Topography of the Femoral Attachment of the Posterior Cruciate Ligament

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Background: The success of posterior cruciate ligament reconstruction has varied. The objective of this study was to determine quantitatively and qualitatively the topography and osseous landmarks of the femoral footprints of the anterolateral and posteromedial bundles of the posterior cruciate ligament in order to enhance repair.

Methods: Twenty unpaired knees from twenty human cadavers were evaluated. The surface features of the femoral footprints of the anterolateral and posteromedial bundles of the posterior cruciate ligament were studied by means of macroscopic observation and three-dimensional laser photography.

Results: We observed, both visually and with three-dimensional laser photography, an osseous prominence located proximal to the femoral footprint of the posterior cruciate ligament in eighteen of the twenty human knees. This osseous landmark, denominated the “medial intercondylar ridge,” determined the proximal border of the posterior cruciate ligament footprint. In eight of the twenty knees, we observed a small osseous prominence between the anterolateral and posteromedial bundles of the posterior cruciate ligament. A clear change in the slope of the femoral footprint of the posterior cruciate ligament was seen between the anterolateral and posteromedial bundles. The average area of the posterior cruciate ligament footprint (and standard deviation) was 209 ± 33.82 mm², the average area of the anterolateral bundle was 118 ± 23.95 mm², and the average area of the posteromedial bundle was 90 ± 16.13 mm².

Conclusions: The femoral footprint of the posterior cruciate ligament has a unique surface anatomy, with a medial intercondylar ridge being frequently present and a medial bifurcate ridge being less frequently present.

Clinical Relevance: These anatomical findings may assist surgeons in performing posterior cruciate ligament reconstruction in a more anatomical fashion.

The posterior cruciate ligament is considered to be the primary restraint to posterior knee translation and a secondary restraint to varus, valgus, and external rotation of the knee joint. It is composed of two functional bundles: the anterolateral bundle and the posteromedial bundle. It has been demonstrated that these two bundles have distinct patterns of tension during the range of motion of the knee joint. The anterolateral bundle is taut near 90° of flexion, and the posteromedial bundle is taut at nearly full extension.

The success of posterior cruciate ligament reconstruction has been variable. Some recent studies have shown that double-bundle posterior cruciate ligament reconstruction can restore knee kinematics better than can single-bundle posterior cruciate ligament reconstruction. Previous studies have demonstrated that the placement of the femoral tunnel for the posterior cruciate ligament reconstruction is more important than the placement of the tibial tunnel in terms of restoring graft forces.

Knowledge of the anatomy of the posterior cruciate ligament is crucial to understanding the function of its two bundles as well as to improving the outcome of reconstruction surgery. Although many studies have provided important information about the femoral footprint of the posterior cruciate ligament, we are not aware of any published detailed anatomical evaluations of the bone landmarks and topography of the posterior cruciate ligament footprint.

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the femoral footprint of the posterior cruciate ligament. In our opinion, a description of these osseous landmarks may assist surgeons in selecting the anatomical placement of femoral tunnels during single or double-bundle reconstruction of the posterior cruciate ligament. Thus, the main objective of this study was to evaluate qualitatively and quantitatively the bone landmarks and topography of the femoral footprints of the anterolateral and posteromedial bundles of the posterior cruciate ligament.

Materials and Methods
Twenty unpaired fresh-frozen human cadaveric knees from twenty adults (fifteen men and five women) were used in this study. The average age at the time of death was seventy-
four years (range, fifty-seven to ninety-three years). Cadaveric knees that showed severe degenerative changes, signs of fractures, or evidence of ligament injury had been excluded from the study. The knees were completely dissected to expose the posterior cruciate ligament and the medial femoral condyle (Fig. 1). The synovial covering of the posterior cruciate ligament was removed, along with the meniscofemoral ligaments. The femoral footprints of the anterolateral and posteromedial bundles of the posterior cruciate ligament could be identified on the basis of the different tension pattern of each bundle during the range of motion of the knee, with the anterolateral bundle being taut in flexion and the posteromedial bundle being taut in full extension. The bundles were separated carefully with use of blunt dissection. The footprints of the anterolateral and posteromedial bundles were carefully defined with ink before all soft tissue was removed to expose the medial wall of the intercondylar notch.

