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*Am J Sports Med* 2008 36: 2083 originally published online July 28, 2008
DOI: 10.1177/0363546508319896

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# Anterior Cruciate Ligament Insertions on the Tibia and Femur and Their Relationships to Critical Bony Landmarks Using High-Resolution Volume-Rendering Computed Tomography

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**Background:** Controversy exists regarding the locations of the anterior cruciate ligament insertions on the femur and tibia and visualization of these insertions during surgical reconstruction.

**Hypothesis:** Anatomical insertions of the anterior cruciate ligament have relationships to bony landmarks of the tibia and femur.

**Study Design:** Descriptive laboratory study.

**Methods:** Eight cadaveric knees were scanned by computed tomography, reconstructed 3-dimensionally, and examined from simulated arthroscopic, sagittal, and axial perspectives. Volume-rendering software was used to document the relationship of the anterior cruciate ligament to the bony anatomy.

**Results:** A bony ridge (Resident's Ridge) at the anterior border of the anterior cruciate ligament was readily noted on the medial wall of the lateral femoral condyle. Superiorly, anterior cruciate ligament fibers inserted up to the roof of the notch and to 3 to 3.5 mm of the articular surface posteriorly and inferiorly. The anterior cruciate ligament inserted into a fovea anterior to the tibial eminence. Posteriorly, anterior cruciate ligament fibers inserted up to a ridge between the medial and lateral intercondylar tubercles. Medially, anterior cruciate ligament fibers inserted onto the ridge at the lateral border of the medial tibial condyle. There was no distinct anterior or lateral bony border with anterior cruciate ligament fibers blending into the anterior horn of the lateral meniscus.

**Conclusion:** The anterior border of the femoral anterior cruciate ligament origin is Resident's Ridge. The ridge between the medial and lateral intercondylar tubercles at the base of the tibial eminence is the posterior margin of the anterior cruciate ligament on the tibia.

**Clinical Relevance:** Bony landmarks can be used to aid in anatomical anterior cruciate ligament reconstruction.

**Keywords:** anterior cruciate ligament; Resident's Ridge; tibial footprint

The anatomy of the anterior cruciate ligament (ACL) has been extensively studied and described.[1-21] Most anatomical studies have involved cadaveric dissections that require destruction of the specimen as measurements are taken, thereby potentially altering the anatomy. Measurements are usually performed manually using calipers after outlining the borders of the ligament in ink.[4,15,21] Descriptions are typically given in a 2-dimensional format in either the sagittal or axial plane. Direct correlation of these measurements to surgical procedures can be difficult, as neither of these orientations is in the planes that are typically seen at the time of arthroscopic or open surgical procedures. A few studies have used imaging techniques such as radiographs and magnetic resonance arthrography (MRA) to define the anatomy.[1,19] Laser micrometry with digitization has also been used to quantify the area of the ACL insertion.[8]

In this study, we use high-resolution computerized axial tomography (CT) with 3-dimensional (3D) reconstructions and a volume-rendering software program GE Cleartender

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No potential conflict of interest declared.

Presented at the 33rd annual meeting of the AOSSM, Calgary, Alberta, Canada, July 2007.

The American Journal of Sports Medicine, Vol. 36, No. 11
DOI: 10.1177/0363546508319896
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program (General Electric, Waukesha, Wis) to study the bony anatomy of the medial wall of the lateral femoral condyle and the tibial plateau to correlate these measurements with the origin and insertion of the ACL. This technique allows multiplanar visualization of an acquired image. The specimen may be studied from various perspectives, including those views typically used at the time of surgery, as well as in planes that have historically been used for anatomical descriptions. By incorporating the volume-rendering program we were able to remove and replace tissues as needed to allow the measurement of all structures and correlate their respective bony relationships. Structures obstructing the views of the tissues to be studied could also be removed and replaced as needed without altering their relationship to the knee.

Confusion exists within the common orthopaedic vernacular and in recent literature because of the use of differing terminology to describe the bony surface anatomy of the tibial plateau. In this study, we use the terminology described in prominent anatomy texts.[6,7,16,17] There is a medial and lateral tibial condyle comprising the articular surfaces of the tibial plateau. Between these articular surfaces there is one intercondylar[16,17] or intercondyloid eminence (spine of the tibia) "which is surmounted on either side by a prominent tubercle on to the sides of which the facets are prolonged named the medial and lateral intercondylar tubercles"[6] (Figure 1).

