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*Title Page

Morphology of the Femoral Insertion Site of the Medial Patellofemoral Ligament

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Abbreviations:

MPFL: medial patellofemoral ligament

AT: adductor tubercle

MCL: medial collateral ligament

3-D: three-dimensional

CT: computed tomography

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ABSTRACT

Purpose: The purpose of this study was to identify the femoral insertion of the medial patellofemoral ligament (MPFL) and related osseous landmarks.

Methods: A total of 31 unpaired human cadaveric knees were studied. The MPFL was identified, and the site of its femoral insertion was marked. Three-dimensional images were created, and the location and morphology of the femoral insertion of the MPFL and related osseous structures were analyzed.

Results: The MPFL was identified in all knees. The femoral insertion of the MPFL was elliptical in shape, and the mean surface area was 56.5 ± 16.9 mm^2. The characteristic features of the femoral insertion of the MPFL could not be identified, but the adductor tubercle was clearly identified in all knees. The center of the femoral insertion of the MPFL was 10.6 ± 2.5 mm distal to the apex of the adductor tubercle on the long axis of the femur, and the position of the insertion site was consistent in all knees.

Conclusion: The adductor tubercle was clearly identified as an osseous landmark. The femoral insertion of the MPFL was approximately 10 mm distal to the adductor tubercle. These findings may improve understanding of the anatomy of the femoral insertion of the MPFL, and may assist surgeons in performing anatomical reconstruction.

Introduction

The medial patellofemoral ligament (MPFL) originates on the superomedial aspect of the patella and enters near the medial femoral epicondyle [21, 36]. The MPFL functions as a primary stabilizer of the patella in early flexion angles [23, 39], contributing to approximately 50% to 60% of the medial stabilizing force of the patella [1, 5, 7]. In cases of patellar dislocation, there is an associated MPFL rupture rate of 94% to 100% [14, 26, 27].

Patients with persistent patellar instability after dislocation are often treated surgically because with conservative treatment, recurrent dislocation occurs at a rate of up to 44% [16]. Most studies have noted a higher rate of recurrence in younger patients [10, 18, 28]. Various surgical techniques have been performed, including anterior tibial tubercle osteotomy, trochleoplasty, lateral release, and vastus medialis obliquus plasty for patellar instability; however, these surgeries do not resolve clinical symptoms in the long term, and symptoms remain in 60% to 70% of patients [5, 12].

The MPFL is the most consistently damaged structure after patellar dislocation [5, 9, 36], and anatomical reconstruction of the MPFL has recently been recognized as a treatment for chronic or recurrent patellar instability [1, 8]. Numerous biomechanical studies of the MPFL have noted better native ligament isometry as a result of fixation at the anatomic site of MPFL insertion and have indicated the importance of accurate anatomical placement of the femoral tunnel [1, 13, 20, 21, 23, 31, 32, 35, 37, 39]. Furthermore, nonanatomical reconstruction of the MPFL is known to potentially lead to nonphysiologic patellofemoral loads and kinematics [1]. In addition, in children and adolescents with recurrent patellar instability, it is essential to consider the distal femoral anatomy to prevent damage to the physis and subsequent growth disturbance during MPFL reconstruction [19, 38].

Several anatomical studies have described the femoral insertion of the MPFL in relation to osseous and soft tissue landmarks [3, 15, 21, 22, 24, 31, 32, 36], and numerous radiographic studies have described femoral tunnel placement and its landmarks [4, 29, 33]. However, optimal femoral tunnel placement is still controversial. Anatomical MPFL reconstruction requires accurate determination of the anatomical position of the femoral insertion of the MPFL and assessment of osseous landmarks during surgery [30, 32]. We consider that a better understanding of identification of the femoral insertion of the MPFL and related osseous landmarks will be useful for improved anatomical MPFL reconstruction.

The aim of this study was to accurately describe the anatomical findings of the MPFL, especially those regarding the femoral insertion of the MPFL and related osseous landmarks. This study posited that characteristic features of the femoral insertion of the MPFL and related osseous structures can be identified.

Materials and Methods

Specimens for this study were 31 unpaired human cadaveric knees (15 from males and 16 from females) with no severe macroscopic degenerative or traumatic changes. The average age at the time of death was 82.7 ± 8.4 years. All cadavers were fixed in 10% formalin and preserved in 50% alcohol for 6 months. These cadavers were donated to our institute for education and research purposes, and informed consent for donation was obtained from each patient and their family prior to death.

