Radiographic Identification of the Primary Posterolateral Knee Structures

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Background: It is often difficult to identify the attachment sites of the fibular collateral ligament, popliteus tendon, and popliteofibular ligament for chronic posterolateral knee injuries or during revision surgeries. Descriptions of radiographic landmarks for these attachment sites would assist in the intraoperative identification of their locations and also allow for postoperative assessment of the placement of reconstruction tunnels.

Hypothesis: Identification of qualitative and quantitative radiographic landmarks for the attachments of the main posterolateral knee structures are reproducible among observers of various experience levels and allow for improved intraoperative and postoperative identification of these attachment sites.

Study Design: Descriptive laboratory study.

Methods: Dissections were performed on 11 cadaveric knee specimens. The attachments and locations of the investigated structures were labeled with radiopaque markers. The positions of the attachments relative to other attachment sites, labeled bony landmarks, and superimposed reference lines were quantified on anteroposterior and lateral radiographs. Measurements were performed by 3 independent examiners. Intraobserver and interobserver reliability was determined using intraclass correlation coefficients.

Results: Overall intraclass correlation coefficients for intraobserver reproducibility and interobserver reliability were calculated to be 0.981 and 0.983, respectively. On the anteroposterior view, the perpendicular distances from a line intersecting the femoral condyles to the popliteus tendon, proximal fibular collateral ligament, and lateral gastrocnemius tendon were 14.5, 27.1, and 34.5 mm, respectively. On the lateral view, the femoral attachments of the fibular collateral ligament, popliteus tendon, and lateral gastrocnemius tendon were 4.3, 12.2, and 13.1 mm, respectively, from the lateral epicondyle. In addition, the fibular collateral ligament and popliteus tendon were located within 1 mm of a reference line projected along the posterior femoral cortex distally, and also were located within the posteroinferior quadrant bound by the posterior femoral cortex extension reference line and another reference line perpendicular to it at the posterior margin of Blumensaat's line.

Conclusion: Comprehensive qualitative and quantitative guidelines for assessing posterolateral knee structures on both anteroposterior and lateral knee radiographs were described.

Clinical Significance: This radiographic information regarding the attachment sites of posterolateral structures can serve as a valuable reference for preoperative, intraoperative, and postoperative assessments of surgical reconstructions.

Keywords: posterolateral knee; radiographic landmarks; knee reconstructions; fibular collateral ligament; popliteus tendon; popliteofibular ligament

Radiographic identification of the attachment sites for both the anterior cruciate ligament and posterior cruciate ligament has been proven to be very useful for intraoperative and postoperative evaluation of proper reconstruction tunnel placement,[16,18] especially for the intraoperative assessment of tibial tunnel placement for posterior cruciate ligament reconstructions[6,19] and postoperative assessment of cruciate ligament graft failures.[6,16,18,19] Unfortunately, currently there are limited radiographic guidelines to assist with the proper positioning of posterolateral knee structures and reconstruction tunnels. Studies have demonstrated that the fibular collateral ligament (FCL), popliteus tendon (PLT), and popliteofibular ligament (PFL) are the primary contributors to static stabilization of the posterolateral knee[4,7,8,24] and are the main structures to address for primary repairs and reconstructions.[3,11,20]

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No potential conflict of interest declared.

The American Journal of Sports Medicine, Vol. 37, No. 3
DOI: 10.1177/0363546508328117
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Unfortunately, during intraoperative procedures, it can be difficult to locate the attachment sites of the FCL, PLT, and PFL among the multiple layers and fibrous connections between local ligaments, tendons, and bones,[4] especially in cases involving chronic injuries of the posterolateral knee, where tissue retraction and scarring can further obscure the locations of these structures and their attachments.[12] Additionally, normal landmarks may be obscured or obliterated in revision posterolateral knee surgeries due to the presence of previous reconstruction tunnels or hardware.[2]

Although previous anatomic studies[2,12] have quantified the gross anatomy for the attachment sites of the primary posterolateral knee structures, there are no guidelines for assessing the radiographic positions of these structures. The purpose of this study was to establish radiographic landmarks for the attachment sites of the primary posterolateral knee structures. Our hypothesis was that identification of qualitative and quantitative radiographic landmarks for the attachments of the primary posterolateral knee structures are reproducible among observers of various experience levels and allow for improved intraoperative and postoperative identification of these attachment sites.

MATERIALS AND METHODS

Sample Preparation

A total of 11 nonpaired, fresh-frozen cadaveric knee specimens with no prior injury, anatomic abnormalities, or disease were used in this study. The mean specimen age was 72 years (range, 45-89). Dissection began with the removal of the skin and subcutaneous tissues of the lateral side of the knee to expose the superficial layer of the iliotibial band and the long and short heads of the biceps femoris muscle. Fascial incisions,[23] followed by a horizontal incision through the biceps bursa,[14] were used to identify the more laterally located structures. The interval between the lateral gastrocnemius and soleus muscles was then identified by blunt dissection to obtain visual access to the more posterolaterally located structures. In addition, the interval between the lateral aspect of the popliteus muscle and the medial aspect of the soleus muscle was entered and dissected proximally to identify the PFL. The dissection was completed by incising the popliteus muscle belly distal to the medial attachment of the PFL and retracting it proximally to identify the popliteus musculotendinous junction.[12,14]

After dissection, the bony attachments of the FCL on the femur (proximal attachment) and on the lateral fibular head (distal attachment), the PLT in the popliteus sulcus of the femur, the PFL on the posteromedial aspect of the fibular styloid, and the lateral gastrocnemius tendon near the lateral supracondylar process of the femur were identified. The center of the insertion of the superficial layer of the iliotibial band on Gerdy's tubercle and the origin of the PFL at the popliteus musculotendinous junction were also identified.[15] Two-millimeter stainless steel spheres (Small Parts Inc, Miami Lakes, Florida) were inserted at the center of these attachment sites by placing the sphere within the center of an osteochondral transfer device (OATS [osteochondral allograft transfer system], Arthrex, Naples, Florida), which corresponded to the diameter of the attachment site of the respective structure, and then gently tapping a small mallet against the end of the OATS device to embed the sphere into the subchondral bone. Finally, the sharp ends of 1-mm diameter T-pins (Advantus Corporation, Jacksonville, Florida) cut to approximately 5 mm in length were embedded flush to the bone at the centers of the lateral epicondyle, the distal femoral attachment of the lateral intermuscular septum, and the tibial tubercle.