Recent literature also reveals controversy as to the exact location of ACL insertions on both the femur and tibia when viewed from an anterior arthroscopic perspective. Further, there is little in the literature describing bony landmarks at the insertion sites to aid in tunnel placement. The purpose of this study is to describe the bony landmarks of the ACL femoral origin and tibial insertion. This was performed in both the sagittal and axial planes, which allowed us to validate our results by comparing them with previously published studies. In addition, we have been able to describe the bony landmarks from the perspective of a simulated 3D anterior arthroscopic view. This view allows identification of the bony boarders of the ACL origin and insertion from a perspective similar to what is seen at the time of surgery.

## MATERIALS AND METHODS

Nine donated, nonpaired, fresh-frozen, cadaveric knee specimens, mid-thigh to mid-tibia, were obtained for this study. Eight were scanned and 1 was rejected because of prior surgery. Gender and race data were unavailable at the time of the study. Before scanning, all knees were thawed to room temperature, and an intra-articular injection was performed with 15 cubic centimeters of air to yield better contrast resolution. All knees were scanned at approximately 90° of flexion to simulate the surgical position that is typically used for arthroscopic ACL reconstruction. The knees were scanned at slice thicknesses of 1.2 mm with a GE Litespeed Quad Slice CT scanner (General Electric, Waukesha, Wis).

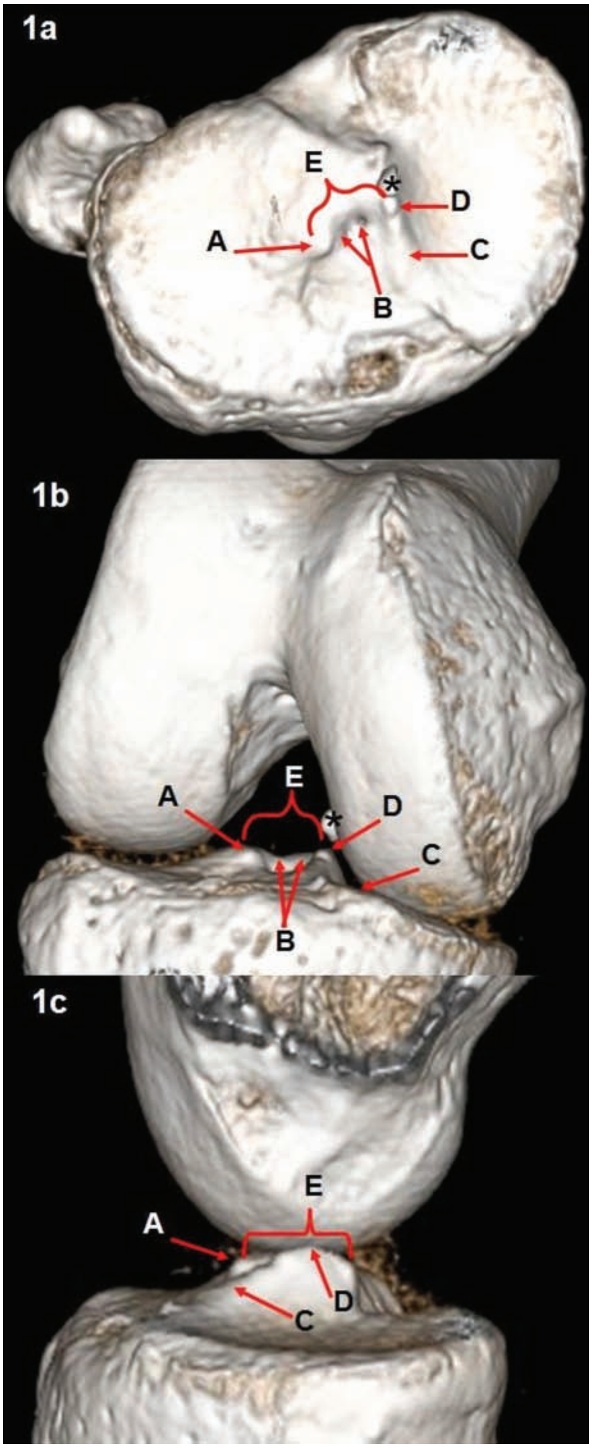


**Figure 1.** Right knee images. Axial view tibial plateau (1a). Simulated arthroscopic view (1b). Sagittal view (1c). Demarcations: A, Lateral Intercondylar Tubercle; B, Anterior Intertubercle Ridge or Tibial ACL Ridge; C, Medial Intercondylar Ridge of the Tibia; D, Medial Intercondylar Tubercle; and E, Intercondyloid Eminence (tibial spine). Asterisk denotes loose body present proximal to the medial intercondylar tubercle. Loose body also present in Figures 3 and 6 (not shown).

