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（博 士）

Morphology of the Femoral Insertion of the Lateral Collateral Ligament and Popliteus Tendon

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Abbreviations:

PLC: posterolateral corner

LCL: lateral collateral ligament

PT: popliteus tendon

PFL: popliteofibular ligament

PCL: posterior cruciate ligament

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ABSTRACT

Purpose: To clarify the femoral insertion of the lateral collateral ligament (LCL) and popliteus tendon (PT) and related osseous landmarks on three-dimensional images.

Methods: Twenty-six non-paired, formalin-fixed human cadaveric knees were evaluated in this study. Femoral insertion of the LCL and PT was identified and marked. Three-dimensional images were created, and the surface area, location, positional relationships, and morphology of the femoral insertion of the LCL, PT, and related osseous structures were analyzed.

Results: The mean surface areas of the LCL and PT femoral insertions were 55.8 ± 25.0 and 52.5 ± 24.2 mm^2, respectively. Variations in the positional relationships between the LCL and PT insertions (PT inserted parallel and posterior to the LCL insertion to the long axis of the femur) were observed. The lateral epicondyle and popliteal sulcus could be clearly identified as osseous landmarks on three-dimensional images in all knees. Most of the LCL were inserted postero-distal to the apex of the lateral epicondyle and the PT was inserted at the anterior end of the popliteal sulcus in all knees.

Conclusion: We observed variation in the positional relationship between the femoral insertion of the LCL and PT. However, the relationships between their insertions and

osseous landmarks were consistent. The findings of this study contribute to the understanding of the PLC osseous anatomy, and should assist surgeons in performing PLC surgery with a more anatomic perspective.

INTRODUCTION

The posterolateral corner of the knee (PLC) consists of the lateral collateral ligament (LCL), illiotibial tract, long and short heads of the biceps femoris mucle, midthird lateral capsular ligament, fabellofibular ligament, posterior arcuate ligament, lateral coronary ligament, posterior capsule, popliteus tendon (PT), and popliteofibular ligament (PFL) [11, 27]. The LCL, PT, and PFL are the main static and dynamic stabilizers of the PLC. The LCL and PFL work as static stabilizers for the primary varus and external rotation at lower angles of 30° knee flexion, and the PT acts as a dynamic stabilizer of external rotation and posterior tibial translation at angles of greater knee flexion [2, 7, 15, 16, 17, 19].

Injuries to the PLC are comparatively rare but are frequently related to multiple ligament injuries caused by high-energy trauma, and cause severe disability because of knee instability and secondary degeneration of the articular cartilage [1, 10]. In addition, PLC injuries are seen in approximately 60% of cases of combined posterior cruciate ligament (PCL) injury [11]. In those cases, isolated PCL reconstruction has been shown to be insufficient for stability [11].

The treatment of PLC injuries of the knee remains controversial. Early surgical repair of the PLC has been advocated for acute injuries with significant clinical instability [4, 5]. However, recent studies reported a significantly higher rate of failure for repair of the PLC compared with reconstruction [18, 25]. Reconstruction of the PLC is a more reliable option than repair alone in the setting of multiligament injuries [18]

Several techniques for reconstruction of the PLC, such as tenodesis of the biceps femoris or isometric reconstructon using single femoral tunnel techniques, have been described [3, 5, 8, 23, 29, 22]. However, in recent years, reconstructive procedures have become more anatomical, using double femoral tunnel techniques, to achieve superior results [2, 11, 16, 21, 24], and it was also demonstrated that anatomical reconstruction of the PLC restores better knee kinematics in a biomechanical study [20].

Several anatomical studies of the femoral insertion of the PLC have been described, and most authors have indicated large positional variations in the femoral insertion of the LCL and PT. Thus, their accurate positions are still controversial [1, 12, 13, 15, 14, 23, 26, 30, 31]. To perform anatomical reconstruction of the PLC using double femoral tunnel techniques, it is necessary to define the femoral insertion of the LCL and PT, and assess their related osseous landmarks.

