Height and Depth Guidelines for Anatomic Femoral Tunnels in Anterior Cruciate Ligament Reconstruction: A Cadaveric Study

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Purpose: To develop guidelines for femoral tunnel placement based on height and depth on the lateral wall of the notch and to apply these guidelines arthroscopically to show tunnel placements within the anterior cruciate ligament (ACL) femoral insertion site. **Methods:** Twelve cadaveric knees were dissected to define the centers of the femoral ACL attachment and its anteromedial (AM) and posterolateral (PL) bundles. In 90° of flexion, the height and depth of each center were determined relative to the low point on the lateral intercondylar notch. Radiographic grid measurements were made to validate these measurements. Subsequently, the measurement guidelines were applied arthroscopically in 10 new cadaveric knees to evaluate their accuracy for an anatomic single-bundle femoral tunnel. Interobserver reliability analysis was evaluated with the intraclass correlation coefficient. **Results:** In 90° of flexion, the height of the ACL center was 8.7 ± 0.6 mm from the low point of the lateral notch; PL center, 7.2 ± 1.2 mm; and AM center, 9.6 ± 1.1 mm. Relative to the low point, the ACL center was 1.7 ± 1.7 mm posterior, the PL center was 3.4 ± 1.5 mm anterior, and the AM center was 4.9 ± 1.7 mm posterior (intraclass correlation coefficient, 0.859). Radiographic grid measurements were consistent with the direct measurements. Application of the guidelines arthroscopically with or without the assistance of a 7-mm offset aimer placed all guide pins for tunnels within the femoral ACL footprint, with 90% within 4 mm of the ACL center. **Conclusions:** This study showed in cadaveric knees in 90° of flexion that the center of the ACL can be located on the lateral notch at a height of 8.7 ± 0.6 mm from the lowest point and anterior 11.5 ± 1.3 mm from the deepest point. How anatomic tunnels can be placed using these measurements was also shown in cadaveric knees. **Clinical Relevance:** An anatomic femoral tunnel for ACL reconstruction can be placed using height and depth guidelines.

An anterior cruciate ligament (ACL) graft should ideally re-create the native ligament's anatomy to best restore normal knee kinematics.[1-4] Support for this type of anatomic ACL reconstruction has evolved from biomechanical and clinical studies.[1-6] However, a common cause for surgical failure is graft misplacement outside the ACL's native attachments.[5,6] Although it has been generally accepted that grafts should be placed anatomically, there has been no consensus on how to locate the ACL attachments. This is particularly a challenge for the femoral attachment where the arthroscopic image varies based on knee flexion and on the viewing portal.[7]

Multiple surgical approaches have been proposed for locating the ACL femoral attachment. These include using a clock-face analogy, bony ridges, ACL remnants, computer navigation, and radiographic localization.[1,2,8-10]

The commonly referenced clock-face analogy has been particularly troublesome because the horizontal axis of the clock and the flexion angle of the knee have rarely been specified.[2,9,11,12] These variables plus the location of the viewing portal will affect the accuracy of this method.[9,13] As an alternative, identifying the ACL remnants can be helpful, but ACL fibers may be absent with chronic injuries, and the border of the remnants may be challenging to define. There has also been interest in referencing tunnel placements relative to the intercondylar and bifurcate ridges. This is based on the understanding that the ACL femoral attachment is

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Table 1. Demographic Data for Study Knees

	Anatomic Measurements (n = 12)	Arthroscopic Procedure (n = 10)
Age, yr	56.5 ± 16.9 (22-79)	62.9 ± 12.9 (41-85)
Height, m	1.74 ± 0.11 (1.50-1.88)	1.71 ± 0.08 (1.57-1.82)
Weight, kg	70.4 ± 16.0 (52.2-102.1)	76.6 ± 11.5 (64.9-95.3)
BMI, kg/m^2	23.6 ± 6.2 (16-37)	26.1 ± 3.4 (23-34)
Male/ female, n	12/0	6/4
Right/left, n	12/0	4/6

NOTE. Data are presented as mean ± 1 SD (range) unless otherwise indicated. There was no statistical difference between groups for age ($P = .34$), height ($P = .42$), weight ($P = .32$), or BMI ($P = .27$).
BMI, body mass index.