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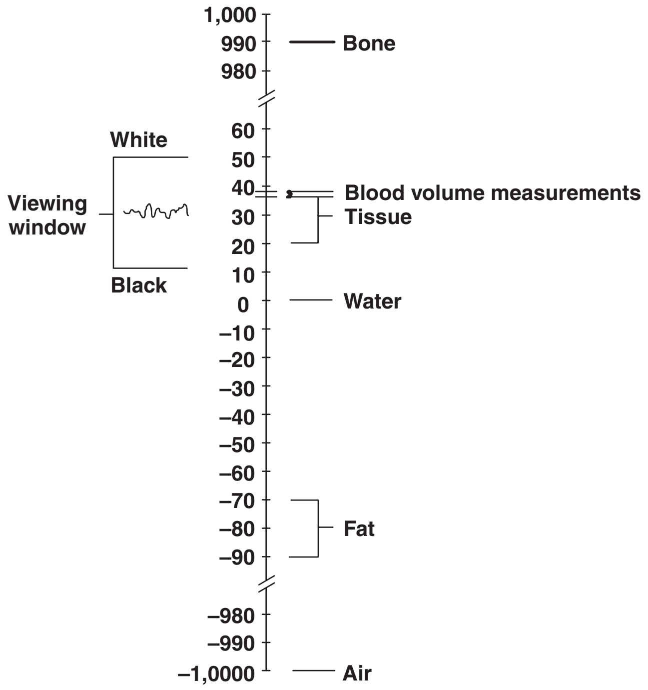


**Figure 2.** The Hounsfield scale depicting the linear relationship of the radiodensity of various biologic tissues. Reprinted with permission from *Journal of Medical Physics*. Hounsfield GN 1980;7(4):283-290.

Raw data were then reconstructed to a 512 × 512 matrix with a display field of view (DFOV) at 16 cm. The GE Cleartender program (General Electric) was used to study and measure the specific femoral and tibial attachment of the ACL. The Cleartender is a volume-rendering program that enhances visualization of ligamentous and soft tissue structures while permitting greater measurement in detail of the specific relationship of these insertions to the adjacent bony landmarks. The ACL footprints were identified by first marking the border of ligament bone interface electronically, with the ligament and bone intact, using the Cleartender marking tools. The ACL was then removed by manipulating the Hounsfield units,[9] leaving the bony structures intact and the electronic markers in place, outlining the footprints. The Hounsfield Unit (HU) scale is an arbitrary linear scale of radiograph attenuation used for CT scans. The radiodensity of distilled water at standard temperature and pressure (STP) has a value of 0 HU, and the radiodensity of air at STP has a value of–1000 HU (Figure 2). At all times during this measurement process the complete anatomy of the ACL could be restored to validate the ligament border being measured. We were able to image and manipulate the insertions from various angles and temporarily remove structures, such as the patella and the medial femoral condyle, to view the specific structure being studied (Figure 3). All measurements were made as a straight line with the surface completely in an orthogonal projection to the view angle of the surface being measured to ensure accuracy. The Cleartender program stated an accuracy of ±0.01 mm. However, we calculated an accuracy of ±0.3 mm from our matrix size of 512 × 512 and DFOV of 16 cm. All measurements were performed by the same investigator.