Data Collection

A fluoroscopy C-arm (MiniView 6800 Mobile Imaging System, GE Healthcare, Milwaukee, Wisconsin) was used to capture images of each specimen in AP and lateral views. True AP views were obtained with the anterior and posterior margins of the medial tibial plateau closely superimposed and the tibial eminences positioned at the center of the femoral intercondylar notch.[17] True lateral radiographs were obtained by ensuring that the posterior aspects of the medial and lateral femoral condyles overlapped and that a minimum of 12 cm of the distal femur was visible on the radiograph. A 1-cm $\times$ 1-cm radiopaque grid was included on all radiographs to correct for magnification disparities due to potential variability in distances between the specimens and the x-ray source.

Radiographic measurements were made digitally in a picture archiving and communication system (PACS) program (Imagecast, IDX Systems Corporation, Buckinghamshire, United Kingdom). The AP and proximodistal positions of each structure were determined in relation to other posterolateral knee structures, labeled bony landmarks, and also a number of specific reference lines projected onto the radiographs. Measurements to structures marked with T-pins were made in reference to the interface of the bony edge and the blunt end of the cut T-pin.

On the AP view, all femoral attachment locations were measured perpendicular to a reference line crossing the most distal edges of the femoral condyles (Figure 1). The femoral transcondylar distance between the adductor tubercle and the lateral intermuscular septum was measured as an indirect representation of the size of each individual knee. Perpendicular distances to a line intersecting the most proximal aspects of the lateral and medial tibial plateaus were measured for the tibial-based structures (Figure 2). The locations of fibular markers were also measured perpendicular to this tibial plateau line (Figure 2).

On the lateral view, a parallel line was drawn distally along the posterior femoral cortex, and perpendicular distances between this reference line and marked attachment sites were quantified to evaluate the relative locations of the attachment sites in the AP direction to aid in intraoperative and postoperative assessment of structure locations. As previously described,[21] the proximodistal locations of the attachments were measured relative to a second line drawn perpendicular to the first and intersecting the most posterior point of Blumensaat's line[1] (Figure 3).

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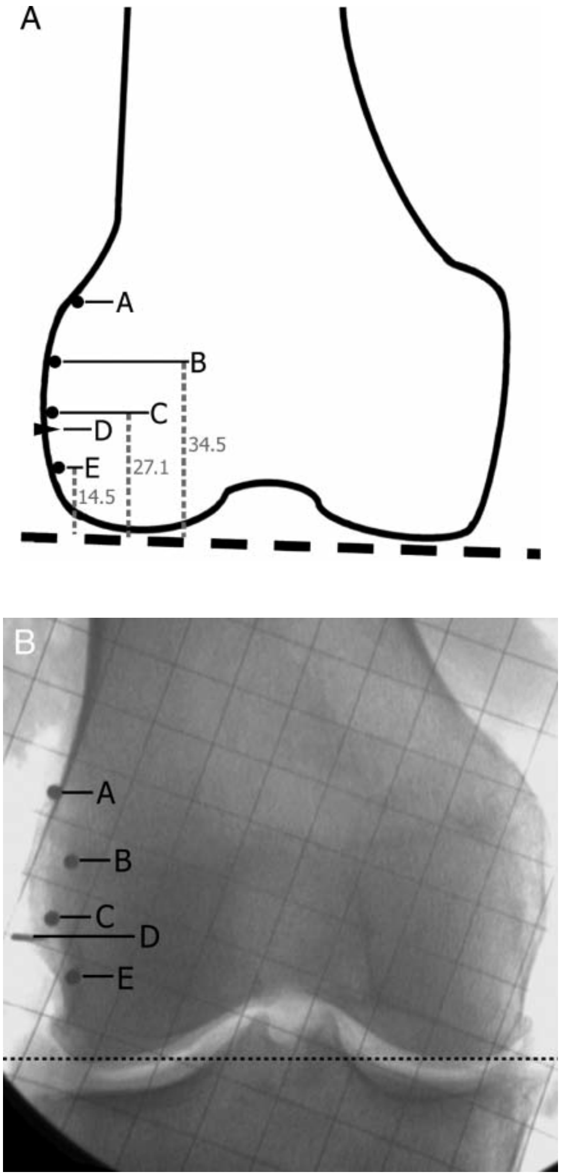

Figure 1. Illustration (A) and AP knee radiograph (B) demonstrating placement of the reference line intersecting the most distal points of the lateral and medial femoral condyles (line 1). Radiographic landmarks shown in the radiograph are qualitative representations of the landmark positions identified in this study and may not correspond quantitatively with the average positions reported in this study. All measurements are in millimeters. A, lateral intramuscular septum; B, lateral gastrocnemius tendon; C, fibular collateral ligament; D, lateral epicondyle; E, popliteus tendon.

