Radiographic Landmarks for Tunnel Positioning in Posterior Cruciate Ligament Reconstructions

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Background: Consistent radiographic guidelines for tunnel placement in single- or double-bundle posterior cruciate ligament (PCL) reconstructions are not well defined. Quantitative guidelines reporting the location of the individual PCL bundle attachments would aid in intraoperative tunnel placement and postoperative assessment of a PCL reconstruction.

Hypothesis: Consistent and reproducible measurements in relation to radiographic landmarks for the entire PCL and its individual bundle attachments are achievable.

Study Design: Controlled laboratory study.

Methods: The femoral and tibial PCL bundle attachment centers of 20 nonpaired fresh-frozen cadaveric knees were labeled using radio-opaque spheres and the attachment areas were labeled using barium sulfate. Anteroposterior (AP) and lateral radiographs of the femur and tibia were obtained, and measurements of the distances between the PCL bundle centers and landmarks were acquired.

Results: On the AP femur view, the anterolateral bundle (ALB) and posteromedial bundle (PMB) centers were 34.1 ± 3.0 mm and 29.2 ± 3.0 mm lateral to the most medial border of the medial femoral condyle, respectively. The lateral femur images revealed that the ALB center was 17.4 ± 1.7 mm and the PMB center was 23.9 ± 2.7 mm posteroproximal to a line perpendicular to the Blumensaat line that intersected the anterior margin of the medial femoral condyle cortex. Anteroposterior tibia images revealed that the ALB and PMB centers were located 0.2 ± 2.1 mm proximal and 4.9 ± 2.9 mm distal to the proximal joint line, respectively. The PCL attachment center was 1.6 ± 2.5 mm distal to the proximal joint line. On the lateral tibia view, the ALB center was 8.4 ± 1.8 mm, the PCL attachment center was 5.5 ± 1.7 mm, and the PMB center was 2.5 ± 1.5 mm superior to the champagne glass drop-off of the posterior tibia.

Conclusion: Radiographic measurements from several clinically relevant views of the femur and tibia were reproducible with regard to the anatomic locations of the ALB and PMB centers. The measurements from the lateral femur and tibia views provided the most clinically pertinent radiographic measurements intraoperatively.

Clinical Relevance: This study established a set of clinically relevant radiographic guidelines for anatomic reconstruction of the PCL. The parameters set forth in this study can be used in both the intraoperative and postoperative settings for both single- and double-bundle PCL reconstructions.

Keywords: posterior cruciate ligament; anterolateral bundle; posteromedial bundle; radiographs; Blumensaat line

A central limitation to the development of successful anatomically based posterior cruciate ligament (PCL) surgical reconstruction is the lack of applying information relating recent advances in knowledge of PCL anatomy1,6,28 to the surgical methods for tunnel placement. Radiography has been reported to accurately assess tunnel position intraoperatively and postoperatively in ligament reconstructions.19,21,23,27 Therefore, reproducible and accurate radiographic guidelines to direct tunnel placement during PCL reconstructions are essential to perform anatomic PCL reconstructions.

Recent reports have detailed the anatomy of the individual PCL bundles. At the femoral attachment, the medial intercondylar ridge1,13 has been reported to mark the proximal border of both the anterolateral bundle (ALB) and
posteromedial bundle (PMB), whereas the medial bifurcate prominence has been reported to mark the separation between the ALB and PMB. At the tibial PCL attachment, the bundle ridge consistently defines the posterior margin of the ALB and the anterior margin of the PMB. Although awareness of these newly reported landmarks may help to improve tunnel placement intraoperatively, radiographic characterization of these structures may further assist with localization of the individual PCL bundles.

Although the anteromedial and posterolateral bundles of the anterior cruciate ligament (ACL) have been well characterized radiographically, studies on the PCL have not adequately described the radiographic locations of the ALB and PMB attachments separately. Anatomic PCL reconstructions have been reported to improve subjective and objective outcomes over nonanatomic reconstruction tunnel placement. Therefore, further studies to define the ideal radiographic guidelines of the PCL are required.