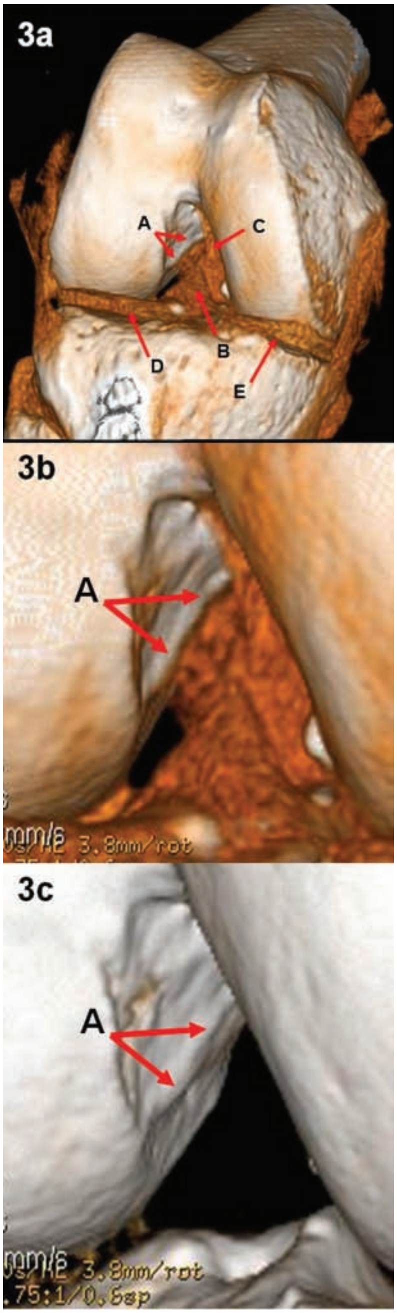


**Figure 3.** Simulated anterior arthroscopic view images. 3a: right knee; ACL and PCL intact; patella and fat pad removed. Demarcations: A, Femoral ACL Ridge (Resident's Ridge); B, ACL; C, PCL; D, lateral meniscus; E, medial meniscus. 3b: right knee; ACL and PCL intact; patella and fat pad removed. Demarcations: A, Femoral ACL Ridge (Resident's Ridge). 3c: right knee; ACL, PCL, patella and fat pad removed. Demarcations: A, Femoral ACL Ridge (Resident's Ridge).

Articular surface anatomy was identified by the distinct difference between the dense smooth subchondral bone and the more irregular bony topography of the intercondylar notch. Manipulation of HU validated the specific margin of the articular surface of interest. The borders of the articular surfaces were clearly visible and easily defined.

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TABLE 1
Anterior Cruciate Ligament (ACL) Femoral Origin

| Femur Results (N = 8) | Mean | Range | Figure Correlation |
|---|---|---|---|
| Length of femoral ACL ridge (Resident's Ridge), mm | 15.5 ± 1.5 | 13.7-18.4 | Figure 5A |
| Length of ACL fibers along femoral ACL ridge, mm | 12.9 ± 0.1 | 11.3-14.1 | Figure 5B |
| Width of ACL footprint posterior to femoral ACL ridge, mm | 7.6 ± 1.4 | 5.9-9.7 | Figure 5C |
| Distance of ACL footprint to the posterior articular surface, mm | 3.5 ± 0.9 | 2.8-5 | Figure 5D |
| Distance of ACL footprint to the inferior articular surface, mm | 3.0 ± 0.9 | 2.8-5 | Figure 5E |
| Angle of femoral ACL ridge with respect to femoral shaft axis, deg | 34.9 ± 3.7 | 30.3-42.3 | Figure 5α |

Measurements of the ACL femoral origin were made while visualizing the femur in the sagittal plane. Measurements of the ACL femoral footprint included its length, width, and distance from the articular margins of the lateral femoral condyle, both posteriorly and inferiorly. Measurements were also taken of the specific length and orientation of a ridge of bone identified immediately anterior to the ACL insertion. This ridge was present in all knees studied. The relationship of the ACL anterior fibers to this ridge was also identified and measured in both the sagittal and the simulated anterior arthroscopy views (Figure 3).

Measurements of the ACL tibial insertion were made while visualizing the tibial plateau in the axial plane. The anterior-posterior dimensions of the ACL tibial footprints were taken from the reference of the anterior-most fibers of the posterior cruciate ligament (PCL) (identified with the same method as the ACL border); the length of the ACL insertion on the tibia was calculated from the measurement of the distance of the anterior and posterior-most fibers of the ACL from this reference point. The medial-lateral dimensions of the ACL footprints were taken from the reference of the ridge at the lateral boarder of the articular surface of the medial tibial plateau. The position of the ACL footprint between the articular surfaces of the medial and lateral tibial condyles was calculated from these measurements. The relationship of the ACL fibers to the medial and lateral intercondylar tubercles, and the ridge that extends between them at the posterior margin of the ACL fovea, was also measured. The relationship of these bony landmarks was then noted in both the axial and the simulated anterior arthroscopic view (Figures 1 and 3).