The aim of this study was to clarify the femoral insertion of the LCL, PT, and related osseous landmarks on three-dimensional images. The hypothesis was that characteristic features of the femoral insertion of the LCL and PT and related structures can be identified even if they are varied.

MATERIALS AND METHODS

Specimen preparation

Twenty-six unpaired human cadaveric knees (18 from males and 8 from females), with no severe macroscopic degenerative or traumatic changes, were used in this study. The mean age at the time of death was 79.3± 9.4 years (range: 56-93 years). All cadavers were fixed in 10% formalin and preserved in 50% alcohol for 6 months.

Dissection began with the removal of the skin and soft subcutaneous tissue on the lateral side of the knee. The iliotibial tract and long heads of the biceps femoris muscle were transected and the vastus lateralis was elevated off of the distal aspect of the femur, leaving the underlying capsular tissues intact. After careful removal of capsular tissues, femoral insertion of the LCL, PT, and other related stulctures were identified and observed grossly (Fig. 1). After cutting the LCL and PT at the midsubstance, the proximal side of the LCL and PT was elevated from the femur, and the femoral insertions of the LCL and PT were outlined using a fine 1.2-mm-diameter drill carefully to prevent destruction of the peripheral structures.

Three-dimensional measurements and visualization

Knees were scanned using a 16-row multislice computed tomography scanner (ECLOS; Hitachi Medical Corporation, Tokyo, Japan). Axial plane images with 0.5-mm slices were obtained and saved as Digital Imaging and Communications in Medicine (DICOM) data. All digital imaging data were uploaded to dedicated software (Mimics version 15.0 and MedCAD module; Materialise N.V., Belgium), and three-dimensional images of the knee were created [9, 21, 28]. The femoral insertion of the LCL and PT and related osseous structures were analyzed on the three-dimensional images. The femoral insertions of the LCL and PT were marked and colored. Then, their surface areas were calculated. The center of the insertions was defined automatically as the centroid of their area using the above-mentioned software mentioned. The linear distance between the centers of the LCL and PT insertions was also calculated. The coordinates of the center of the femoral insertion of the LCL and PT were mapped on squares in the true lateral view from the three-dimensional images. The maximum antero-posterior diameter of the length between the anterior cortical line and most posterior lateral condyle on the true lateral view from the three-dimensional images was used as a standard (100%), and squares fitting the medial and lateral condyle on the three-dimensional images were created. The X-axis was the bottom of the square, the Y-axis was the distal perpendicular line on the squares, and the origin of the coordinate axes was the point of intersection between the lowest line and distal perpendicular lines. These three-dimensional measurements were based on the method of Fujino et al. [9]. Positional relationships between the insertions of the LCL and PT to the long axis of the femur were assessed. A more than 50% overlap on the Y-axis between the LCl insertion area and PT insertion area was classed as “parallel”. Other related osseous structures were also detected. The apices of the related osseous structures were determined as the points protruding the furthest based on coronal CT images of the lateral femoral condyle. When comparing the accuracy of three-dimensional models generated from CT with the optical scan, the average error was 0.2±0.31 mm, or around one-third of the pixel size [6]. The accuracy of the length and area measurements was less than 0.1 mm and 0.1 mm^2 , respectively.

RESULTS

Macroscopic findings

The LCL and PT were clearly identified in all knees. The lateral epicondyle and popliteal sulcus could be identified; however, in some specimens, it was difficult to determine the apex of the lateral epicondyle because of its broad shape. The distal origin of the LCL inserted to the lateral aspect of the fibula head, the LCL overlapped the PT, and the proximal origin of the LCL inserted to the posterior slope of the lateral epicondyle. The shape of the LCL widened toward the femoral insertion. The proximal origin of the PT inserted to the anterior part of the popliteal sulcus and distaly, and the PFL originated at the musculo-tendinous junction of the PT.