The purpose of our study was to establish quantitative radiographic guidelines for identifying the anatomic femoral and tibial attachment sites of the entire PCL and its individual anterolateral and posteromedial bundles. We hypothesized that a standardized radiographic protocol could reproducibly describe the radiographic positions of the entire PCL as well as its bundle attachments. These guidelines have the potential to facilitate anatomic placement of PCL reconstruction tunnels intraoperatively, aid in postoperative evaluations of PCL reconstructions, and support preoperative planning of revision surgeries, potentially leading to more successful PCL reconstruction outcomes.

MATERIALS AND METHODS

Specimen Preparation

Twenty nonpaired, fresh-frozen human cadaveric knee specimens (average age, 49.1 years [range, 21-59 years]; 14 men and 6 women) with no history of injury or disease were used. Institutional review board approval was not required for this study since it was performed on cadaveric specimens only. All dissections were performed with the senior author present (R.F.L.). Dissection began with the removal of all soft tissues with the exception of the PCL, collateral ligaments, and menisci. The anterior and posterior meniscofemoral ligaments were identified and excised. After observing the tensioning pattern of the PCL fibers throughout the full range of knee motion, the surgeon carefully separated the ALB and PMB using a blunt-tipped probe. Subsequently, each bundle was sectioned and the peripheries of the femoral and tibial bundle footprints were marked with a permanent ink pen. After sharp dissection of the PCL fibers from their bony attachments, the center of each bundle was immediately marked with a 2-mm stainless steel sphere (Small Parts, Inc, Miami, Florida). In a modification of a previously described technique, the spheres were shallowly embedded in bone and fixed in place with glue (Henkel Co, Dusseldorf, Germany). Metal soldering wire (Malin Co, Cleveland, Ohio) was fixed along the medial intercondylar ridge of the distal femur for radiographic imaging. All imaging was conducted with the knee specimen at full extension. After initial femoral anteroposterior (AP) and lateral radiographic imaging, a radio-opaque barium sulfate (BaSO₄) (E-Z-EM, Inc, Lake Success, New York) emulsion was applied to each femoral bundle attachment site to denote the bundle attachment area.

On the tibia, 1-mm-diameter t-pins (Swinton Ave Trading Ltd, Inc, Boca Raton, Florida) were used to label the inferolateral corner of the transverse shiny white attachment fibers of the posterior horn of the medial meniscus and the posterior root attachments of the medial and lateral menisci. Metal soldering wire was fixed along the tibial bundle ridge, which has been reported to mark the separation between the ALB and PMB. Preliminary pilot imaging studies on 4 knees revealed that the geometric center point of the PCL attachment remained equidistant from the anterolateral and posteromedial bundle centers and at the bundle ridge. When we attempted to label it, the marker overlapped with the bundle ridge wire marker. Thus, we used the intersection of the bundle ridge and a line connecting the individual bundle centers as a reference point to calculate distances from the geometric center point of the tibial PCL attachment. Measurements from this landmark are referred to as “PCL tibial attachment center” measurements.

Image Collection

A fluoroscopy mini C-arm (Hologic, Inc, Bedford, Massachusetts) was used to obtain femoral and tibial images according to standard radiographic techniques. True AP views of the femur were obtained by ensuring minimal margins and maximal overlap between the medial and lateral borders of the condyles. True lateral views of the femur were obtained by aligning the posterior aspects of the medial and lateral femoral condyles. True AP views of the tibia were obtained with the anterior and posterior margins of the medial tibial plateau closely superimposed, the intercondylar eminences of the tibia positioned at the center of the femoral intercondylar notch, and the tibia covering one third of the fibular head. True lateral views of the tibia were obtained with a well-defined joint line and complete overlap of the posterior cortex of the proximal tibia. With the radiographic markers in place, the femoral and tibial radiographs were obtained in full extension for the AP and lateral views.

Measurements

Quantitative radiographic measurements were performed in a digital picture archiving and communication system (PACS) (Stryker, Kalamazoo, Michigan). Distances were calibrated with a metal sphere measuring 2.54 cm in diameter (Stryker) placed directly in the plane of the specimen at the level of the studied structures. Anatomic positioning nomenclature was reported according to standard positioning in the extended knee. Measurements involving structures labeled with the 2-mm spheres were made in reference to the spherical centers, whereas those involving...
t-pins were made from the proximal end of the pins, which
were inserted with the entire pin flush with the bony
surface.