## RESULTS

### Anterior Cruciate Ligament Femoral Origin

Table 1 provides a summary of the ACL femoral insertion.

In all 8 knees, a bony ridge on the lateral wall of the intercondylar notch was noted running in a straight line from posterior-superior to anterior-inferior (from the perspective of the simulated arthroscopic view). This ridge and its relationship to the ACL were easily visualized in both the sagittal and simulated anterior arthroscopy views (Figures 3-5). In the simulated arthroscopic view, the ridge appeared as a prominence or elevation on the medial wall of the lateral femoral condyle (Figure 3). In the sagittal view, the ridge

**Figure 4.** Sagittal flexion view of right knee with arrow depicting the Femoral ACL Ridge (Resident's Ridge).

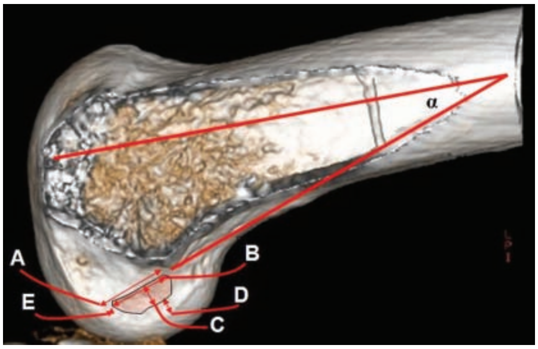


**Figure 5.** Sagittal view with pictorial description of measurements taken. Demarcations: A, length of Femoral ACL Ridge (Resident's Ridge); B, ACL fibers along Femoral ACL Ridge; C, length of ACL fibers behind Femoral ACL Ridge; D, posterior fibers to posterior articular surface; and E, inferior margin Femoral ACL Ridge to articular surface. α denotes angle of ACL ridge in relation to femoral axis.

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was more difficult to visualize, but again appeared as a linear prominence or elevation (Figures 4 and 5). The ridge tapered and disappeared just before the articular surface of the femoral condyle inferiorly and superiorly terminated at the roof of the femoral intercondylar notch. In all knees, the anterior fibers of the ACL inserted immediately posterior to the most prominent edge of this ridge. The angle of this ridge was 34.9 ± 3.7° in correlation with the long axis of the femoral shaft (Figure 5). The length of this ridge was 15.5 ± 1.5 mm, and the length of the anterior fibers of the ACL along the ridge was 12.9 ± 0.1 mm (Figure 5). The ACL insertion extended posteriorly for a distance of 7.6 ± 1.4 mm. Posteriorly, these fibers ended 3.5 mm from the articular margin and inferiorly 3.0 mm from the articular margin of the lateral femoral condyle. None of the fibers of the ACL were inserted onto the top of the femoral notch roof, nor did any extend past the midline of the roof in the coronal plane.

### Anterior Cruciate Ligament Tibial Insertion

Table 2 provides a summary of the ACL tibial insertion.

The ACL inserted on the tibia into a depression or fovea between the tibial condyles (Figure 6). The posterior fibers of the ACL inserted just anterior to a ridge that runs between the two tibial intercondylar tubercles. This ridge was identified as a distinct change in height of the tibial plateau. Its shape and length were variable but generally followed a curved shape, open anteriorly, that extended from the medial to the lateral intercondylar tubercles. The distance from the most posterior margin of this ridge to the most anterior PCL fibers measured 16.5 ± 2.1 mm. Anterior cruciate ligament fibers extended up to the base of the tibial spine, and none of the fibers were noted to insert on the tibial spine. Medially, the ACL fibers inserted directly onto the ridge at the lateral-most border of the articular surface of the medial tibial condyle. This lateral ridge of the medial condyle is the anterior extension of the medial tibial intercondylar tubercle (Figure 1). The distance from the most medial fibers of the ACL to the most lateral fibers on the tibial insertion varied slightly from anterior to posterior. The anterior border was 7.4 ± 1.3 mm, and posteriorly it was 7.3 ± 1.1 mm from the medial tibial condyle. This border was measured as a percentage of the distance between the condyles of the tibia as 70.6% ± 10%. There was no distinct bony lateral border of the ACL footprint as the fibers blended into the anterior horn of the lateral meniscus. The anterior border of the ACL was more variable and also had no distinct bony border. The average length of the ACL tibial insertion was 10.7 ± 1.3 mm and the average width 7.4 ± 1.2 mm.