Three-dimensional measurements of femoral insertions of the LCL and PT

Femoral insertions of both the LCL and PT varied greatly in size. The mean surface areas of the LCL and PT femoral insertions were 55.8 ± 25.0 and 52.5 ± 24.2 mm^2, respectively. The mean linear distance between LCL and PT femoral insertions was 8.18 ± 1.84 mm.

Locations and coordinates with a true lateral view from three-dimensional images

Coordinates for the centers of the LCL and PT femoral insertions were obtained. On the true lateral view from the three-dimensional images, the average proximal–distal and anteroposterior ratio for the centre of the femoral insertion of the LCL were x = 34.2 ± 3.8% and y = 33.4 ± 4.2%, respectively, and those for the center of the femoral insertion of the PT were x = 23.5 ± 4.8% and y = 30.8 ± 5.1%, respectively (Fig. 2).

Positional relationships among the LCL, PT, and related osseous landmarks

Positional relationships between the insertion of the LCL and PT varied by specimen. Two different types of relationship, with the PT inserted parallel or posterior to the LCL insertion, were observed. The PT inserted parallel to the LCL insertion in 13 out of the 26 knees, and posterior to the LCL insertion in the other 13 knees (Fig. 3).

The apex of the lateral epicondyle and popliteal sulcus could be clearly identified as osseous landmarks on the three-dimensional images in all knees. The characteristic features of the LCL insertion were not evident; however, most of the LCL were inserted in the postero-distal slope of the apex of the lateral epicondyle, in 24 out of the 26 knees. The PT inserted to the anterior end of the popliteal sulcus in all knees (Fig. 4).

DISCUSSION

The most important findings of this study was to identify the femoral insertion of the LCL and PT and their related osseous landmarks on three-dimensional images. Positional relationships between the LCL and PT varied; however, the apex of the lateral epicondyle and popliteal sulcus were cleary identified as osseous landmarks. Most of the LCL were inserted in the postero-distal slope of the apex of the lateral epicondyle, and the PT were inserted to the anterior end of the popliteal sulcus in all knees.

This study revealed the average surface areas of the femoral insertion of the LCL and PT, and that they showed marked variation. Brinkman et al. [1], using an Isotrak digitizing system to assess thirty-four cadavers, reported that the average surface areas of the femoral insertion of the LCL and PT were 51.7 mm^2 (range: 22.9 to 88.8) and 65.9 mm^2 (range: 31 to 104), respectively. They also reported that both surface areas varied markedly. However, LaPrade et al. [15], using a computer-controlled video motion analysis capture system with only ten cadavers, reported that the average surface areas of the femoral insertion of the LCL and PT showed low-level variation, at 48 mm^2 (range: 43 to 52) and 59 mm^2 (range: 53 to 62), respectively. These results may have been affected by the lower number of specimens. Determination of the graft size may require attention due to the possibility that the surface areas of the insertion site of the LCL and PT show high-level variation. The mean linear distance between LCL and PT femoral insertions in this study was similar to the result of Brinkman et al. [1] The results cannot be compared to previous findings because of the different methods of measurement, but they provide useful information for surgeons who perform anatomical reconstruction with the double femoral tunnel technique.

This study also showed coordinate positions of the the centers of the LCL and PT femoral insertions with a true lateral view using three-dimensional images. On average, the PT tend to insert postero-distal to the LCL insertion. A few studies have mentioned the positions of the centers of LCL and PT femoral insertions. Pietrini et al. [23], investigated this using length measurement with a fluoroscopic lateral view, and reported that femoral insertions of the LCL and PT were close to parallel along the posterior femoral cortex reference line, and the LCL and PT insertions on the femur were 0.4 mm posterior to the posterior cortical extension line and 11.7 mm distal to the perpendicular line at the Blumensaat point (intersection of the horizontal and vertical components of the Blumensaat line) for the LCL, and 0.9 mm posterior to the posterior cortical extension line and 25.8 mm distal to the perpendicular line at the Blumensaat point for the PT. However, because their findings were based on actual fluoroscopic length measurements, individual differences in the size of the femur condyle cannot be ignored. Kamath et al. [13], investigated this using length measurement with a fluoroscopic lateral view, and showed the average location of the LCL femoral insertion as a percentage of the width of the lateral femoral condyle and vertical offset relative to the Blumensaat line. They reported that the LCL inserted at a point equivalent to 58% across the width of the femoral condyle and 2.3 mm inferior to the Blumensaat line. However, they did not indicate the insertion site of the PT, and it is necessary to define the femoral insertion of the PT for double femoral tunnel anatomical PLC reconstruction. Although our findings cannot be compared to those previous findings because of the different methods of measurement, our measurement using the true lateral view on a three-dimensional image may be simpler and more reproducible, and may assist surgeons in confirming both femoral insertions of the LCL and PT during surgery with fluoroscopy.

