Original Article

Measurement of the Whole and Midsubstance Femoral Insertion of the Anterior Cruciate Ligament: The Comparison with the Elliptically Calculated Femoral Anterior Cruciate Ligament Footprint Area

Abstract

Purpose: The purpose of this study was to measure the detailed morphology of the femoral anterior cruciate ligament (ACL) footprint. The correlation and the comparison between the measured area and the area which mathematically calculated as elliptical were also evaluated. **Materials and Methods:** Thirty nine nonpaired human cadaver knees were used. The ACL was cut in the middle, and the femoral bone was cut at the most proximal point of the femoral notch. The ACL was carefully dissected, and the periphery of the ACL insertion site was outlined on both the whole footprint and the midsubstance insertion. Lateral view of the femoral condyle was photographed with a digital camera, and the images were downloaded to a personal computer. The area, length, and width of the femoral ACL footprint were measured with Image J software (National Institution of Health). Using the length and width of the femoral ACL footprint, the elliptical area was calculated as 0.25 π (length × width). Statistical analysis was performed to reveal the correlation and the comparison of the measured and elliptically calculated area. **Results:** The sizes of the whole and midsubstance femoral ACL footprints were 127.6 ± 41.7 mm^2 and 61 ± 20.2 mm^2, respectively. The sizes of the elliptically calculated whole and midsubstance femoral ACL footprints were 113.9 ± 4.5 mm^2 and 58.4 ± 3 mm^2, respectively. Significant difference was observed between the measured and the elliptically calculated area. In the midsubstance insertion, significant correlation was observed between the measured and the elliptically calculated area (Pearson's correlation coefficient = 0.603, P = 0.001). However, no correlation was observed in the whole ACL insertion area. **Conclusion:** The morphology of the femoral ACL insertion resembles an elliptical shape. However, due to the wide variation in morphology, the femoral ACL insertion cannot be considered mathematically elliptical.

Keywords: *Anatomy, anterior cruciate ligament, elliptical, femoral*

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Introduction

In recent decades, anterior cruciate ligament (ACL) reconstruction has been widely performed as an anatomical procedure due to numerous studies reporting its superior ability to restore normal knee function when compared to nonanatomical reconstruction.[1-8] With the rising frequency of anatomical ACL reconstruction, the anatomy of the ACL has been studied in greater detail.[2,4,9-16] One of the primary goals of anatomical ACL reconstruction is the restoration of native anatomy.[1,17,18] As revealed in previous studies, the shape of the ACL footprint is not round. Rather, it is close to elliptical in shape.[15,19-28] To restore the normal ACL footprint in reconstruction, a double-bundle technique[1,12,13] or a rectangular tunnel technique is thought to be more suitable[25] than a single-bundle technique with a round tunnel. Recently, some authors have reported the use of elliptical tunnels in ACL reconstruction.[21-23] However, it is commonly known that a wide variation exists in ACL anatomy.[2,3,14,15] The morphology of the ACL footprint does not always resemble an elliptical shape. If the ACL footprint can be calculated mathematically as an accurate elliptical shape, more attention should be given to surgical devices or techniques for creating elliptical tunnels. However, if this is not the case, further research is necessary to determine the efficacy and proper use of elliptical tunnels in ACL reconstruction.

The purpose of this study was to reveal the correlation and the comparison between the

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measured femoral ACL footprint area and the femoral ACL footprint area, mathematically calculated as elliptical.

The hypothesis of this study was that the native femoral ACL footprint would be close to elliptical in shape, but that there would be some differences between the calculated areas.

Materials and Methods

Thirty nine nonpaired formalin-fixed Japanese cadaveric knees were used (15 males, 24 females, median age 80, range 54–96). Knees with osteoarthritic changes were excluded.

Evaluation of the anterior cruciate ligament insertion site

All surrounding muscles and other soft tissues around the knee were resected before ACL dissection. Knees were cut at approximately 200 mm proximal to the femur and distal tibia. All soft tissues were carefully dissected. Anteromedial and posterolateral (AM and PL) bundles were identified according to the difference in tension patterns during complete knee range of motion. With the knee at 90° of flexion, relaxed fibers of the ACL were regarded as the PL bundle.[2,12-14] After soft tissue resection, the ACL was cut in half. On the femoral side, the femur was split along the sagittal plane through the most superior point of the anterior outlet of the intercondylar notch with an oscillating saw to expose the femoral attachment of the ACL. The outline of the whole femoral ACL footprint was marked first with colored ink, and the midsubstance insertion site of the femoral ACL footprint was then marked [Figure 1a].[2] Following the identification of the AM and PL bundle midsubstance fibers, the midsubstance insertion and the fan-like extensions were divided according to the AM and PL bundles and marked.[2,12-14] Referring to the midsubstance tissue of the ACL, the border between the midsubstance insertion area and fan-like extension fibers of the ACL footprint was clearly distinguished.[14] As the intercondylar ridge could not be found out in every knee in this study, the ridge was not referred for the evaluation of the ACL footprint. An accurate lateral view of the femoral condyle was photographed with a digital camera (Casio, Co. Ltd., Tokyo, Japan).[2,14] When the pictures were taken, a measure was placed at the same plane of the footprint. The images were downloaded to a personal computer, and the footprint area was calculated after adjusting the computer images to the actual knee size using Image J software (National Institute of Health, Bethesda, Maryland, USA).[2,14] The accuracy of the area measurement was <0.1 mm^2 [Figure 1]. The following areas were calculated: the whole ACL area, the whole midsubstance insertion area, the whole AM area, the midsubstance insertion area of the AM bundle, the whole PL area, and the midsubstance insertion area of the PL bundle.