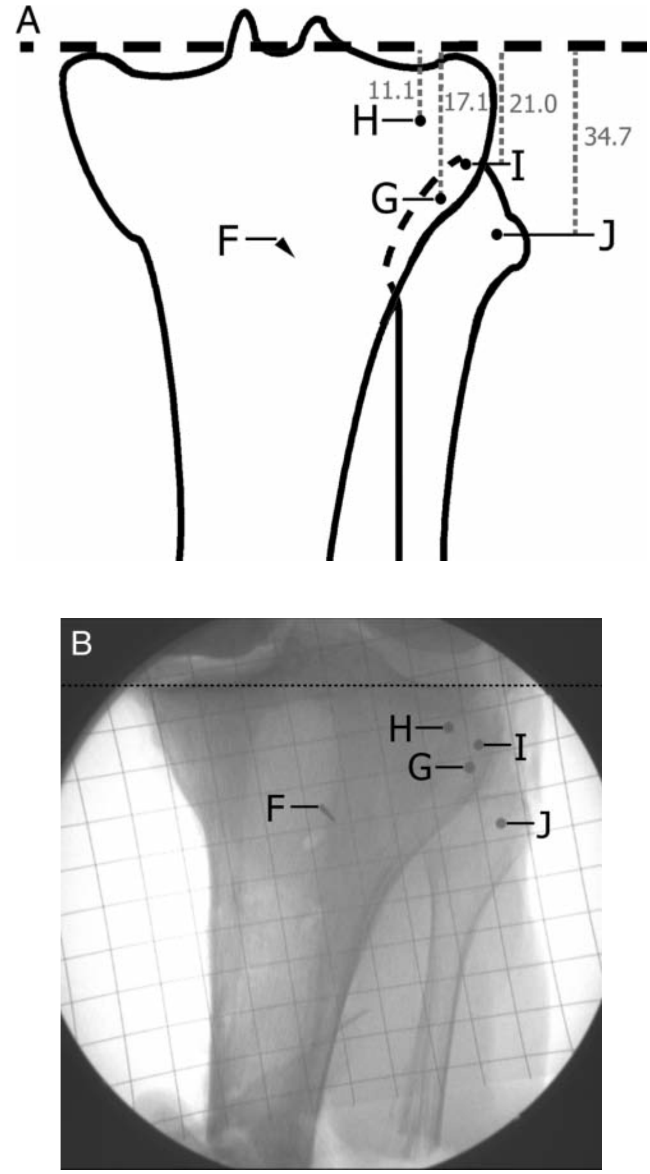

Figure 2. Illustration (A) and AP knee radiograph (B) demonstrating placement of a reference line crossing the most proximal aspects of the lateral and medial tibial plateaus. Radiographic landmarks shown in the radiograph are qualitative representations of the landmark positions identified in this study and may not correspond quantitatively with the average positions reported in this study. All measurements are in millimeters. F, tibial tubercle; G, Gerdy's tubercle; H, popliteus musculotendinous junction; I, popliteofibular ligament; J, fibular collateral ligament.

To determine the AP locations of the tibial attachment sites on the lateral radiographs, a line representing the diaphyseal axis of the tibia was drawn crossing the center points of 2 digitally drawn circles. One circle was immediately distal to the tibial tubercle and the other circle was approximately 3 cm distal to the first circle. Each circle was sized and positioned such that the anterior and posterior tibial borders were tangent to its circumference. A line representing the tibial slope, drawn through the most superior points at the anterior and posterior edges of the medial tibial plateau on the lateral knee radiographs, was used to measure proximodistal positions (Figure 4).[5] On the fibula,

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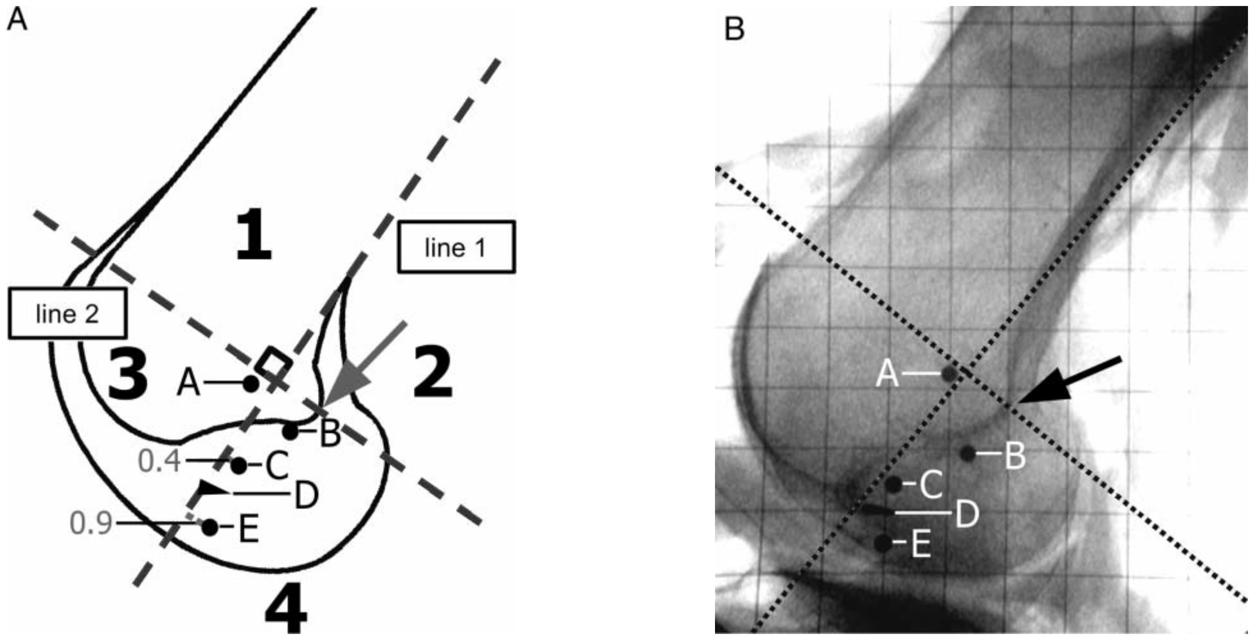

Figure 3. Illustration (A) and lateral knee radiograph (B) demonstrating the placement of the femoral reference lines. Line 1 was drawn as an extension of the posterior femoral cortex, while line 2 was drawn perpendicular to line 1 and passed through the posterior portion of Blumensaat's line (indicated by arrows in [A] and [B]). Numbers 1 through 4 in the illustration indicate quadrants of the lateral distal femur. Radiographic landmarks shown on the radiograph are qualitative representations of the landmark positions identified in this study and may not correspond quantitatively with the average positions reported in this study. A, lateral intramuscular septum; B, lateral gastrocnemius tendon; C, fibular collateral ligament; D, lateral epicondyle; E, popliteus tendon. Quadrant 1, proximoanterior; quadrant 2, proximoposterior; quadrant 3, distoanterior; quadrant 4, distoposterior.

the first reference line was drawn along the diaphyseal axis using the same method described above for the tibia, and the second reference line was drawn perpendicular to the first line through the most anteroproximal point of the fibular head (Figure 5).