Preparation began by removing the skin and soft subcutaneous tissue on the medial side of the knee; the sartorius, gracilis, and semitendinosus muscles were also removed. After removal of these tissues, the fascia of the vastus medialis muscle was identified. The superficial fiber of the MPFL was loosely attached to the distomedial portion of the vastus medialis muscle; the vastus medialis muscle was released from the MPFL by careful dissection. The medial retinaculum was peeled from the MPFL. The MPFL was located superficial to the medial joint capsule in an extra-articular layer. Therefore, it was readily released from the articular capsule. After identification of the MPFL, gross observation of the MPFL and other related structures was performed (Fig. 1a, b).

The MPFL was cut 5 cm from the femoral insertion of the MPFL, and the ligament was everted to peripherally observe the tissue around the ligament fiber. The femoral insertion of the MPFL was defined as the area of the ligament fiber arising from the femur. The native femoral insertion site was carefully outlined using a 1.2-mm fine drill to avoid destroying the surrounding structures.

Three-dimensional measurements and visualization

Knees were scanned using a 16-row multislice computed tomography (CT) 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 imported into dedicated software (Mimics version 15.0 and MedCAD module; Materialise N.V., Belgium), and three-dimensional (3-D) images of the knee were created [37, 39]. The morphology of the femur on the 3-D images was analyzed with a focus on the femoral insertion of the MPFL and related osseous structures. The femoral insertion site of the MPFL was marked and colored. The surface area of the femoral insertion of the MPFL on the 3-D images was calculated using the above-mentioned software. The center of the insertion site was defined automatically as the centroid of the area using the software mentioned. The apices of the related osseous structures were determined as the points protruding the furthest based on coronal CT images of the medial femoral condyle. The direct distance between the center of the femoral insertion of the MPFL femoral and the apex of related structures was measured on 3-D images (Fig. 2). The accuracy of the length and area measurements was less than 0.1 mm and 0.1 mm^2. When comparing the accuracy of 3-D 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 [11].

With the dedicated software in transparent mode (MODE: Toggle Transparency), the 3-D images were set so that the posterior portion of the medial femoral condyle and the lateral femoral condyle would fully coincide. These images were projected onto a two-dimensional (2-D) view, and a true lateral view was created. In addition, an original coordinate plane was created to standardize and ensure the reproducibility of the knee size and guide the fluoroscope during surgery.

A line was drawn on the true lateral view from the 3-D surface of the translucent model between the anterior femoral cortex and the most posterior portion of the medial condyle to serve as the standard (100%) (Fig. 3a). 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 of the lowest line and distal perpendicular lines. The coordinates of the center of the femoral insertion of the MPFL and related osseous structures were plotted on squares in the true lateral view (Fig. 3b).

Results

Macroscopic findings

The MPFL was readily evident under the vastus medialis muscle because of the presence of loose soft tissue over the MPFL. The proximal margin of the ligament overlapped the adductor magnus tendon in all knees (Fig. 1); it fanned out toward the patella and was attached to the medial condyle of the femur. The femoral origin of the MPFL was attached between the adductor tubercle and medial epicondyle. The adductor tubercle was clearly identified by palpation, but the medial epicondyle was difficult to palpate because it was flat or shaped like a shallow groove. The medial retinaculum was conjoined to superficial fibers of the MPFL, but was readily identified by tracing the fibers. Therefore, these fibers were readily separated from the MPFL.

Three-dimensional measurements of the femoral insertion of the MPFL

The femoral insertion site was elliptical in shape, and the mean surface area of the MPFL insertion was 56.5 ± 16.9 mm^2 (Fig. 2). Quantitative data are summarized in Table 1.

Three-dimensional visualization of the femoral insertion of the MPFL and related osseous structures

The geometry of the femoral insertion of the MPFL varied, and characteristic features of the insertion site were not evident. The medial femoral epicondyle was flat or appeared as a shallow groove; thus, its apex could not be clearly identified. However, the prominence of the adductor tubercle was clearly identified in all knees, and the position between the femoral insertion of the MPFL and adductor tubercle was consistent.

The femoral insertion of the MPFL was distal to the apex of the adductor tubercle, parallel with the long axis of the femur; the mean linear distance between the two was 10.6 ± 2.5 mm (Fig. 2). Data are shown in Table 1.

On the lateral view of the 3-D images, the average proximal–distal and anteroposterior ratios for the center of the femoral insertion of the MPFL were x = 61% ± 4.3% and y = 42% ± 3.9%, respectively, and those for the apex of the adductor tubercle were x = 79% ± 4.9% and y = 44% ± 4.2%, respectively (Fig. 3). Geometric data regarding these locations are shown in Table 2.