Several studies described positional relationships of the femoral insertion of the LCL and PT. LaPrade et al. [15] and Kim et al. [14] reported that the PT always inserted anterior to the LCL insertion to the long axis of the femur, while Jung et al. [12] reported that the PT was inserted mostly at the postero-inferior site of the LCL insertion site. Brinkman et al. [1] suggest that the LCL and PT generally insert parallel to the long axis of the femur, and also reported that their positional relationships varied. Zeng et al. [31] and Jung et al. [12] reported in their recent gross anatomical study that three variations in positional relationships between the LCL and PT femoral insertion were observed. However, the present study showed two variations, the PT inserted parallel or posterior to the LCL individually, although the PT tended to insert posterior to the LCL in the average of the coordinate plane.

On three-dimensional images in this study, the characteristic features of the LCL insertion were not evident; however, most of the LCL were inserted in the postero-distal slope of the apex of the lateral epicondyle. LaPrade et al. [15] reported that the LCL inserted postero-proximal to the lateral epicondyle, and the main femoral insertion resided in a small osseous depression just posterior to the lateral epicondyle. Brinkman et al. [5] described the LCL as inserted postero-proximal to the lateral epicondyle on average; however, they also showed that LCL were not always inserted postero-proximal to the epicondyle. These differences might be caused by difficulty in the identification of the apex of the lateral epicondyle because of their broad shape on gross anatomy, compared with our automatic identification using three-dimensional computed tomography. We also found that the PT inserted to the anterior end of the popliteal sulcus in all knees. This finding is similar to the observations by LaPrade et al. [15] and Staubli et al. [26], who reported that the PT inserted proximally, at the anterior end of the popliteal sulcus. Thus, it is necessary to identify the apex of the lateral epicondyle and popliteal sulcus by three-dimensional computed tomography to confirm the accurate position of the femoral insertion of the LCL and PT preoperatively.

This study had several limitations. Firstly, a comparatively small number of specimens were investigated. Because of normal anatomical variation, a study with a larger sample size is needed. Secondly, cadavers with a mean ages of 79 years were used. Even though no specimens had severe macroscopic degenerative or traumatic changes, it cannot be ruled out that degenerative changes may have affected identification of the osseous landmarks. Thirdly, Although we used an accurate method of three-dimensional measurement, there are possibilities that human dissection and subjective decisions regarding the insertion site of the LCL and PT introduced error and bias.

The clinical relevance of this study is the identification of the femoral insertion of the LCL and PT and related osseous landmarks on three-dimensional images. The results of this study may improve our understanding of the anatomy of the femoral insertion of the LCL and PT, and may assist surgeons in performing PLC reconstruction with a more anatomic perspective.

CONCLUSION

We observed variation in the positional relationships between the femoral insertion of the LCL and PT. However, the relationships between their insertions and osseous landmarks were consistent, in that the LCL was inserted in the postero-distal slope to the apex of the lateral epicondyle, and the PT was inserted to the anterior end of the popliteal sulcus.