Data Analysis

To examine interobserver reliability, 3 examiners of different levels of experience (a board-certified orthopaedic surgeon specializing in sports medicine [examiner 1], a medical student [examiner 2], and a premedical student [examiner 3]) were assigned to independently draw in digital reference lines and make measurements on blinded radiographs. Intraobserver reproducibility was evaluated by having each examiner measure the same set of blinded radiographs on 2 separate occasions at least 2 weeks apart. Subsequently, single-measure intraclass correlation coefficients (ICCs) (SPSS Inc, Chicago, Illinois) were used to determine variability within and among measurement groups. Intraclass correlation coefficients were also calculated for each anatomic relationship measured. For all analyses, statistical significance was assumed for $P < .05$.

RESULTS

All measurements refer to the centers of the structural attachment sites and landmark locations and are presented as averages. For the purposes of this work, the line drawn parallel to the distal aspect of the femoral condyles and the line crossing the proximal aspect of the tibial plateaus on the AP views are referred to as the femoral condylar line and tibial plateau line, respectively.

Anteroposterior View

On the femur, the PLT had the most distal femoral attachment and was located 14.5 mm proximal to the femoral condylar line. The FCL and lateral gastrocnemius tendon attached 27.1 mm and 34.5 mm proximal to the femoral condylar line, respectively (Table 1). For the tibia, Gerdy's tubercle was located 17.1 mm distal to the tibial plateau line and the popliteus musculotendinous junction was 11.1 mm distal to the tibial plateau line (Table 1). The PFL and FCL attached 21.1 mm and 34.7 mm distal to the tibial plateau line, respectively (Table 1).

Lateral View

Femur. On the lateral view, the FCL, PLT, and lateral gastrocnemius tendon were located in the most distal and posterior quadrant created by the intersections of the posterior femoral cortex line and the perpendicular line crossing the posterior aspect of Blumensaat's line (Table 2). In addition, the FCL and PLT were both located within 1 mm posterior to the posterior femoral cortex extension line.

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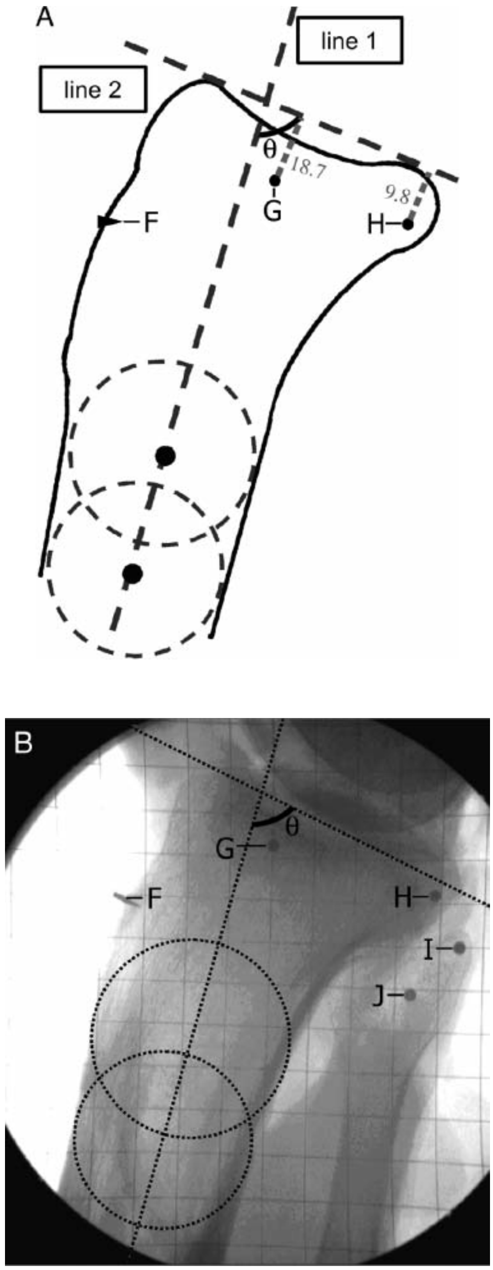

Figure 4. Illustration (A) and lateral knee radiograph (B) demonstrating the technique to identify the center of the tibial diaphysis (line 1) and the line parallel to the medial tibial plateau (line 2). The smaller angle between lines 1 and 2 represents the posterior tibial slope. Radiographic landmarks shown in the radiograph are qualitative representations of the landmark positions identified in this study and may not correspond quantitatively with the average positions reported in this study. All measurements are in millimeters. F, tibial tubercle; G, Gerdy's tubercle; H, popliteus musculotendinous junction; I, popliteofibular ligament; J, fibular collateral ligament; θ, posterior slope angle.