Discussion

The most important finding of the current study was its identification of the femoral insertion of the MPFL and related osseous landmarks using 3-D images. The adductor tubercle was clearly identified as an osseous landmark. The femoral insertion of the MPFL was approximately 10 mm distal to the apex of the adductor tubercle on the long axis of the femur, and the position of the femoral insertion of the MPFL and apex of the adductor tubercle was consistent in all knees.

This study provided detailed data concerning the surface area of the femoral insertion of the MPFL. Few studies have referred to the shape and size of the femoral insertion of the MPFL. In their gross anatomical observations, Aragäo et al. [2] only reported that the length of the femoral insertion of the MPFL averaged 17 ± 6.0 mm. The current study is the first to report the surface area of the femoral insertion site. These measurements should aid in selecting the most appropriate graft size for anatomical MPFL reconstruction.

Several studies have described the osseous and soft tissue landmarks for the femoral insertion of the MPFL in relation to the adductor tubercle [24, 36], medial epicondyle [1, 21, 31, 32], osseous groove between the adductor tubercle and medial epicondyle [3], and medial collateral ligament [22]. However, Redfern et al. [25] indicated that intraoperative identification of these landmarks was sometimes difficult because of ligament rupture, tissue injury, and scar formation after patellar dislocation. The femoral insertion of the MPFL and the medial femoral epicondyle could not be identified in this study by examination of the gross anatomy or on 3-D images. The adductor tubercle can be used as an osseous landmark for intraoperative drilling during anatomical MPFL reconstruction.

The femoral insertion of the MPFL was approximately 10 mm distal to the apex of the adductor tubercle on the long axis of the femur, and this position was consistent in all knees. In an anatomical study, Tuxøe et al. [36] reported that the MPFL was attached 2 to 4 mm anterior to the adductor tubercle. LaPrade et al. [15] described the gross anatomy of the MPFL insertion site and reported that the site was 1.9 mm anterior and 3.8 mm distal to the adductor tubercle. Smirk et al. [31] reported that the optimal attachment points for an MPFL graft were just distal to the adductor tubercle. In addition, the current anatomical findings from the 3-D images are similar to the biomechanical findings from the 3-D model of Yoo et al. [39], who recently reported that the natural isometric ligament at the femoral fixation was located 10 mm distal (inferior) to the adductor tubercle or the midpoint between the medial femoral epicondyle and adductor tubercle.

The current study identified accurate coordinate positions of both the femoral insertion of the MPFL and adductor tubercle on the true lateral view of 3-D translucent images. Schottle et al. [29] used radiographic landmarks and reported that the femoral insertion of the MPFL was 1.3 mm anterior to the posterior femoral cortical line and 2.5 mm distal to the posterior origin of the medial condyle. Barnett et al. [4] stated that the femoral attachment was an average of 3.8 mm anterior to the posterior femoral cortical line and 0.9 mm distal to the perpendicular line, intersecting the posterior aspect of Blumensaat's line. Although the current findings cannot be compared to these previous findings because of the different methods of measurement used, previous studies have indicated that the femoral insertion of the MPFL is more anteriorly located than shown in the present study. These differences between the current findings and those of previous studies might be due to the use of a more accurate measurement system in the current study. In the current study, mapping was performed using translucent images, while previous studies used radiographic 2-D measurement that may have led to rotation or inclination, and thus introduced error [34]. The current method has several advantages over previous techniques. One is the analysis of bone morphology with determination of the insertion site positions within the related osseous structures of the medial condyle. These measurements should aid in determination of the guidewire position during fluoroscopy as well as intraoperative determination of the tunnel position when a navigation system is used.

There are several limitations to this study. First, specimens were taken from patients with a mean age of 83 years; therefore, degenerative changes may have hampered the identification of osseous landmarks. Second, the intact knees of cadaveric specimens were dissected and analyzed. Patients with patellar dislocation, however, may have congenital deformities of the femur [6]. Such a possibility could not be ruled out in the current study. Third, the current study used an accurate method of 3-D measurement and visualization using reliable geometric data, but this technique involved human dissection and decisions regarding osseous landmarks, which may have led to bias. Fourth, all peripheral fibers of the MPFL were included; thus, indirectly inserted fibers may have been included in the femoral insertion of the MPFL.

The clinical relevance of the current study stems from its discernment of the femoral insertion of the MPFL and related osseous landmarks on 3-D images. The results of this study may improve current understanding of the anatomy of the femoral insertion of the MPFL, and may assist surgeons in performing anatomical reconstruction.