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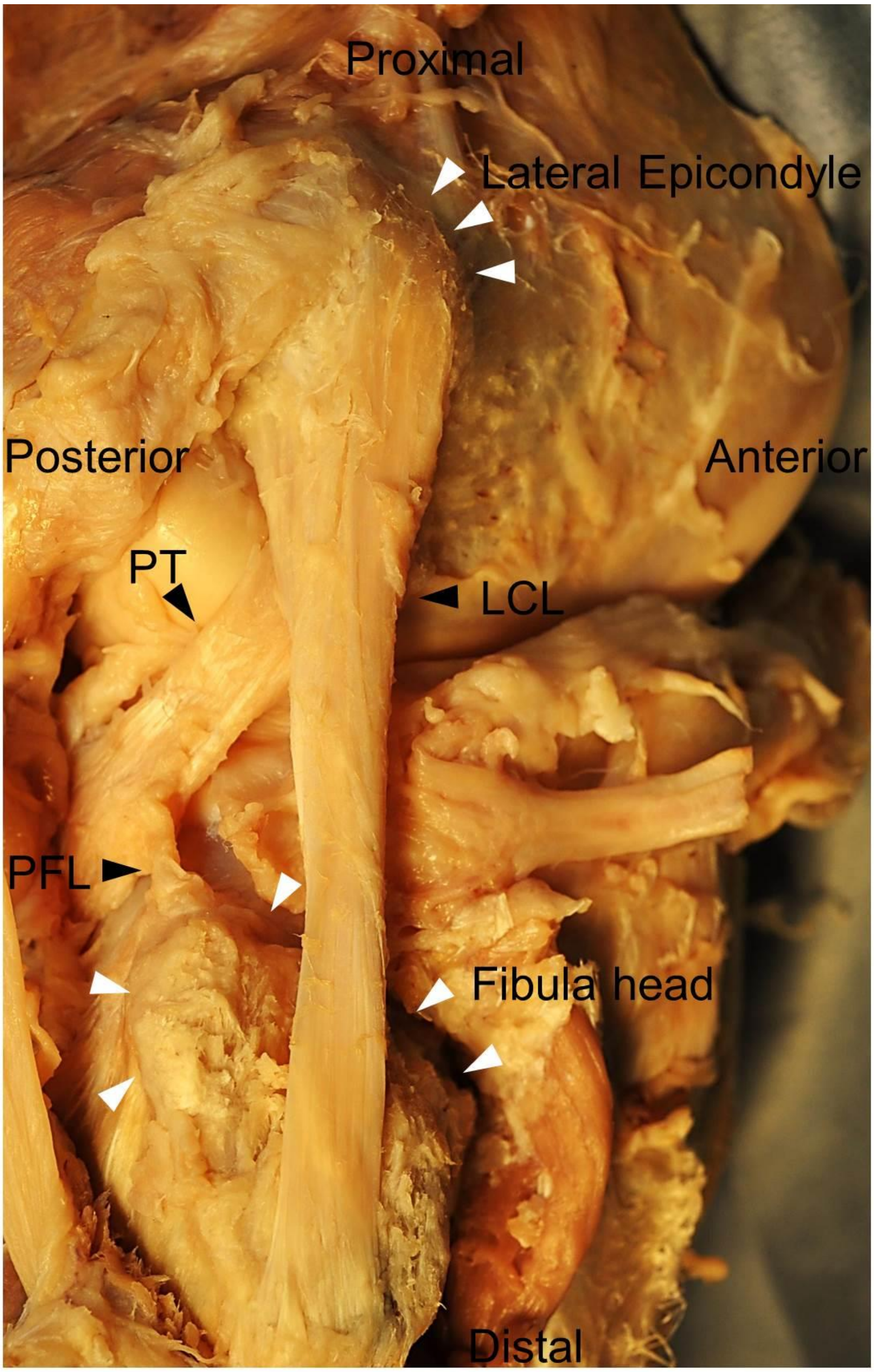

Fig. 1 Posterolateral view of the right knee, showing the lateral collateral ligament (LCL), popliteus tendon (PT), and lateral epicondyle.