On the AP femur radiographs (Figure 1 and Supplementary
Figure A1 in the appendix, available in the online ver-
sion of this article at http://ajs.sagepub.com/supplemental/),
the superior/inferior locations of the bundle centers were
measured perpendicular to a line that intersected the distal
margins of the femoral condyles (distal condyle line). Me-}


dlial/lateral positions of the bundles were measured
from a line drawn perpendicular to the distal condyle line
and intersecting the most medial border of the medial fem-
oral condyle (medial epicondyle line) and to a parallel line
intersecting the radiographic apex of the intercondylar
notch (apex line).

On the lateral femur radiographs (Figure 2 and Supple-
mentary Figure A2, available online), 2 separate axes were
used: (1) an axis generated off of a vertical line drawn al-
ong the posterior cortex of the proximal femur (posterior cortex
line) and (2) an axis generated off of the Blumensaat line.
Using the axis based on the posterior cortex line, the AP
positions of the individual bundle centers were measured
perpendicular to the posterior cortex line, and superior/
inferior distances to the distal condyle line and medial inter-
condylar ridge were measured parallel with the posterior
cortex line. Using the second axis based off of the Blumen-
saat line, distances were measured perpendicular to the
Blumensaat line. In addition, a subsequent line was gen-


rated that was perpendicular to the Blumensaat line and
that intersected the junction of the Blumensaat line with


the most anterior margin of cortical bone of the overlapped
femoral condyles. Distances from this line posteroproxi-

mally to the bundle centers parallel with the Blumensaat
line were measured. Following application of the BaSO₄,
the lateral femoral radiographs were repeated and measure-
ments were acquired from the margins of the bundle attach-
ment areas along the same axes used to measure the bundle
centers (Supplementary Figure A3, available online).

On the AP tibia radiographs (Figure 3 and Supplementary
Figure A4, available online), a reference line was drawn
along the proximal joint line, and subsequent perpendicular
lines were drawn intersecting pertinent bony and soft tissue
landmarks. Superior/inferior distances were measured from
the bundle centers and PCL attachment center to the prox-
imal joint line and to the level of the inferolateral corner of the
shiny white fibers of the posterior horn of the medial menis-
cus.¹ Medial/lateral distances were measured to lines that
intersected the apexes of the tibial eminences and to the pos-
terior meniscal root attachments.

On the lateral tibia radiographs, the AP distance of the
bundle attachment centers (Figure 4 and Supplementary
Figure A5, available online) and margins of the bundle
attachment areas (Supplementary Figure A3, available
online) were measured perpendicular to a reference line
drawn through the center of the long axis of the tibia
(long axis of tibia line). Vertical measurements were
made from the bundle centers and the tibial PCL attach-
ment center to a reference line perpendicular to the tibial
axis line and intersecting the champagne glass drop-off
ridge\(^1\) (CGD line). Next, a line was created to repre-
sent the theoretical path of a guide pin according to reports of
standard pin placement during drilling of a PCL transsti-""""bial reconstruction tunnel.\(^{21,27}\) To accomplish this, an
angled line was superimposed on the lateral tibial radi-
ograph that originated from the tibial PCL attachment cen-
ter and was directed anteroinferiorly at a 45° angle from
the tibial axis line toward the distal anterior tibia (guide
wire line). A line parallel to the guide pin line and inter-
secting the most anterosuperior edge of the concave poste-
rrior tibia immediately distal to the champagne glass drop-off
was also superimposed (Figure 4 and Supplementary
Figure A5, available online). The distance between the
guide wire line to the concave posterior tibia was measured
to quantify a potential safety margin to avoid posterior
wall breakout.\(^9,15\)

**Statistical Analysis**

To determine the reliability of the distance measurements,
2 reviewers independently measured blinded radiographs
using the PACS program. Each reviewer measured the
same set of radiographs on 2 separate occasions at least
2 weeks apart to evaluate intraobserver intraclass corre-
lation coefficient (ICC) reproducibility. The measured values
were compared between reviewers to evaluate interob-
server ICC consistency. Reliability analysis was performed
with the use of Predictive Analytics Software (PASW) Sta-
tistics version 18.0.0 (SPSS, Inc, an IBM Company, Chi-
cago, Illinois). Two-way mixed, single-measure ICCs were
calculated to determine reliability within (intraobserver)
and among (interobserver) reviewers for measurement
values.\(^{11}\) Interclass correlation coefficients of >0.75 were
considered excellent.\(^{25}\) Final measurements, percentages,
and variations were reported by averaging values from
both occasions and reviewers for a single averaged value.