Conclusion

The adductor tubercle was clearly identified as an osseous landmark. The femoral insertion of the MPFL was approximately 10 mm distal to the apex of the adductor tubercle on the long axis of the femur, and the position of the femoral insertion site and apex of the adductor tubercle were consistent on 3-D images.

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Fig. 1 *Macroscopic findings*

a. Photographs of the medial patellofemoral ligament (MPFL) with the vastus medial obliquus (medial view, left knee). **b**. Photograph of the femoral insertion of the MPFL and its fiber expansion to the adductor magnus tendon. The proximal margin of the ligament overlapped the adductor magnus tendon (medial posterior oblique view, left knee). *VMO*: vastus medial obliquus, *MPFL*: medial patellofemoral ligament, *AMT*: adductor magnus tendon, *MCL*: medial collateral ligament, *MR*: medial retinaculum

Fig. 2 Image of a reconstructed surface model showing the medial side of the left knee with marking of the insertion of the MPFL, adductor tubercle, and medial femoral epicondyle (medial posterior oblique view, left knee). On the femur, the circled red area is the femoral insertion of the MPFL, the blue dots indicate the apex of the adductor tubercle, and the white triangular area is the medial femoral epicondyle. The surface area of the femoral insertion site and the linear distance between the center of the femoral insertion of the MPFL and apex of the adductor tubercle were measured using dedicated software. The small picture of the femur in the medial posterior oblique view shows the orientation of the specimen. *AT*: adductor tubercle, *D*: distance

Fig. 3 a. Original coordinate plane with squares. Squares with reference lines A, B, C, and D were drawn on the true lateral view. Line A: A line extending from the anterior femoral cortex was drawn through the origin of the medial trochlea and parallel with the long axis of the femur. Line B: Contact points at the most distal portion of the medial condyle were plotted perpendicular to the long axis. Line C: Contact points at the most posterior portion of the medial condyle were plotted parallel with the long axis. Line D:

A line perpendicular to the long axis was drawn to create squares. The asterisk indicates the standard length (as 100%) for lines A and C and for lines B and D. **b**. Each point shows the standardized coordinates of the femoral insertion of the MPFL and apex of the adductor tubercle on the true lateral views of the 3-D images. The red dots indicate the femoral insertion of the MPFL, and the blue triangles indicate the apex of the adductor tubercle in all specimens.

Figure
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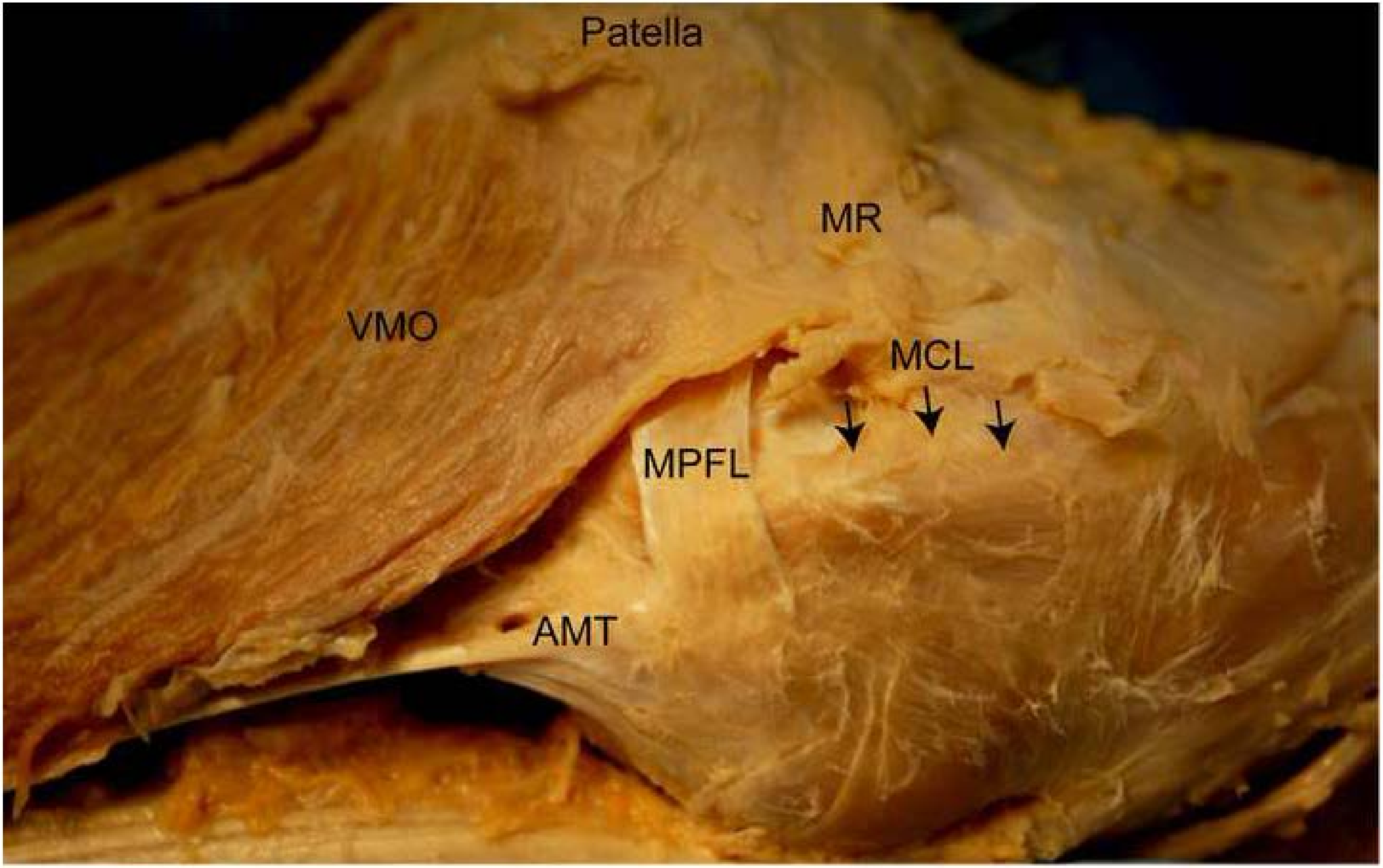