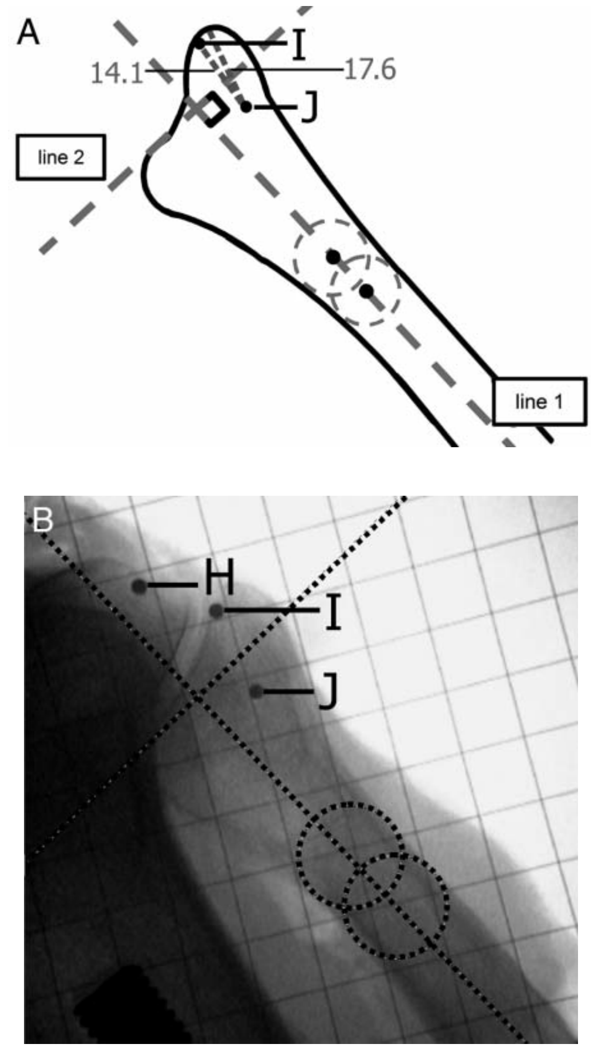

Figure 5. Illustration (A) and lateral knee radiograph (B) demonstrating the placement of the fibular reference lines. Line 1 represents the fibular diaphyseal axis, whereas line 2 is drawn intersecting the most anterior and proximal aspect of the fibular head. Radiographic landmarks shown in the radiograph are qualitative representations of the landmark positions identified in this study and may not correspond quantitatively with the average positions reported in this study. All measurements are in millimeters. H, popliteus musculotendinous junction; I, popliteofibular ligament fibular attachment; J, fibular collateral ligament fibular attachment.

The lateral gastrocnemius tendon was also located within this same radiographic quadrant. The FCL attachment on the femur was 4.3 mm from the lateral epicondyle, 14.2 mm from the PLT attachment, 9.6 mm from the lateral gastrocnemius tendon attachment, and 19.5 mm from the lateral intermuscular septum. It was found to be located 0.4 mm posterior to the posterior extension line and 11.7 mm distal to the perpendicular line crossing Blumensaat's point (Table 2).

The distance from the PLT origin on the femur to the lateral epicondyle was 12.2 mm. The PLT was located 22.6 mm from the lateral gastrocnemius tendon attachment site and 33.2 mm from the lateral intermuscular septum. The PLT origin site was 0.9 mm posterior to the posterior

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TABLE 1
Quantitative Relationships of Posterolateral Knee Structures to Landmarks and Reference Lines on the AP View[a]

Relationship	Mean Distance in mm (Standard Deviation)
Distance from femoral condylar line to:	
Proximal FCL	27.1 (2.4)
PLT	14.5 (2.0)
LGT	34.5 (2.9)
Distance from tibial plateau line to:	
Gerdy's tubercle	17.1 (2.6)
PMTJ	11.1 (2.5)
Distal FCL	34.7 (4.5)
PFL	21.0 (4.0)

[a]FCL, fibular collateral ligament; PLT, popliteus tendon; LGT, lateral gastrocnemius tendon; PMTJ, popliteus musculotendinous junction; PFL, popliteofibular ligament.

TABLE 2
Quantitative Relationships of Femoral Posterolateral Knee Attachments to Radiographic Landmarks and Reference Lines on the Lateral View[a]

Relationship	Mean distance in mm (Standard Deviation)
Landmark measurements	
Proximal FCL to lateral epicondyle	4.3 (1.0)
Proximal FCL to PLT origin	14.2 (2.8)
Proximal FCL to LGT	9.6 (2.4)
Proximal FCL to lateral intermuscular septum	19.5 (4.8)
PLT origin to lateral epicondyle	12.2 (3.0)
PLT origin to LGT	22.6 (2.8)
PLT origin to lateral intermuscular septum	33.2 (4.9)
LGT origin to lateral epicondyle	13.1 (2.2)
LGT origin to lateral intermuscular septum	13.1 (3.5)
Reference line measurements[b]	
Proximal FCL to posterior cortex extension	–0.4 (3.7)
Proximal FCL to line through Blumensaat's point	–11.7 (5.2)
PLT origin to posterior cortex extension	–0.9 (4.3)
PLT origin to line through Blumensaat's point	–25.8 (4.9)
LGT origin to posterior cortex extension	–3.7 (3.3)
LGT origin to line through Blumensaat's point	–3.2 (4.4)

[a]FCL, fibular collateral ligament; PLT, popliteus tendon; LGT, lateral gastrocnemius tendon.
[b]A + sign next to reference line measurements indicates that the attachment was quantified to be proximal or anterior to the reference line, whereas a – sign indicates that the attachment was distal or posterior.

cortex extension line and 25.8 mm distal to the line drawn through Blumensaat's point (Table 2).

The lateral gastrocnemius tendon attachment site was 13.1 mm from the lateral epicondyle and 13.1 mm from the lateral intermuscular septum. It was positioned 3.7 mm posterior to the posterior cortex extension line and 3.2 mm distal to the line crossing Blumensaat's point (Table 2).

Tibia. The posterior tibial slope was 13.3°. Gerdy's tubercle and the popliteus musculotendinous junction were located 18.7 mm and 9.8 mm distal to the tibial slope reference line, respectively (Table 3).

Fibula. The fibular attachment of the FCL was 17.6 mm distal to the apex of the fibular styloid and 14.1 mm distal to the PFL attachment. The FCL attachment was 8.7 mm distal to the line intersecting the most anterior point of the fibular head (Table 4). The PFL attached 4.8 mm distal to the apex of the fibular styloid (Table 4).