**RESULTS**

All measurements and percentages are reported in Tables
1 to 6. The main clinically important measurements and
standard deviations follow. Percentages in relation to ref-
ence lines are listed in the corresponding tables.

**AP Femur**

Radiographic measurements for the AP view of the femur
are reported in Table 1 and illustrated in Figure 1. The
ALB and PMB centers were located 14.1 ± 1.2 mm and
15.8 ± 2.0 mm superior to the distal condyle line, respec-
tively. The ALB center was 34.1 ± 3.0 mm lateral to the
most medial border of the medial femoral condyle, whereas
the PMB center was located 29.2 ± 3.0 mm lateral.

**Lateral Femur**

Radiographic measurements for the lateral view of the femur are reported in Table 2 and illustrated in Figure 2. The
ALB center was located 17.4 ± 1.7 mm posteroproxi-
mal to the anterior cortex line of the femoral condyles
along a reference line parallel with the Blumensaat line.
Radioarthritic Landmarks for PCL Reconstructions

### Table 1: Quantitative Relationships of the Femoral Attachments of the PCL Bundles to Landmarks and Reference Lines on AP Radiographs

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB to:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Distal condyle line      | –14.1 ± 1.2      | –152.1 ± 25.3
| Apex line                | –6.6 ± 1.5       | –8.3 ± 1.9
| Medial epicondyle line   | 34.1 ± 3.0       | 42.8 ± 1.9
| Medial intercondylar ridge | 6.1 ± 1.9   | 65.6 ± 24.3
| PMB to:                  |                  |            |
| Distal condyle line      | –15.8 ± 2.0      | –170.5 ± 31.3
| Apex line                | –11.4 ± 2.0      | –14.4 ± 2.7
| Medial epicondyle line   | 29.2 ± 3.0       | 36.7 ± 1.7
| Medial intercondylar ridge | 5.2 ± 1.8   | 57.1 ± 25.3

### Table 2: Quantitative Relationships of the Femoral Attachments of the PCL Bundles to Landmarks and Reference Lines on Lateral Radiographs

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB to:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Posterior cortex line    | –0.8 ± 2.6       | –2.1 ± 7.4
| Anterior cortex line     | 17.4 ± 1.7       | 47.7 ± 14.7
| Distal condyle line      | –13.6 ± 1.3      | –50.0 ± 11.8
| Blumensaat line          | 4.7 ± 1.2        | 17.3 ± 6.1
| Medial intercondylar ridge | 6.1 ± 1.8   | 22.1 ± 7.7
| PMB to:                  |                  |            |
| Posterior cortex line    | 7.9 ± 2.5        | 22.0 ± 10.1
| Anterior cortex line     | 23.9 ± 2.7       | 65.6 ± 20.7
| Distal condyle line      | –14.8 ± 2.0      | –54.6 ± 14.0
| Blumensaat line          | 10.7 ± 1.4       | 39.4 ± 10.0
| Medial intercondylar ridge | 5.5 ± 1.7   | 20.0 ± 6.8

### Table 3: Quantitative Relationships of the Femoral Attachments of the PCL Bundles to Landmarks and Reference Lines on Lateral Radiographs After the Addition of BaSO₄

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB</td>
<td></td>
</tr>
<tr>
<td>Anterior margin to posterior cortex line</td>
<td>–3.8 ± 2.2</td>
</tr>
<tr>
<td>Posterior margin to posterior cortex line</td>
<td>3.6 ± 2.0</td>
</tr>
<tr>
<td>Superior margin to distal condyle line</td>
<td>–18.7 ± 1.8</td>
</tr>
<tr>
<td>Inferior margin to distal condyle line</td>
<td>–8.2 ± 1.3</td>
</tr>
<tr>
<td>Near margin to the Blumensaat line</td>
<td>1.8 ± 1.0</td>
</tr>
<tr>
<td>Far margin to the Blumensaat line</td>
<td>9.8 ± 1.8</td>
</tr>
<tr>
<td>PMB</td>
<td></td>
</tr>
<tr>
<td>Anterior margin to posterior cortex line</td>
<td>3.4 ± 2.2</td>
</tr>
<tr>
<td>Posterior margin to posterior cortex line</td>
<td>13.9 ± 2.0</td>
</tr>
<tr>
<td>Superior margin to distal condyle line</td>
<td>–20.1 ± 2.6</td>
</tr>
<tr>
<td>Inferior margin to distal condyle line</td>
<td>–9.0 ± 1.8</td>
</tr>
<tr>
<td>Near margin to the Blumensaat line</td>
<td>6.1 ± 1.6</td>
</tr>
<tr>
<td>Far margin to the Blumensaat line</td>
<td>15.4 ± 1.7</td>
</tr>
</tbody>
</table>