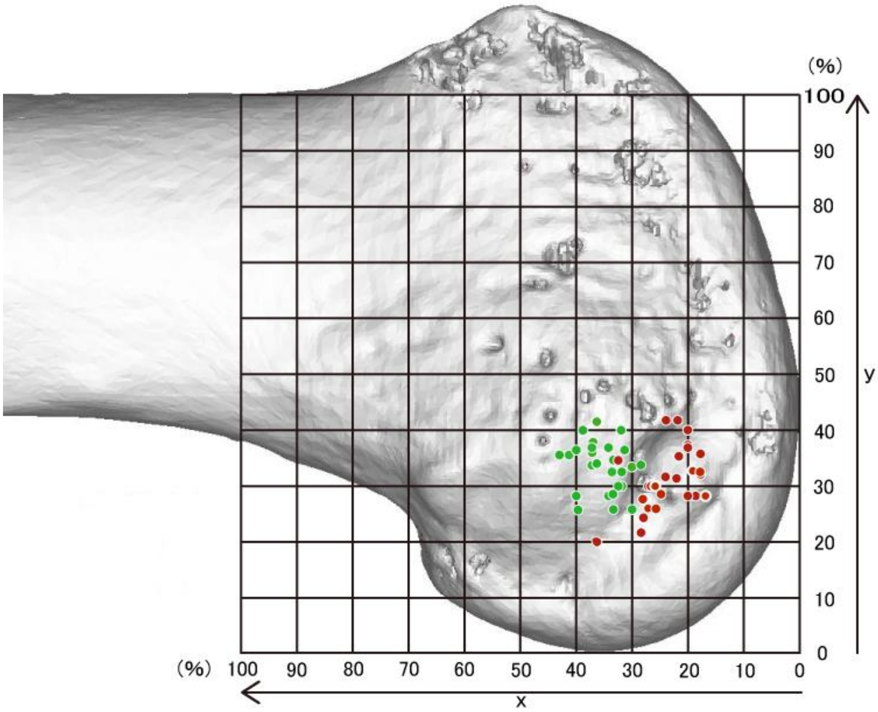

Fig. 2 Coordinates for the centers of the LCL (green circle) and PT (purple circle) femoral insertions

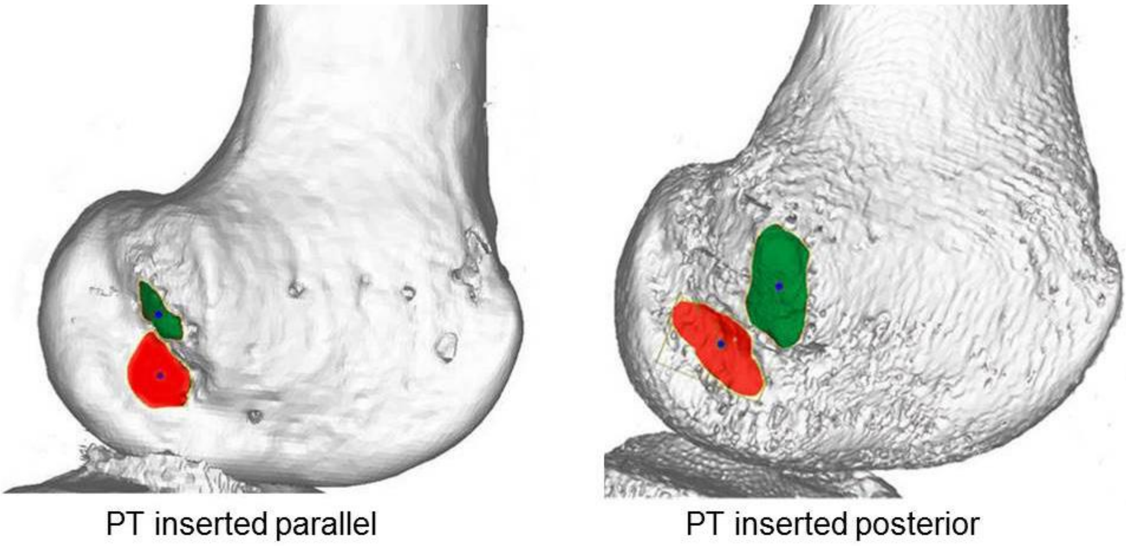

Fig. 3 Two variation in the positional relationship between the LCL and PT insertion sites

The green areas are femoral insertion of the LCL, and the red areas are femoral insertion of the PT. The blue dots indicate the center of their insertions.