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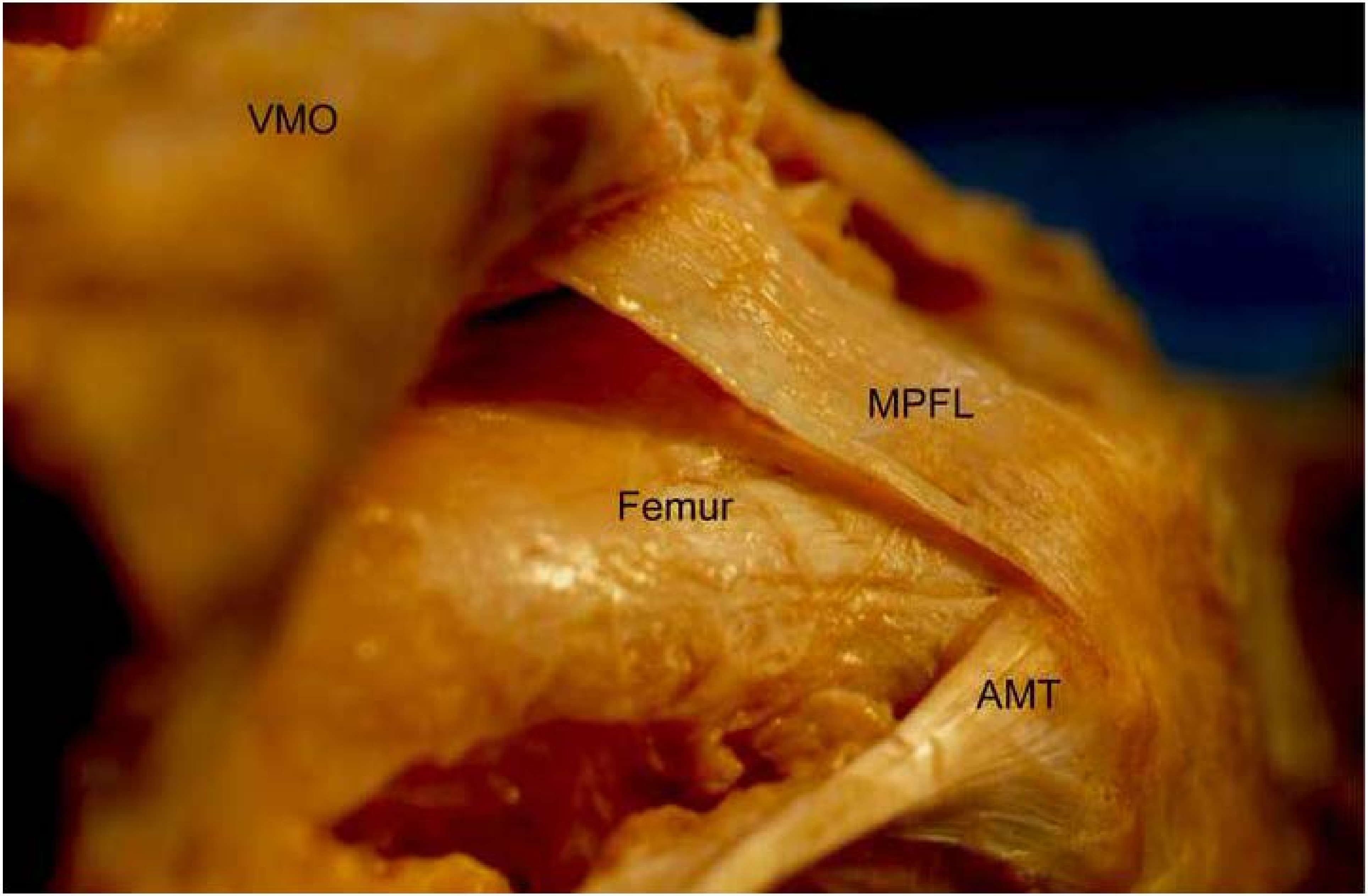