## DISCUSSION

The purpose of this study was to describe the bony landmarks of the medial wall of the lateral femoral condyle and the tibial plateau in correlation with the insertional fibers of the ACL from both the sagittal and axial plane as well as the perspective of a simulated 3D anterior arthroscopic view. Our study demonstrated several bony landmarks on the medial wall of the lateral femoral condyle and the tibial plateau that can be used arthroscopically to identify the anatomical footprints of the ACL.

The medial wall of the lateral femoral condyle was clearly seen to have a more complex structure than just a flat surface. On the medial side of the lateral femoral condyle, a ridge of bone could be identified from both the sagittal and the simulated arthroscopic views (Figures 3 and 4). This ridge clearly demarcated the anterior-most border of the origin of the ACL. We believe that this ridge represents what is referred to in common orthopaedic vernacular as "Resident's Ridge," as described by Clancy.[11] If this ridge were to be named purely from an anatomical perspective, then a more appropriate terminology would be "Anterior Femoral Ridge of the ACL or the Femoral ACL Ridge."

The posterior and inferior borders of the ACL consistently extended to approximately 3 mm from the borders of the articular surface of the lateral femoral condyle. Both of these landmarks could be visualized from both the sagittal and simulated arthroscopic perspective views. The superior border of the ACL had no true bony landmark and never inserted on the top dead center of the femoral roof. It extended up to, but not on, the roof of the femoral notch.

The tibial plateau also had distinct bony margins for the ACL footprint that could be identified from both an axial, sagittal, and a simulated arthroscopic view. These boundaries were consistently seen on the medial and posterior aspect of the ACL footprint. On the medial side, the ACL fibers always inserted up to the articular margin at the lateral edge of the medial tibial condyle. Anatomically, this border is a bony ridge that is the anterior extension of the medial intercondylar tubercle and as such could be named the "Medial Intercondylar Ridge of the Tibia." The lateral margin of the ACL had no such bony border as the fibers blended into the anterior horn of the lateral meniscus. The ACL fibers extended on average approximately 70.6% of the distance between the articular surfaces of the medial and lateral tibial condyles, as measured from the medial side.

The posterior margin of the ACL footprint ended at the base of a ridge of bone at the anterior aspect of the tibial eminence (tibial spine) between the medial and lateral tibial intercondylar tubercles. We believe that this represents the posterior margin of an "ACL fovea" as described by Girgis et al.[4] No fibers of the ACL attached posterior to this ridge, nor attached to the tibial eminence (tibial spine). If this ridge were to be named from an anatomical perspective it could be termed the "Anterior Intertubercle Ridge of the Tibia" or the "Tibial ACL Ridge." The anterior border of the ACL footprint had no bony landmark but did extend a distance of 10.7 mm from the posterior border of the ACL fovea and 27.2 mm from the anterior fibers of the PCL.

Girgis et al[4] studied 44 dissected cadaveric knees in several groupings using calipers to measure the ligamentous structures (ACL and PCL) and their relationship to the femur and tibia. They described the origin of the ACL in the sagittal plane on the medial aspect of the lateral femoral condyle in the shape of a segment of a circle with the anterior border straight and the posterior convex. The average length of the ACL was 23 mm, and the distance from the posterior fibers of the ACL to the articular surface

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TABLE 2
Anterior Cruciate Ligament (ACL) Tibial Insertion

| Tibia Results (N = 8) | Mean | Range | Figure Correlation |
|---|---|---|---|
| Distance from the posterior fibers of the ACL to anterior border of the anterior PCL fibers, mm | 16.5 ± 2.1 | 12.7-19.1 | Figure 6b (F) |
| Length of the ACL footprint as measured from the tibial intertubercle ridge to the anterior fibers of the ACL, mm | 10.7 ± 1.3 | 9.3-13.1 | Figure 6b (G) |
| The width of the posterior ACL footprint as measured from the medial intercondylar ridge of the tibia to the lateral ACL fibers, mm | 7.3 ± 1.1 | 5.9-9 | Figure 6b (H1) |
| The percentage of the width of the ACL footprint in relation to the distance from the medial intercondylar ridge of the tibia to the medial border of the articular surface on the lateral tibial condyle, % | 70.6 ± 10 | 57.8-87.8 | Figure 6b (H2) |
| The width of the anterior ACL footprint as measured from the medial intercondylar ridge of the tibia to the lateral ACL fibers, mm | 7.4 ± 1.3 | 6.3-9.7 | Figure 6b (H3) |