At first, gross observation of the bone topography, with special attention to the femoral footprints of the anterolateral and posteromedial bundles, was performed in all knees (Fig. 2). Second, the knees were photographed with a laser three-dimensional digitizer camera (VIVID 910 3D Digitizer; Konica Minolta Sensing, Osaka, Japan), and the images were analyzed with specific software (Geomagic Studio 9; Geomagic, Research Triangle Park, North Carolina) (Fig. 3). This noncontact method allows three-dimensional visualization and digital measurements of the observed surface through the analysis of 307,000 triangulation blocks. The precision of the three-dimensional images is approximately 0.0008 mm. The accuracy is 0.22 mm for the x axis, 0.16 mm for the y axis, and 0.10 mm for the z axis. Thus, it serves as an accurate means of measuring the area of the femoral footprint of the posterior cruciate ligament as well as the distance and length of all observed features. The central point of each area was located visually on the digital images. The distance between the centers of the anterolateral and posteromedial footprints was measured, and the shortest distance from the center of each bundle’s footprint to the edge of the articular cartilage and to the medial intercondylar ridge was identified. The surface anatomy of the medial wall of the intercondylar notch was also observed with this method, with measurements made of defined osseous landmarks. We use the terms “proximal/distal” and “anterior/posterior” throughout this article to describe the location of the structures on the medial intercondylar wall when the knee was in the anatomical position.

Results

The femoral footprints of the posterior cruciate ligaments varied in shape and size. The shape was a semicircle in fifteen of the twenty knees and an oval in five. The femoral attachment of the posterior cruciate ligament was concave in nineteen knees and flat in one. The three-dimensional laser digital measurement showed the average area (and standard deviation) of the femoral posterior cruciate ligament footprint to be $209 \pm 33.82 \text{ mm}^2$, with the average area of the anterolateral bundle measuring $118 \pm 23.95 \text{ mm}^2$ and the average area of the posteromedial bundle measuring $90 \pm 16.13 \text{ mm}^2$. The average distance between the central points of the bundles...
Fig. 4
Image made with three-dimensional laser photography, showing the medial intercondylar ridge (black arrows) and the medial bifurcate ridge (white arrows). This image simulates a lateral portal view of the left knee when the knee is near 90° of flexion. The small picture of the femur in the left corner shows the orientation of the specimen.

Fig. 5
Left: Image made with three-dimensional laser photography, showing the medial intercondylar wall of the left knee. To emphasize the osseous features on the medial intercondylar wall, the femoral shaft is omitted. Note a small ridge (the medial bifurcate ridge, black arrow) between the anterolateral and posteromedial bundles. Right: A cross section through the entire posterior cruciate ligament footprint with a schematic diagram of the angle formed between the anterolateral (AL) and posteromedial (PM) bundle attachments. The small picture of the femur in the middle shows the orientation of the specimen.
was 11 ± 1.18 mm. With the knee at 90° of flexion, the average shortest distances from the centers of the anterolateral and posteromedial bundles to the articular cartilage edge were 7 ± 1.02 mm and 8 ± 0.99 mm, respectively.

An osseous prominence located proximal to the femoral attachment of the posterior cruciate ligament was grossly and digitally identified in eighteen of the twenty knees. This osseous prominence was named the “medial intercondylar ridge” by the senior author (F.H.F.). With the knee in the anatomical position, the medial intercondylar ridge runs obliquely through the entire femoral footprint of the posterior cruciate ligament from proximal to distal and from anterior to posterior (Fig. 4). Its average length was 14.24 ± 2.3 mm. The average distances between the medial intercondylar ridge and the center point of the posterior cruciate ligament averaged 58 ± 25.4 mm² and that of the posteromedial footprint averaged 64.6 ± 24.7 mm². These differences in the literature may be due to the different methods used for measurement as well as to ethnic and gender differences in the human subjects that were studied. Our study confirmed that the anterolateral and posteromedial bundles have distinctive femoral footprints. Our measurements of the average areas of the anterolateral and posteromedial footprints are larger than those previously described in the literature. This discrepancy may be due to the reasons mentioned above and mainly to the fact that the three-dimensional analysis used in this study may cover the total area of the concave attachment of the posterior cruciate ligament more accurately. Also, it is important to note that we included all peripheral fibers of the posterior cruciate ligament attachment in our measurements. We believe that these additional factors may have contributed to the larger areas that we observed.