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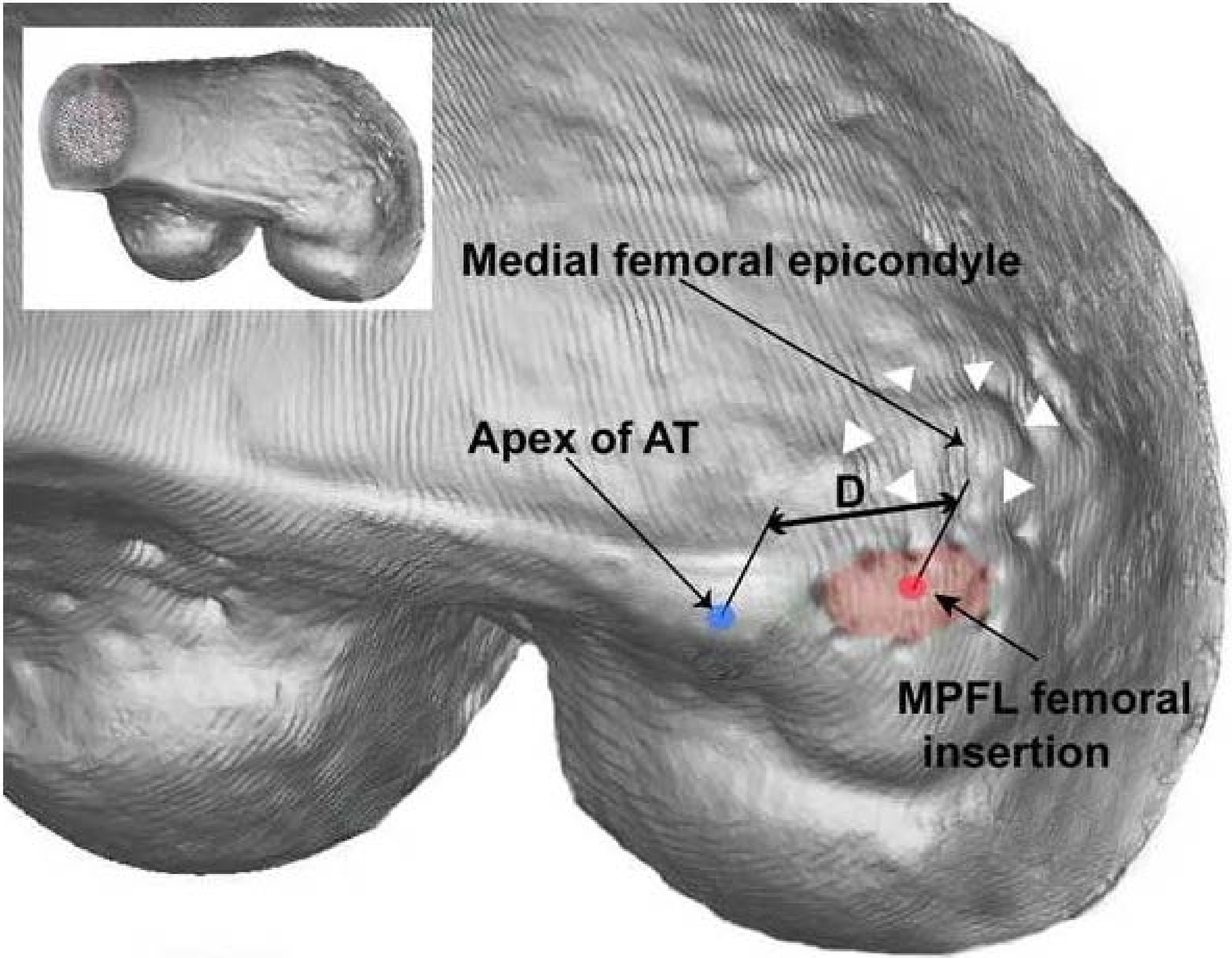