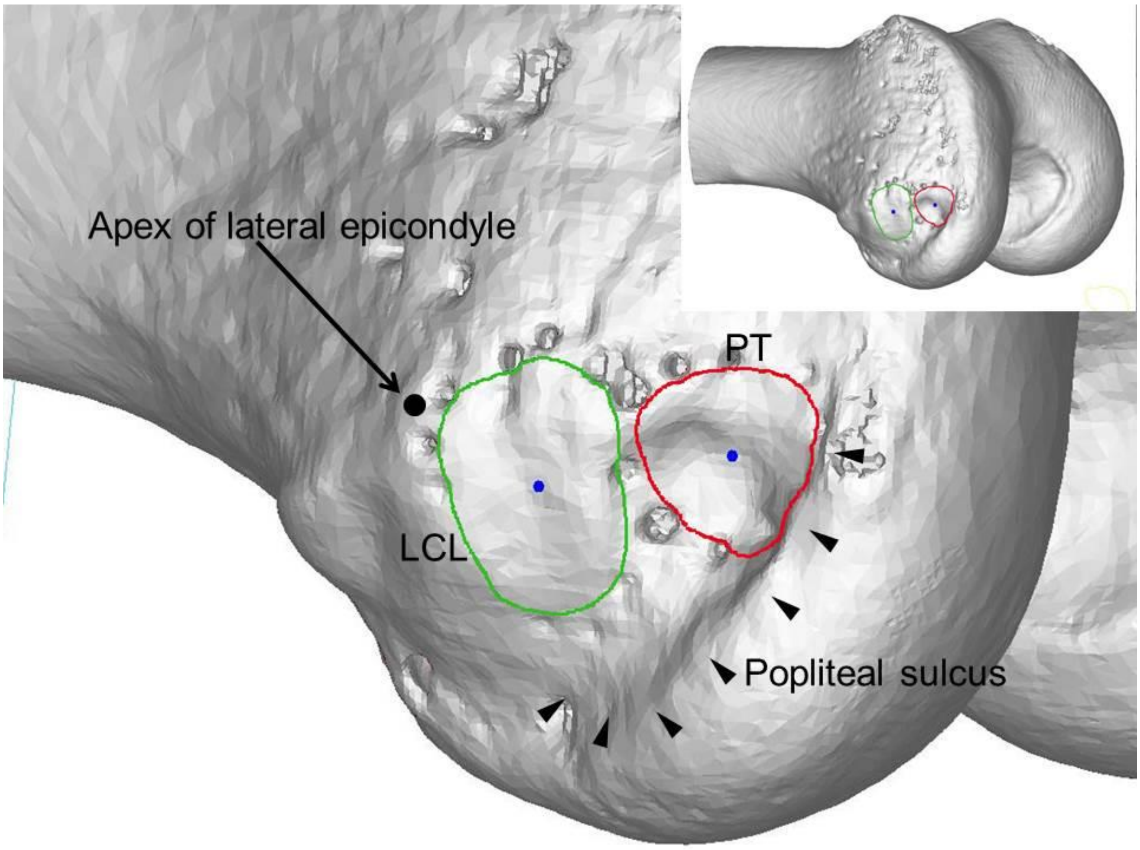

Fig. 4 The positional relationships between each insertion and the related bony landmarks. Image of a reconstructed surface model showing the lateral side of the right knee. The green circle is the femoral insertion of the LCL, and the red circle is the femoral insertion of the PT. The blue dots indicate the center of their insertions.