### AP Tibia

Radiographic measurements for the AP view of the tibia are reported in Table 4 and illustrated in Figure 3. The ALB and PMB centers were located 0.2 ± 2.1 mm proximal and 4.9 ± 2.9 mm distal to the proximal joint line, respectively. The PCL attachment center was 1.6 ± 2.5 mm distal to the proximal joint line. The ALB center was located 2.2 ± 1.0 mm superior and the PMB center 2.9 ± 1.0 inferior to the PCL tibial attachment center.

### Lateral Tibia

Radiographic measurements for the lateral view of the tibia are reported in Table 5 and illustrated in Figure 4. The ALB and PMB centers were located 8.4 ± 1.8 mm and 2.5 ± 1.5 mm superior to the champagne glass drop-off, respectively, whereas the PCL attachment center was 5.5 ± 1.7 mm superior to the champagne glass drop-off. The guide wire reference line was 7.0 ± 1.6 mm anterosuperior from the nearest concave edge of the posterior tibia. Radiographic measurements for the lateral view of the tibia with BaSO₄ are reported in Table 6 and illustrated in Supplementary Figure A3 (available online).

### Data Analysis

Interobserver ICC consistency was assessed among each of the reviewers in the first and second measurement trials. The interobserver ICC values were 0.997 and 0.997 for...

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TABLE 4
Quantitative Relationships of the Tibial Attachments of the PCL Bundles to Landmarks and Reference Lines on AP Radiographs

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximal joint line</td>
<td>−0.2 ± 2.1</td>
<td>−0.3 ± 2.6</td>
</tr>
<tr>
<td>Lateral tibial eminence</td>
<td>−5.2 ± 2.3</td>
<td>−6.7 ± 2.8</td>
</tr>
<tr>
<td>Medial tibial eminence</td>
<td>8.1 ± 2.3</td>
<td>10.5 ± 2.9</td>
</tr>
<tr>
<td>Lateral posterior root attachment</td>
<td>−4.2 ± 3.2</td>
<td>−5.3 ± 3.8</td>
</tr>
<tr>
<td>Medial posterior root attachment</td>
<td>8.7 ± 1.8</td>
<td>11.4 ± 2.5</td>
</tr>
<tr>
<td>Shiny white fibers of PHMM</td>
<td>0.7 ± 1.6</td>
<td>0.9 ± 2.1</td>
</tr>
<tr>
<td>Tibial PCL attachment center</td>
<td>−2.2 ± 1.0</td>
<td>−2.8 ± 1.3</td>
</tr>
<tr>
<td>PMB to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximal joint line</td>
<td>4.9 ± 2.9</td>
<td>6.2 ± 3.4</td>
</tr>
<tr>
<td>Lateral tibial eminence</td>
<td>−4.4 ± 2.1</td>
<td>−5.8 ± 3.0</td>
</tr>
<tr>
<td>Medial tibial eminence</td>
<td>9.0 ± 3.2</td>
<td>11.5 ± 3.7</td>
</tr>
<tr>
<td>Lateral posterior root attachment</td>
<td>−3.2 ± 3.3</td>
<td>−4.3 ± 4.2</td>
</tr>
<tr>
<td>Medial posterior root attachment</td>
<td>9.6 ± 2.8</td>
<td>12.4 ± 3.3</td>
</tr>
<tr>
<td>Shiny white fibers of PHMM</td>
<td>5.8 ± 2.3</td>
<td>7.5 ± 2.7</td>
</tr>
<tr>
<td>Tibial PCL attachment center</td>
<td>2.9 ± 1.0</td>
<td>3.7 ± 1.3</td>
</tr>
<tr>
<td>Tibial PCL attachment center to proximal joint line</td>
<td>−1.6 ± 2.5</td>
<td>2.1 ± 3.0</td>
</tr>
</tbody>
</table>

Values are reported as the mean ± standard deviation. Measurements made in the superior and medial directions are indicated by positive values. All percentages were created by normalizing values using the maximum medial-lateral width of the tibial plateau. AP, anteroposterior; ALB, anterolateral bundle; PCL, posterior cruciate ligament; PHMM, posterior horn of the medial meniscus; PMB, posteromedial bundle.