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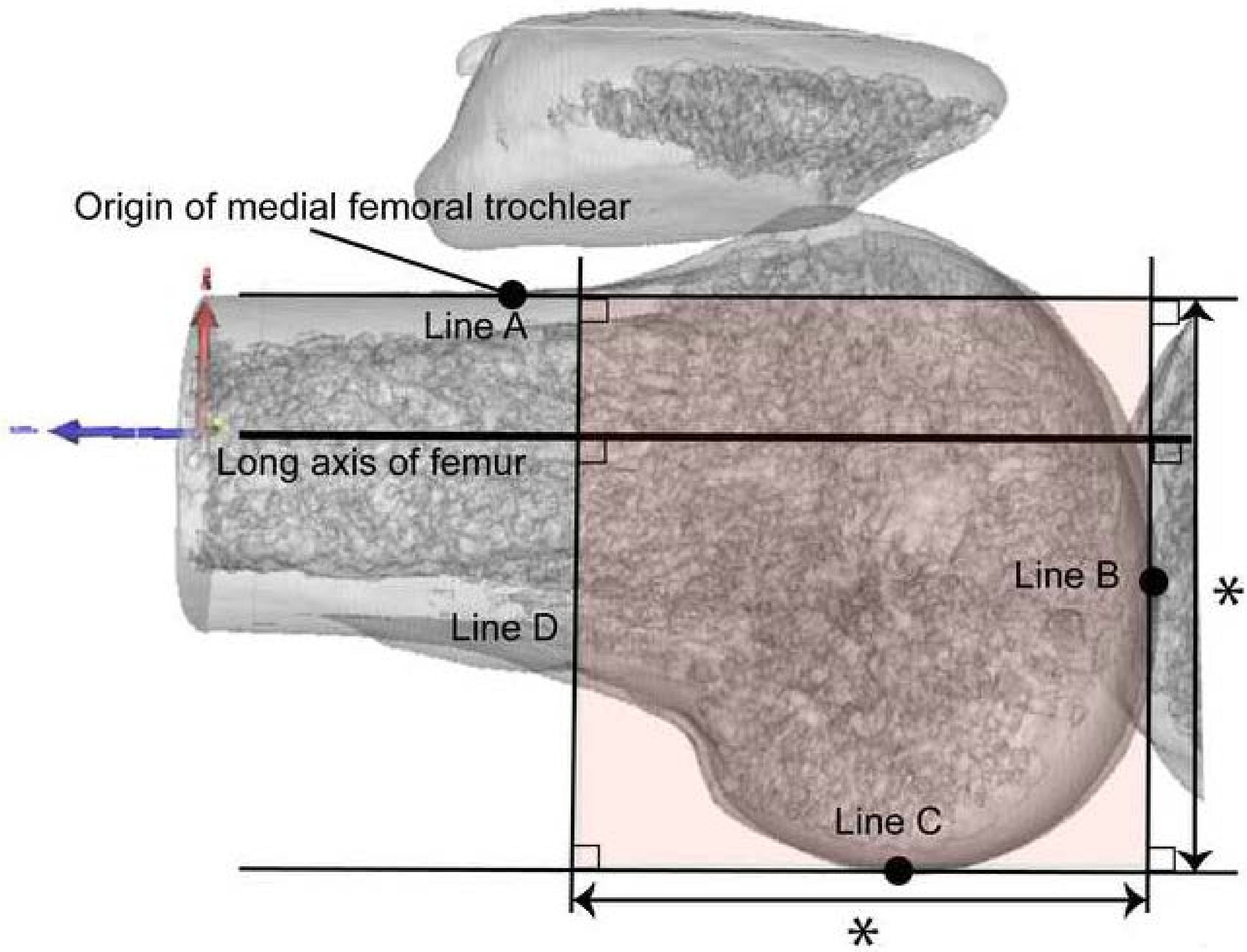