Data Analysis

Intraobserver ICCs were 0.974, 0.985, and 0.984 for examiners 1, 2, and 3, respectively (Table 5). The overall combined intraobserver ICC was 0.981. These high intraobserver ICCs indicate a high likelihood that persons not involved with this trial would obtain consistent measurements for the same radiographs. Interobserver reliability was assessed between each of the examiners in trial 1, trial 2, and with both trials combined. There was no significant difference between examiners for either trial state (Table 6). The overall interobserver ICC for the combined trial was 0.983, which again suggests that examiners not involved with this study would also have a high probability of measuring similar distances between these posterolateral knee radiographic landmarks.

An analysis was performed using the femoral transcondylar width as a correction factor for the relative knee size. There was no correlation between knee size, based on femoral condylar width, and the magnitude by which its measurements deviated from the study means. Further, following correction of all measurements based on femoral condylar width, the overall means for each measured distance changed, at most, less than 0.5 mm.

DISCUSSION

Despite recent advances in the diagnosis and treatment of posterolateral rotatory instability, injuries to this aspect of the knee remain difficult to address clinically, largely due to the intricate and complex anatomy of the posterolateral structures.[12,22,23] While posterolateral reconstructions have been biomechanically shown to significantly restore static stability for varus and external rotation[3,11] (Figure 6), failure of these reconstructions owing to improper graft placement can make it difficult to perform future reconstructions, and the resultant instability can lead to meniscal tears, osteoarthritis, or potential graft failure of concurrent cruciate ligament reconstructions.[9,10,13] Even to the trained observer, precisely locating the attachment sites of the primary posterolateral structures can pose a

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TABLE 3
Quantitative Relationships of Tibial Posterolateral Knee Structures to Radiographic Landmarks and Reference Lines on the Lateral View[a]

Relationship	Mean Distance in mm (Standard Deviation)
Landmark measurements	
Gerdy's tubercle to PMTJ	45.4 (5.3)
Reference line measurements[b]	
Posterior tibial slope	+13.3º (3.81º)
Gerdy's tubercle to tibial slope reference line	–18.7 (3.8)
PMTJ to tibial slope reference line	–9.8 (4.0)

[a]Unless otherwise indicated, all measurements were performed on radiographic images in the lateral view. PMTJ, popliteus musculotendinous junction.
[b]A + sign next to reference line measurements indicates that the attachment was quantified to be proximal or anterior to the reference line, whereas a – sign indicates that the attachment was distal or posterior.

TABLE 4
Quantitative Relationships of Fibular Posterolateral Knee Attachments to Radiographic Landmarks and Reference Lines on the Lateral View[a]

Relationship	Mean Distance in mm (Standard Deviation)
Landmark measurements	
Distal FCL to fibular styloid apex	17.6 (4.1)
Distal FCL to PFL	14.1 (4.1)
PFL to fibular styloid apex	4.8 (2.3)
Reference line measurement[b]	
Distal FCL to line along anterior fibular head	–8.7 (3.4)

[a]FCL, fibular collateral ligament; PFL, popliteofibular ligament.
[b]A + sign next to reference line measurements indicates that the attachment was quantified to be proximal or anterior to the reference line, whereas a – sign indicates that the attachment was distal or posterior.

TABLE 5
Intraobserver Intraclass Correlation Coefficients (ICCs) and 95% Confidence Limits for Posterolateral Knee Radiographic Landmarks

	ICC	Lower 95% Limit	Upper 95% Limit
Combined	0.981	0.979	0.983
Examiner 1	0.974	0.969	0.978
Examiner 2	0.985	0.982	0.987
Examiner 3	0.984	0.980	0.986

significant challenge, particularly in the presence of chronic injuries or in revision surgeries. We understand the difficulty and clinical limitation of applying quantitative measurements from a study to all knees due to normal variation between knees. For this reason, we have provided both qualitative and quantitative descriptions of the main posterolateral knee attachment sites to improve the clinical applicability of this study. Using the femoral transcondylar distance as an indirect measure of knee size, we found that there was no correlation between the size of a knee and the deviation of its measurements from the mean. Further, after correction of measured distances for each individual knee based on this femoral transcondylar distance, the overall means for the measured distances in this study were changed by less than 0.5 mm, which is clinically insignificant. Therefore, we do not believe that size variation is a significant limitation of this study, and the observed variation is instead a product of normal anatomic variation between knees. The results confirmed our hypothesis and allowed us to develop consistent radiographic guidelines for the primary posterolateral knee structures.

TABLE 6
Interobserver Intraclass Correlation Coefficients (ICCs) and 95% Confidence Limits for Posterolateral Knee Radiographic Landmarks

All Observers	ICC	Lower 95% Limit	Upper 95% Limit
Trial 1	0.983	0.980	0.985
Trial 2	0.983	0.981	0.986
Combined	0.983	0.981	0.985

The results of our intraobserver reproducibility and interobserver reliability analyses indicate that our methods may be performed in a consistent manner regardless of experience or skill level. This study, therefore, establishes a reliable and transferable protocol for identifying the attachment sites of the main posterolateral knee structures on radiographic images.

On the lateral radiographic view, the distal femur can be divided into quadrants by the reference line extending along the posterior femoral cortex and the perpendicular reference line intersecting the posterior aspect of Blumensaat's line (Figure 3). The femoral attachments of the FCL and the PLT were both located within the posterodistal quadrant created by these reference lines. Further, the femoral attachment sites of the FCL and PLT were close to equidistant from the posterior femoral cortex extension reference line (0.4 mm posterior for the FCL and 0.9 mm posterior for the PLT). Thus, verification of structure or tunnel placement within this posterodistal radiographic quadrant and close to parallel along the posterior femoral cortex reference line can assist in both intraoperative and postoperative assessment of structure and graft placement.

Radiographic landmarks for the femoral AP views revealed that the PLT was the most distal structure (ie, closest to the femoral condylar line) among the investigated structures. The FCL attachment was located nearly twice the distance from the femoral condylar line as the PLT attachment (27.1 mm vs 14.5 mm, respectively).