The first and second trials, respectively. These values indicate a high consistency of measurements within a reviewer. The intraobserver ICC values were 0.998 and 0.999 for each reviewer. These values demonstrate that the examiners were able to independently measure reference lines and distance measurements consistently.

DISCUSSION

In this study, we report a reproducible set of clinically applicable radiographic guidelines to assist with intraoperative and postoperative assessment of anatomic tunnel placement in PCL reconstructions. Our study yielded excellent interclass and intraclass correlation coefficients, demonstrating that the methods are highly repeatable and accurate. Because of the frequent reported intraoperative use of lateral radiographs during PCL reconstructions, the most important findings of this study were on the lateral views of the femur and tibia. On the lateral femur view, the measurements to the Blumensaat line and the anterior cortex line are likely the most pertinent findings. This measurement axis is a proven technique, and it has been used in ACL radiographic studies. In addition, on the lateral tibia radiographs, the PCL attachment center measurement to the champagne glass drop-off, which has been reported to be an important landmark on lateral tibial radiographs, is a critical finding because it is easily observed both radiographically and arthroscopically. This is an important measurement to ensure anatomic placement of the PCL tibial tunnel. These relationships are critical to proper placement of PCL tunnels intraoperatively and could be used to quickly assess proper tunnel placement after inserting a transibial PCL reconstruction tunnel guide pin.

Our study contrasted the notion that the tibial PCL tunnel is found 1 cm distal to the joint line, as initially reported by Racanelli and Drez. We found that the PCL attachment center was radiographically located 1.6 mm

TABLE 5
Quantitative Relationships of the Tibial Attachments of the PCL Bundles to Landmarks and Reference Lines on Lateral Radiographs

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long axis of the tibia line</td>
<td>31.4 ± 3.8</td>
<td>59.4 ± 6.5</td>
</tr>
<tr>
<td>CGD line</td>
<td>−8.4 ± 1.8</td>
<td>−15.8 ± 3.0</td>
</tr>
<tr>
<td>Tibial PCL attachment center</td>
<td>−3.8 ± 1.1</td>
<td>−7.1 ± 1.9</td>
</tr>
<tr>
<td>PMB to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long axis of the tibia line</td>
<td>35.8 ± 4.2</td>
<td>67.6 ± 6.7</td>
</tr>
<tr>
<td>CGD line</td>
<td>−2.5 ± 1.5</td>
<td>−4.8 ± 2.8</td>
</tr>
<tr>
<td>Tibial PCL attachment center</td>
<td>3.6 ± 0.9</td>
<td>6.8 ± 1.6</td>
</tr>
<tr>
<td>Tibial PCL attachment center to:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long axis of the tibia line</td>
<td>34.1 ± 4.1</td>
<td>64.4 ± 6.6</td>
</tr>
<tr>
<td>CGD line</td>
<td>−5.5 ± 1.7</td>
<td>−10.4 ± 3.1</td>
</tr>
<tr>
<td>Distance between 45° lines</td>
<td>7.0 ± 1.6</td>
<td>13.2 ± 2.8</td>
</tr>
</tbody>
</table>

Values are reported as the mean ± standard deviation. Measurements made in the anterior and superior directions are indicated by positive values. All percentages were created by normalizing values using the maximum anterior-posterior length of the tibial plateau. ALB, anterolateral bundle; CGD, champagne glass drop-off; PCL, posterior cruciate ligament; PMB, posteromedial bundle.