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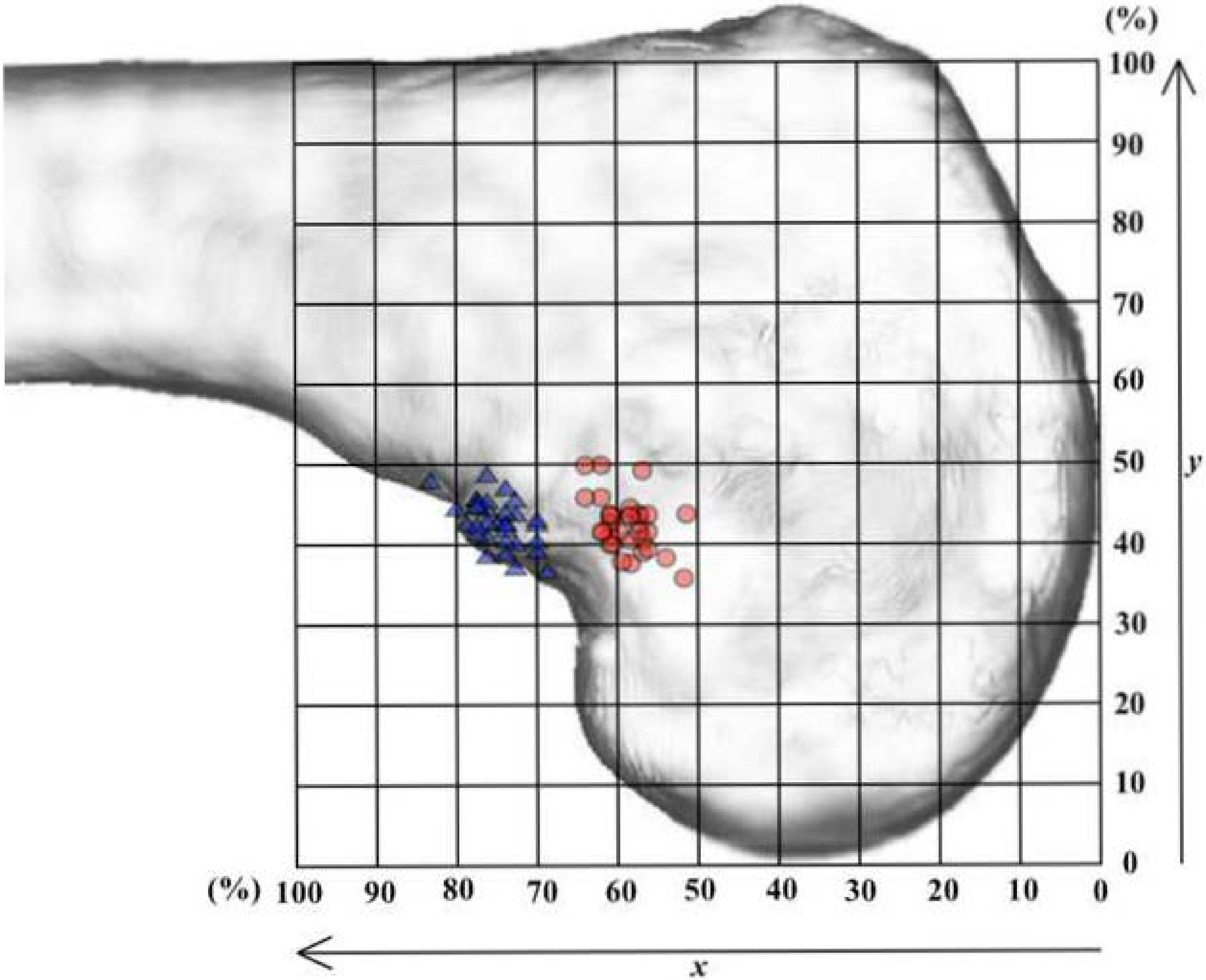

Table

Table 1 3-D measurement with a true lateral view of 3-D images (Data are presented as mean ± SD, Range)

Femoral insertion of the MPFL	The linear distance of both the MPFL femoral insertion and adductor tubercle (mm)
Surface area (mm2)	
56.5 ± 16.9 (30.8-92.6)	10.6 ± 2.5 (5.7-17.7)

Table

Table 2 Locations and Coordinates with a true lateral view of 3-D images (Data are presented as mean ± SD, Range)

	The center of the MPFL femoral insertion (%)	The apex of the adductor tubercle (%)
P-D ratio (x)	61 ± 4.3 (51-68)	79 ± 4.9 (64-89)
A-P ratio (y)	42 ± 3.9 (34-50)	44 ± 4.2 (36-53)