull AM, Amis AA: The attachments of the anteromedial and posterolateral fibre bundles of the anterior cruciate ligament: Part 1: tibial attachment. *Knee Surg. Sports Traumatol. Arthrosc.* 15(12), 1414–1421 (2007).
- 33 Mochizuki T, Muneta T, Nagase T, Shirasawa S, Akita KI, Sekiya I: Cadaveric knee observation study for describing anatomic femoral tunnel placement for two-bundle anterior cruciate ligament reconstruction. *Arthroscopy* 22(4), 356–361 (2006).
- 34 Siebold R, Ellert T, Metz S, Metz J: Femoral insertions of the anteromedial and posterolateral bundles of the anterior cruciate ligament: morphometry and arthroscopic orientation models for double-bundle bone tunnel placement – a cadaver study. *Arthroscopy* 24(5), 585–592 (2008).
- 35 Purnell ML, Larson AI, Clancy W: Anterior cruciate ligament insertions on the tibia and femur and their relationships to critical bony landmarks using high-resolution volume-rendering computed tomography. *Am. J. Sports Med.* 36(11), 2083–2090 (2008).
- **High-resolution volume rendering computed tomography was utilized to demonstrate the femoral and tibial attachment sites of the anterior cruciate ligament with respect to the bony landmarks.**
- 36 Shino K, Suzuki T, Iwahashi T *et al.*: The resident's ridge as an arthroscopic landmark for anatomical femoral tunnel drilling in ACL reconstruction. *Knee Surg. Sports Traumatol. Arthrosc.* 18(9), 1164–1168 (2010).
- **Confirms that the Resident's ridge is a useful landmark for anatomical femoral tunnel drilling in arthroscopic anterior cruciate ligament reconstructions.**
- 37 Farrow LD, Gillespie RJ, Victoroff BN, Cooperman DR: Radiographic location of the lateral intercondylar ridge: its relationship to Blumensaat's line. *Am. J. Sports Med.* 36(10), 2002–2006 (2008).
- **Demonstrates a method by which appropriate femoral tunnel position can be identified intraoperatively with fluoroscopy.**
- 38 Morgan CD, Kalman VR, Grawl DM: Definitive landmarks for reproducible tibial tunnel placement in anterior cruciate ligament reconstruction. *Arthroscopy* 11(3), 275–288 (1995).
- 39 Hutchinson MR, Bae TS: Reproducibility of anatomic tibial landmarks for anterior cruciate ligament reconstructions. *Am. J. Sports Med.* 29(6), 777–780 (2001).
- 40 Tállay A, Lim MH, Bartlett J: Anatomical study of the human anterior cruciate ligament stump's tibial insertion footprint. *Knee Surg. Sports Traumatol. Arthrosc.* 16(8), 741–746 (2008).
- 41 Zantop T, Wellmann M, Fu FH, Petersen W: Tunnel positioning of anteromedial and posterolateral bundles in anatomic anterior cruciate ligament reconstruction: anatomic and radiographic findings. *Am. J. Sports Med.* 36(1), 65–72 (2008).