TABLE 6
Quantitative Relationships of the Tibial Attachments of the PCL Bundles to Landmarks and Reference Lines on Lateral Radiographs After the Addition of BaSO₄

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Distance, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALB</td>
<td></td>
</tr>
<tr>
<td>Anterior margin to long axis of the tibia line</td>
<td>28.3 ± 3.4</td>
</tr>
<tr>
<td>Superior margin to CGD line</td>
<td>−11.3 ± 2.3</td>
</tr>
<tr>
<td>Superior margin to tibial PCL attachment center</td>
<td>−7.8 ± 2.0</td>
</tr>
<tr>
<td>PMB</td>
<td></td>
</tr>
<tr>
<td>Posterior margin to long axis of the tibia line</td>
<td>37.1 ± 3.9</td>
</tr>
<tr>
<td>Inferior margin to CGD line</td>
<td>−1.0 ± 2.7</td>
</tr>
<tr>
<td>Inferior margin to tibial PCL attachment center</td>
<td>6.0 ± 1.2</td>
</tr>
</tbody>
</table>

Values are reported as the mean ± standard deviation. Measurements made in the anterior and superior directions are indicated by positive values. ALB, anterolateral bundle; CGD, champagne glass drop-off; PCL, posterior cruciate ligament; PMB, posteromedial bundle.
distal to the joint line. We believe that differences in labeling technique, more accurate and higher resolution images with digital measuring features, and more precise calibration techniques may have made our study results slightly different than their initial landmark study completed. Therefore, our findings indicate that anatomic placement of a single tibial PCL tunnel should be located between 1 and 2 mm distal to the joint line on the AP view. We believe that this important landmark can be readily assessed with intraoperative fluoroscopy or radiographs to verify the correct tibial tunnel guide wire position.

A recent article has also reported on a slightly different review of the radiographic landmarks for the ALB and PMB. In this study, the authors compared 3-dimensional photographic images with the results of radiography and reported similar results. Their radiography results, although comparable, differ from the present study because they refer to radiographic grids and reference lines to delineate the radiographic position of the ALB and PMB. In addition, they do not report on the AP femoral relationships or on the margins of the PCL bundle attachment footprints.

Although few reports have noted obtaining intraoperative femoral radiographs to ensure proper tunnel placement during PCL reconstructions, we believe that both AP and lateral femur views may play important roles during surgery. Because femoral tunnel placement has been reported to be the most important determinant of knee stability in PCL reconstructions, one should be confident that he or she is placing the femoral tunnels consistently in the proper anatomic location. Our results demonstrated consistent PCL bundle anatomy and highly repeatable femoral measurements. The findings of the femoral location of the ALB attachment provide guidelines for those opting for a single-bundle PCL reconstruction approach. The ALB is functionally the most critical bundle to reconstruct when a single-bundle PCL reconstruction approach is used. The ALB is measured at the proximal joint line, anatomic placement of a single tibial tunnel but also to not position it too far posterodistal to the posterior tibial facet not only to anatomically place the tibial tunnel but also to position it too far posterodistal to the posterior cortex breakthrough and potential neurovascular injury. In addition, although the authors believe that intraoperative AP imaging with the knee in full extension is the most reliable method, it is important to flex the knee to 90° while reaming the tibial tunnel to minimize the risk of neurovascular compromise.

We acknowledge that this study has some limitations. Our study numbers, although one of the largest describing knee radiographic landmarks, are still relatively small. Most important, one should recognize the potential limitations of 2-dimensional radiographic measurements of the complex 3-dimensional femoral PCL attachment site. Thus, it is important to recognize this relationship and be cognizant that both AP and lateral radiographs must be concurrently evaluated to accurately assess the PCL femoral attachment radiographically.

CONCLUSION

This study provides radiographic guidelines to identify the individual bundles and centers of the PCL attachment points with using radiographically pertinent landmarks. On the lateral femur view, the ALB center should be located 17.4 mm posteroproximal to the anterior cortex line of the femoral condyles, whereas the PMB center should be located 23.9 mm posteroproximal to this reference line. Tibial placement of ALB and PMB centers should be located 8.4 mm and 2.5 mm superior to the radiographically visualized champagne glass drop-off of the posteroproximal tibia on the lateral radiograph, respectively, whereas the PCL attachment center should be 5.5 mm superior to it. Contrary to previous reports of placing the PCL tunnel 1 cm distal to the proximal joint line, anatomic placement of a single tibial PCL tunnel should be located between 1 and 2 mm distal to the joint line on the AP view. These findings can be directly applied to proper tunnel positioning intraoperatively during PCL reconstruction and also to assess reconstruction tunnel placement postoperatively.

REFERENCES