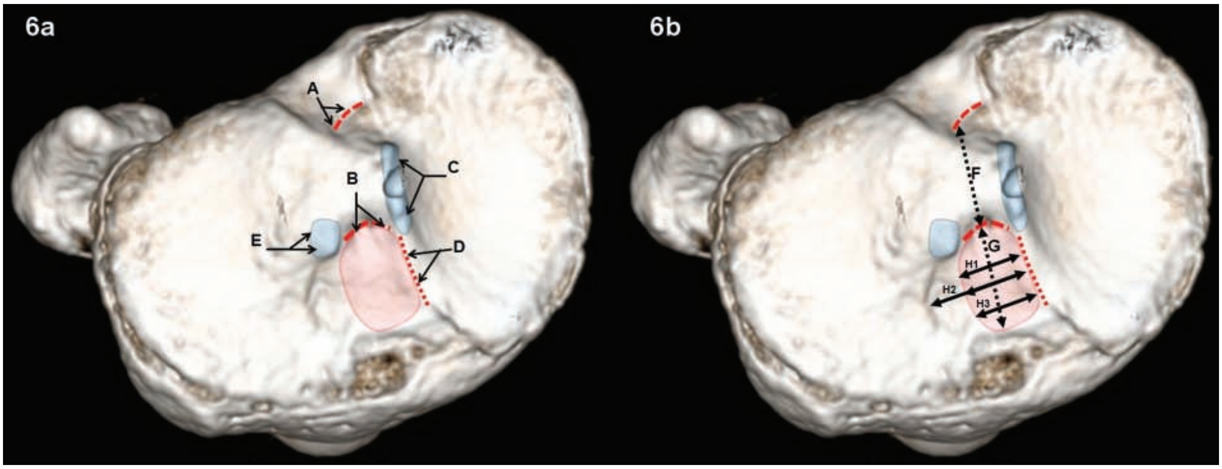


**Figure 6.** Axial view of tibial ACL footprint. Bony landmarks on the tibia (6a). Demarcations: A, anterior border of the PCL fibers; B, anterior intertubercle ridge or Tibial ACL Ridge and posterior border of the ACL fibers; C, medial intercondylar tubercle; D, Medial Intercondylar Ridge of the Tibia; and E, lateral intercondylar tubercle. View depicting length and width measurements along with correlations of the bony landmarks on the tibia (6b). Demarcations: F, distance of the anterior-most fibers of the PCL to the posterior ACL fibers at the intertubercle ridge; G, length of ACL fibers measured from the anterior intertubercle ridge or Tibial ACL Ridge to the anterior fibers of the ACL; H, anterior and posterior ACL width dimensions as well as the ACL footprint as percentage of total tibial eminence medial to laterally.

of the femoral condyles was 4 mm. No mention was made of a ridge in relationship to the ACL origin. The tibial insertion was described in a wide depressed area in front of and lateral to the "anterior tibial spine" (tibial eminence), with an average length of 30 mm and originating 15 mm posterior to the superior articular surface of the tibia. They noted variable fibers attached to the base of the spine, but no fibers of the ACL attached to the tip of the "anterior tibial spine" (tibial eminence), nor were there any fibers that attached posterior to the spine. Odensten and Gillquist[15] performed a very similar study on 33 cadaveric knees. They described the ACL femoral origin on the lateral femoral condyle as an oval, with a maximum diameter of 18 mm and a lesser diameter of 11 mm. Again, no mention was made of a ridge on the lateral femoral condyle. The ACL tibial insertion was described, quite differently from Girgis et al,[4] as an oval 17 mm long and 11 mm wide. Its center was described as 23 mm posterior to the meniscocapsular junction and 7 mm lateral from the articular surface of the medial tibial condyle.