In addition to the medial intercondylar ridge, we also observed a subtle osseous prominence located between the femoral footprints of the anterolateral and posteromedial bundles (Fig. 4). It was identified in eight of the twenty knees as a discrete osseous ridge on the bone. We propose that it be called the “medial bifurcate ridge.” The average length of the medial bifurcate ridge was 5.8 ± 1.38 mm. In addition, a change of slope was observed between the femoral footprints of the anterolateral and posteromedial bundles (Fig. 5). With use of the medial bifurcate ridge as the pivot, the average angle formed by the anterolateral and posteromedial femoral footprints was 140° ± 12.8°. All quantitative data are given in Table I.

### Discussion

The anatomy of the posterior cruciate ligament has been described in several studies. The footprint area and the locations of the two bundles have been reported. However, the details of the bone anatomy related to the femoral footprint of the posterior cruciate ligament have not been described, to our knowledge. A detailed description of the femoral footprints of the anterolateral and posteromedial bundles is needed to enable surgeons to accurately place femoral tunnels in posterior cruciate ligament surgery.

Girgis et al. reported the anatomical measurements of the total posterior cruciate ligament footprint, but they did not evaluate the anatomical measurements of each bundle’s footprint separately. Harner et al. and Morgan et al. reported that the femoral attachment of the posterior cruciate ligament spans, on the average, a distance of 32 mm in anterior-to-posterior depth. Single-bundle reconstruction may not cover all of the femoral footprint of the posterior cruciate ligament and does not reproduce the anatomy of the anterolateral and posteromedial bundles or their functional patterns. Harner et al. used a digitizing system (accurate to within 0.8 mm) to record the coordinates of the periphery of the attachment of the posterior cruciate ligament and its bundles. They used thirty equally spaced points to collect the data. The average area of the femoral footprint of the posterior cruciate ligament was reported to be 128 ± 22 mm², and they did not find significant differences between the areas of the anterolateral and posteromedial bundles. In another anatomic study, Takahashi et al. used photographs with a measurement scale (one scale for each photograph of each femur) to evaluate the femoral attachment of the posterior cruciate ligament. They reported that the area of the anterolateral femoral footprint averaged 58 ± 25.4 mm² and that of the posteromedial femoral footprint averaged 64.6 ± 24.7 mm². These differences in the literature may be due to the different methods used for measurement as well as to ethnic and gender differences in the human subjects that were studied. Our study confirmed that the anterolateral and posteromedial bundles have distinctive femoral footprints. The footprint area and posterior depth. Single-bundle reconstruction may not cover all of the femoral footprint of the posterior cruciate ligament and its bundles. They used thirty equally spaced points to collect the data. The average area of the femoral footprint of the posterior cruciate ligament was reported to be 128 ± 22 mm², and they did not find significant differences between the areas of the anterolateral and posteromedial bundles. In another anatomic study, Takahashi et al. used photographs with a measurement scale (one scale for each photograph of each femur) to evaluate the femoral attachment of the posterior cruciate ligament. They reported that the area of the anterolateral femoral footprint averaged 58 ± 25.4 mm² and that of the posteromedial femoral footprint averaged 64.6 ± 24.7 mm². These differences in the literature may be due to the different methods used for measurement as well as to ethnic and gender differences in the human subjects that were studied. Our study confirmed that the anterolateral and posteromedial bundles have distinctive femoral footprints. Our measurements of the average areas of the anterolateral and posteromedial footprints are larger than those previously described in the literature. This discrepancy may be due to the reasons mentioned above and mainly to the fact that the three-dimensional analysis used in this study may cover the total area of the concave attachment of the posterior cruciate ligament more accurately. Also, it is important to note that we included all peripheral fibers of the posterior cruciate ligament attachment in our measurements. We believe that these additional factors may have contributed to the larger areas that we observed.