posterior-inferior to the intercondylar ridge and its anteromedial (AM) and posterolateral (PL) bundles are separated by the bifurcate ridge.[8,14] However, these bony ridges can be difficult to identify, and even when located, there is uncertainty on how high to place the femoral tunnel.[14] Radiographic criteria using intra-operative fluoroscopy and image-guided technology have also been advocated as methods to identify the ACL attachment.[1,8,15] Although these technologies are useful as research tools, most surgeons have found these methods to be cumbersome and even inaccurate if the radiographic images are not well-aligned.[1]

Some surgeons have proposed using measurements from points of intra-articular anatomy to locate the ACL femoral attachment.[14,16-18] However, the landmarks for these measurements may not be easily visualized arthroscopically, and agreement on specific landmarks has been lacking.[14,16,17] In this context, a practical method to locate the femoral ACL footprint based on height and depth in the notch would be helpful.

The purposes of this study were to develop guidelines for femoral tunnel placement based on height and depth on the lateral wall of the notch and to apply these guidelines arthroscopically to show tunnel placements within the ACL femoral insertion site. The hypothesis was that guide pins and therefore tunnels could be placed close to the ACL center using height and depth measurements.

Methods

Anatomic Measurements

Twelve fresh-frozen human knees from 12 male cadavers were used for the anatomic measurements. Demographic data for the knees are listed in Table 1. All specimens were thawed for 24 hours before dissection, and none had evidence of ligament injury or significant osteoarthritic changes. The knees were dissected free of all soft tissues, and the medial condyle was removed parallel to the roof of the intercondylar notch. The ACL attachment was carefully dissected to remove synovial tissue and to delineate the fibers of the direct and indirect insertions.[19,20] The AM and PL bundles were identified based on their tensioning pattern with flexion and extension, and they were separated minimally with a No. 15 blade. The 2 bundles were outlined with a surgical marking pen. Subsequently, the bulk of the ACL was resected, leaving 1 mm of ligament attached to the femur. The center points (equidistant along their major and minor axes) of the AM bundle, PL bundle, and entire ACL were marked with a pen (Fig 1).

Locations on the lateral wall of the intercondylar notch were described using the terminology of height as being either proximal or distal and depth as being either anterior or posterior (Fig 1).[21,22] For all measurements and descriptions, knees were in 90° of flexion. A horizontal axis was drawn through the low point on the lateral wall at the edge of the articular cartilage parallel to the shaft of the femur. The vertical axis to measure height was orthogonal to the horizontal axis starting at the low point of the articular cartilage (Fig 1). Horizontal measurements from the ACL center points were also made to the anterior and posterior cartilage borders of the notch. All measurements were made with calipers and rounded to the nearest 0.5 mm and were made by 2 of the authors (A.D.D. and M.E.S.). The recorded value was the average of the 2 measurements.

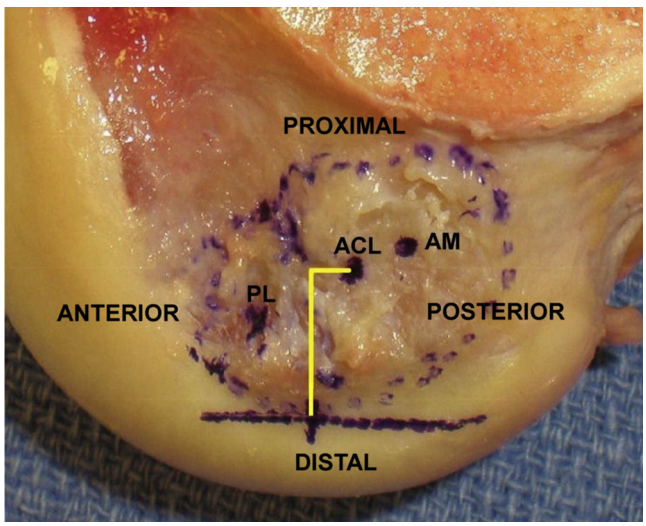

Fig 1. The femoral anterior cruciate ligament (ACL) attachment of a right knee with the height positions of proximal/distal and depth positions of anterior/posterior labeled. An example of height and depth for the ACL center is depicted by the yellow lines. These lines were drawn with the knee in 90° of flexion from the low point of the lateral notch. (AM, anteromedial; PL, posterolateral.)