The technique for drawing a line parallel to the axis of the tibia representing the diaphyseal axis was modified in our study from the original Dejour and Bonnin method[5] to

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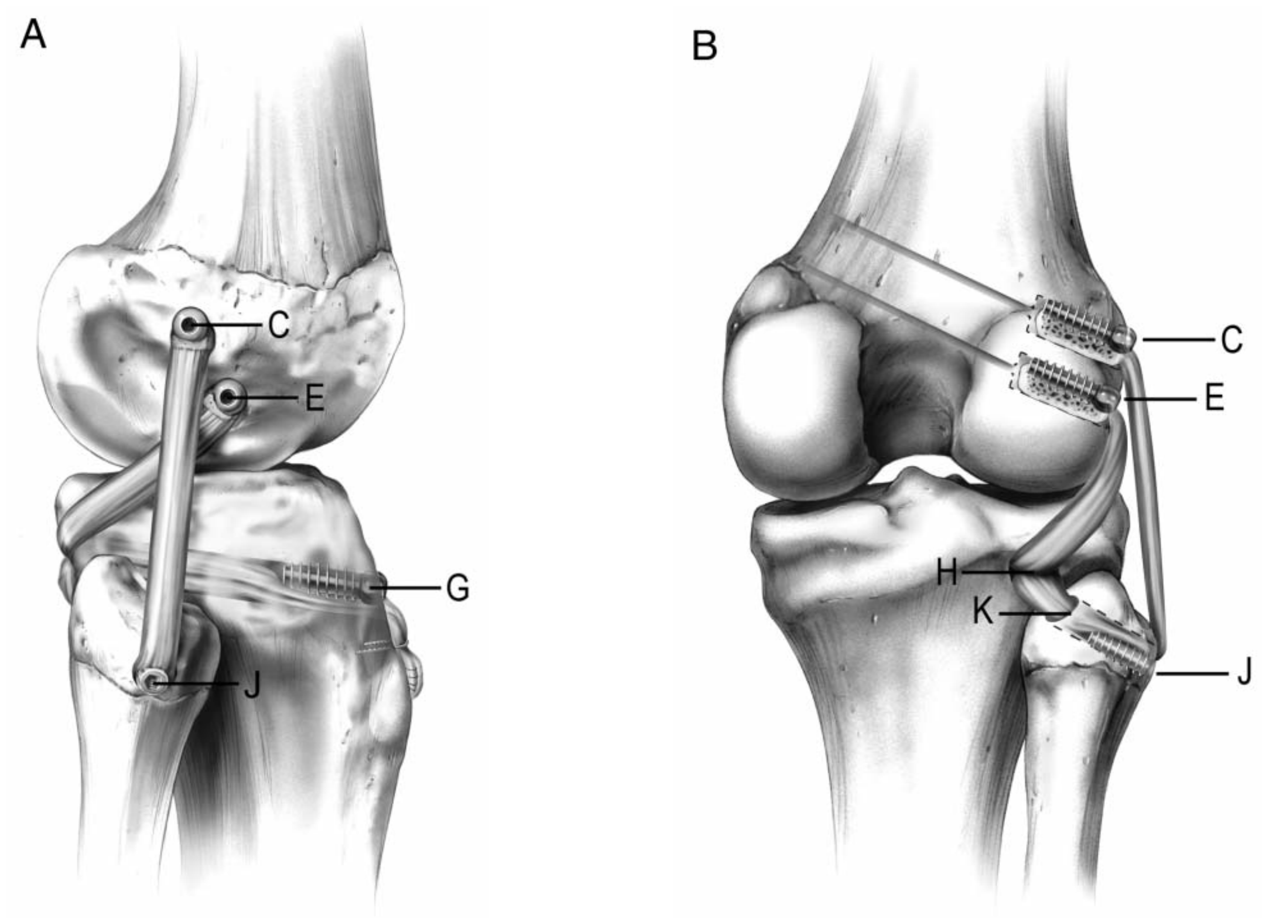

Figure 6. Illustrations of an anatomic reconstruction of the fibular collateral ligament, popliteus tendon, and popliteofibular ligament with notation of the important radiographic markers. A, lateral view, right knee; B, posterior view, right knee. C, fibular collateral ligament femoral tunnel; E, popliteus tendon femoral tunnel; G, Gerdy's tubercle; H, popliteus musculotendinous junction; J, fibular collateral ligament fibular tunnel entrance; K, popliteus tendon tunnel exit. Reprinted, with permission, from LaPrade RF, Johansen S, Wentorf FA, Engebretsen L, Esterberg JL, Tso A. An analysis of an anatomical posterolateral knee reconstruction: an in vitro biomechanical study and development of a surgical technique. *Am J Sports Med.* 2004;32:1405-1414.

generate digital circles instead of perpendicular lines drawn across the tibial width to identify the center of the tibial shaft. Although clinically useful, the Dejour and Bonnin method requires observers to approximate the midpoints of these perpendicular lines to successfully construct the tibial diaphyseal axis line.[5] Instead, computer generation of 2 circles on a lateral radiographic image such that the anterior and posterior borders of the cortices of the tibia are tangent to the circumference automatically ensures that the circle's center lies equidistant from both shaft borders and consequently along the diaphyseal axis. A digitally generated line that intersects the centers of these 2 circles will thus accurately represent the diaphyseal axis. This technique was further supported for reproducibility by the significant ICCs obtained for measurements involving the tibial and fibular diaphyseal axes. We believe that this circle method may be applied in preoperative and postoperative assessments of posterolateral knee radiographs as well as a wide array of other radiographic evaluations of long bones.