The location of the femoral footprint of the posterior cruciate ligament has been described in many different ways. Wind et al. reported that the center of the footprint is located 1 cm proximal to the articular cartilage.
Mejia et al. 16 used the “o’clock” method and suggested that the posterior cruciate ligament may extend from 12 to 4 o’clock in the right knee and from 12 to 8 o’clock in the left knee. Takahashi et al. 17 measured the distances between the centers of the anterolateral and postero-medial bundle footprints and the anterior border of the articular cartilage using a line parallel to the Blumensaat line. The average distances were 9.6 mm and 10.6 mm for the anterolateral and postero-medial bundles, respectively. Morgan et al. 18 defined the centers of the anterolateral and postero-medial bundles by using three different axes in reference to the articular cartilage. Their results showed that the center of the anterolateral bundle originated 13 mm posterior and 13 mm inferior to the anterior border of the articular cartilage whereas the center of the postero-medial bundle originated 8 mm posterior and 20 mm inferior to the anterior border of the articular cartilage. In a recent study, Edwards et al. 19 used the “o’clock” method and suggested that the o’clock method and the center of a circle outlining the posterior aspect of the medial femoral condyle as a reference. The centers of the footprints of the posterior cruciate ligament bundles were found to be at a variety of o’clock positions when measured parallel to the femoral intercondylar notch roof or the femoral shaft. On the femoral side, the center of the anterolateral bundle was on the average, 7 ± 2 mm from the articular cartilage at 10:20 ± 00:30 o’clock, and the center of the postero-medial bundle was 10 ± 3 mm from the articular cartilage at 08:30 ± 00:30 o’clock.

These previous studies were conducted with use of different methods, and the results were reported in different ways. Thus, it may be somewhat confusing for surgeons attempting to choose the appropriate site for placement of the femoral tunnel in a reconstruction of the posterior cruciate ligament. Our findings suggest a different approach for determining the footprints of the anterolateral and postero-medial bundles. The medial intercondylar ridge was found to define the proximal limit of the posterior cruciate ligament, whereas the medial bifurcate ridge was found to separate the femoral footprints of the anterolateral and postero-medial bundles. We believe that these two ridges may be used to assist the surgeon in determining the placement of the anterolateral and postero-medial tunnels on the femoral side. During the surgery, both tunnels should be placed more distally than the medial intercondylar ridge, and they should be separated by the medial bifurcate ridge.

Previous investigators have reported that the femoral attachment of the posterior cruciate ligament is relatively planar and approximates a half-moon shape 20. In this study, we found that the femoral attachment site of the posterior cruciate ligament was concave in nineteen of twenty knees and was relatively planar in only one specimen. The shape of the femoral attachment site was approximately semicircular in fifteen femora and oval in five. We found that the two bundles were located in different planes and there was a change of slope between the femoral footprints of the anterolateral and postero-medial bundles. This finding may also be used to assist in the anatomical placement of femoral tunnels in reconstructions of the posterior cruciate ligament. However, it is important to note that the bone topography reported here describes subtle features related to the femoral footprint of the posterior cruciate ligament. Careful probing and removal of the residual posterior cruciate ligament soft tissue are necessary to identify these structures.

This study had at least two limitations. First, a relatively small number of knees was examined considering the great possibility of anatomical variations. Second, despite the accuracy of the three-dimensional laser measurement systems, the measurements relied on human judgment (i.e., determining the center of a footprint), which may have introduced bias.

We demonstrated that the femoral footprint of the posterior cruciate ligament has a unique surface anatomy, with a medial intercondylar ridge being frequently present and a second osseous landmark, the medial bifurcate ridge, being identified less frequently. These osseous landmarks may be used as a guide for placement of anatomical femoral tunnels during reconstructions of the posterior cruciate ligament.

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References