Although our data are not the same dimensionally, our measured results are similar in location and orientation to

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those published by Girgis et al[4] and Odensten and Gillquist.[15] Our study consists of a relatively small number of specimens, and the measurements of the ACL insertions may have a broader variance with a larger number of specimens. However, the purpose of our study was to document the consistent relationship of the bony landmarks of the femur and tibia to the ACL insertions. This was accomplished from both the 2-dimensional sagittal and axial views, as have been previously reported,[1,2,4,5,8,15] as well as from the perspective of a 3D-reconstructed CT model. The 3D reconstructions allowed us to establish these relationships from multiple perspectives, including a simulated surgical view. Another limitation of our study is the lack of age and gender information. Cadaveric specimens were donated from several sources and even though we were not provided with gender, age, and race demographics, we were certain all specimens were nonpaired. Another possible limitation consists of a slight variation of error in measurements taken. We calculated our possible error to be ±0.3 mm, which still should be mpore accurate than what can be done using calipers directly on cadaveric specimens.

In an attempt to delineate the anatomy of the so-called "Resident's Ridge" (as described by Clancy) Hutchinson and Ash[11] performed sections on 10 human cadaveric knees to study the slope and cortical thickness of the medial wall of the lateral intercondylar notch of the femur. They described a ridge in 9 of 10 specimens as a change of slope greater than 5° in the "femoral roof notch that was just anterior to the femoral attachment of the ACL." We believe that this ridge, or change in slope, is the same structure we were able to demonstrate in this study.

Farrow et al[3] described a "lateral intercondylar ridge" in 194 of 200 paired femora from adult skeletal donors. The description of this ridge is similar to our demonstration of the Resident's Ridge; however, no soft tissues were present to correlate with ACL anatomy.

Giron et al[5] attempted to define the anatomy and landmarks of the ACL femoral origin from an arthroscopic view. They used the face of a clock (o'clock position) to localize what was thought to be the optimal position on the wall of the femoral notch for ACL reconstruction. Markolf et al[13] also used the face of a clock to describe the optimal position on the lateral wall of the femoral notch for ACL reconstruction, but there are significant differences between the two studies as to the orientation of the clock face, and hence the potential for confusion in their descriptive techniques. Steiner et al[20] identified the need for knee flexion angle as well as transverse reference axis for the clock face to be established for this method to be precise.

Recent ACL reconstruction studies have shown that optimal knee mechanics are restored by graft placement inside the anatomical footprint of the ACL.[14,18] If the femoral tunnel is to be placed within the anatomical footprint of the ACL, then these landmarks we have identified can be used to aid in ACL reconstruction. The borders of the ACL reconstruction should be posterior to the Femoral ACL Ridge (Resident's Ridge), up to but not on to the roof of the notch, and within 3 mm of the articular margin of the lateral femoral condyle on the inferior and posterior aspect of the notch (Figure 5). If the tibial tunnel is to be placed within the anatomical footprint of the ACL, then the medial edge of the ACL reconstruction should be at the lateral edge of the articular margin of the medial tibial condyle (Medial Intercondylar Ridge of the Tibia) and extend laterally approximately 70.6% of the distance between the medial and the lateral tibial condylar articular surfaces (Figure 6). The posterior border of the tibial tunnel should extend only to the base of the anterior intertubercle ridge (Tibial ACL Ridge) between the medial and the lateral intercondylar tubercles and should be no more posterior than the tibial eminence (tibial spine).

It is our conclusion that the Resident's Ridge represents the anterior border of the femoral ACL insertion. The superior border is the junction of the medial wall of the lateral femoral condyle and the roof of the intercondylar notch. The inferior and posterior border is 3 mm from the articular margin of the lateral femoral condyle. On the tibia, the anterior intertubercle ridge (Tibial ACL Ridge) between the medial and lateral tibial intercondylar tubercles represents the posterior border of the ACL. The medial border of the ACL is the lateral border of the articular surface of the medial tibial condyle, or the "Medial Intercondylar Ridge of the Tibia." The lateral border is the lateral meniscus, with the footprint of the ACL extending approximately 70% of the distance from the medial to the lateral tibial condylar surface. The anterior border of the ACL is approximately 11 mm from the posterior border and has no distinct bony margin.

## ACKNOWLEDGMENTS

A special thanks to David Hollander, MD, Victoria Cox, PA, and the rest of the staff at Aspen Valley Hospital as well as Ed Havel, CT MR, at Yampa Valley Medical Center for his incredible help.

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