Prior gross anatomy studies have both provided qualitative details and quantified the locations of the attachment sites of the main posterolateral knee structures.[2,12,22,23] Although certainly valuable from an anatomic and intraoperative visual perspective, these findings are of limited use during the analysis of intraoperative and postoperative radiographs. We believe that integrating both bony landmarks and superimposed reference lines on radiographs is an effective method to measure the locations of the main posterolateral structure attachments because it allows not only for quantification of the attachment sites radiographically, but could also prove directly advantageous from a clinical standpoint. Intraoperatively, for example, bony landmarks of the posterolateral knee may be easily distinguished via sight or palpation to help locate the attachment sites of interest. However, such landmarks may not be visible on a postoperative radiograph, in which case relevant reference lines projected onto the radiographic image would effectively facilitate the evaluation of the location of surgical fixation hardware or tunnel locations following surgical reconstructions.

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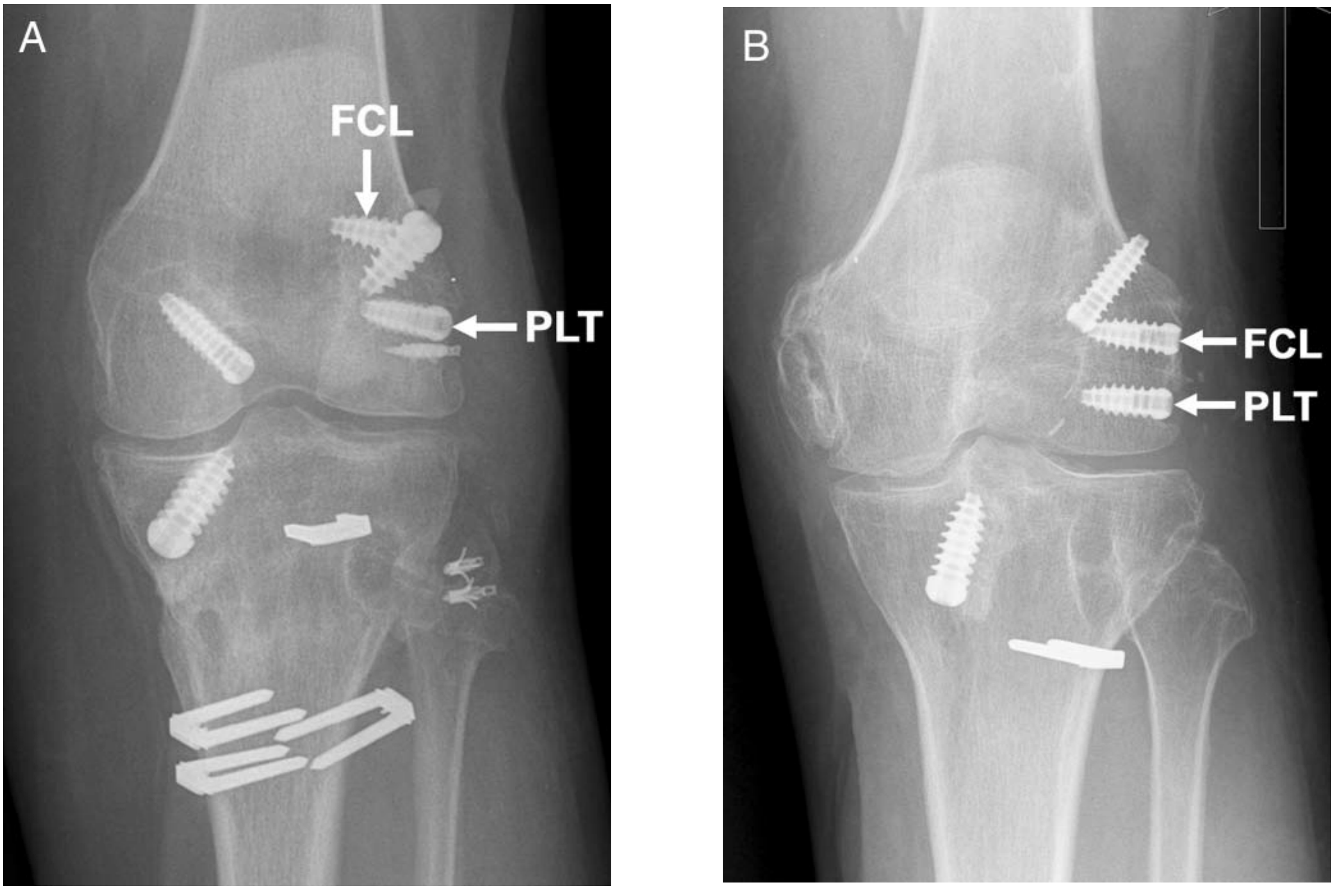

Figure 7. Anteroposterior radiographs of (A) a malpositioned fibular collateral ligament (FCL) and popliteus tendon (PLT) reconstruction graft and (B) an anatomic FCL and PLT reconstruction graft.

Although we recognize the relatively small specimen sample size as a potential limitation of our investigation, prior radiographic landmark studies have obtained consistent results using similar sample sizes.[21] We believe that the high ICCs observed for interobserver and intraobserver reliability provide validation of our study with measurements similar to previously published quantitative anatomic studies[13] and support our results and proposed measurement techniques (Figure 7). We also acknowledge that our measurements differ somewhat from those recorded in previous gross anatomic studies of the posterolateral knee[12] and attribute these discrepancies to different quantification techniques; whereas the anatomic study measured distances in 3 dimensions, our measurements were performed on 2-dimensional images. The use of oblique radiographs in our study would have likely reconciled these quantitative differences.

Future studies should assess the application of the proposed radiographic guidelines directly to patients without the use of radiopaque markers so as to further verify the clinical relevance of these guidelines. As part of another follow-up experiment, physicians could identify significant posterolateral attachment sites using our guidelines on unmarked radiographs and then compare their results both among one another and to marked radiographs; this could serve to further substantiate the reliability of our methods.

In conclusion, these posterolateral knee radiographic landmarks were found to be reproducible. We believe that this qualitative and quantitative radiographic information regarding the attachment sites of posterolateral structures will serve as a valuable reference for preoperative, intraoperative, and postoperative assessments of surgical reconstructions.

ACKNOWLEDGMENT

The authors thank Paul Lender, BA, for his assistance on this project.

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