The center position of each bundle was calculated automatically by Image J software. Following Siebold's method,[15] the length of the ACL footprint was calculated as an orientation line through the centers of the AM and PL bundles (whole and midsubstance insertion). The width of each bundle's insertion site was calculated as the greatest length of line perpendicular to the ACL length line.

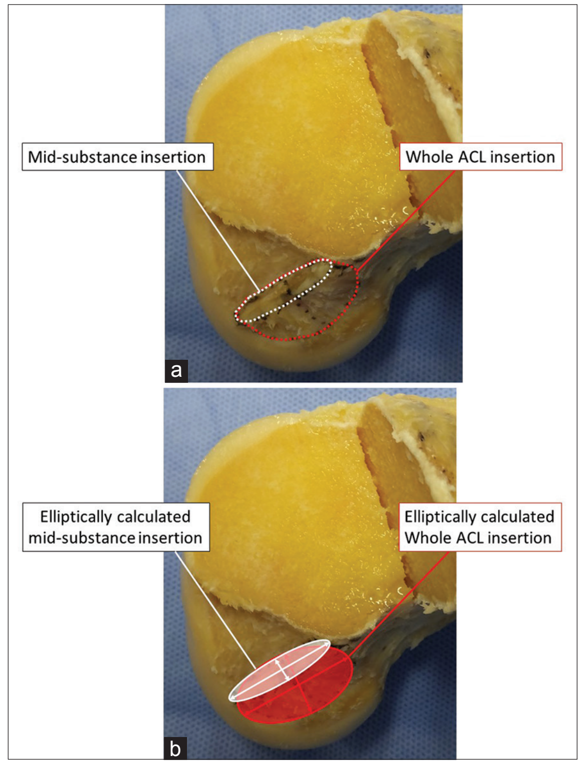

Figure 1: Measured and elliptically calculated femoral ACL insertion. (a) After marking an outline of the ACL footprint, each footprint was photographed with a digital camera. The pictures were downloaded to a personal computer and the area of the midsubstance insertion and the whole ACL insertion were measured using Image J software (National Institute of Health). (b) Using the length and width of the femoral ACL insertion, the elliptical area was calculated as: 0.25 π (length × width). ACL = Anterior cruciate ligament

Calculation of the elliptical area

Using the data of the length and width of the femoral ACL footprint, the elliptical area was calculated as 0.25 π (length × width) [Figure 1b].

Statistical analysis

Data are presented as mean and standard deviation. Comparison of the measured and the elliptically calculated area was performed using Mann–Whitney U-test (both on the whole and midsubstance insertion). The correlation of the measured and elliptically calculated area was evaluated using Pearson's coefficient correlation test. It was assumed that there was statistical significance when $P < 0.05$. All statistical data were calculated with SPSS 19.0 (SPSS Inc., Chicago, IL, USA).

Considering the mean and standard deviations in the width of the ACL footprint, the calculated sample size was 35.

This study has been approved by the ethics committee of Nihon University School of Medicine. The IRB number was 20-14.

Results

The measured and elliptically calculated anterior cruciate ligament footprint size and areas

The length and width of the femoral whole ACL footprint were 14.9 ± 3 and 9.8 ± 1.9 mm, respectively. The length and width of the femoral ACL midsubstance insertion were 14.6 ± 3.3 and 5.1 ± 1.2 mm, respectively.

The sizes of the whole and midsubstance femoral ACL footprints were 127.6 ± 41.7 mm^2 and 61 ± 20.2 mm^2, respectively. The sizes of the elliptically calculated whole and midsubstance femoral ACL footprints were 113.9 ± 4.5 mm^2 and 58.4 ± 3 mm^2, respectively [Table 1]. Significant differences were observed between the measured and the elliptically calculated areas both in the whole ACL insertion ($P < 0.05$) and in the midsubstance insertion ($P < 0.05$) [Figure 2].

Correlation in size between the measured and elliptically calculated anterior cruciate ligament footprint area

In the midsubstance insertion, significant correlation was observed between the measured and the elliptically calculated area (Pearson's correlation coefficient = 0.603, $P = 0.001$) [Figure 3]. However, no correlation was observed in the whole ACL insertion.

Table 1: The measured femoral anterior cruciate ligament insertion area, length and width, and the elliptically calculated area

Measured and calculated area	
Whole femoral ACL insertion area	127.6±41.7 mm^2
Length and width of whole ACL insertion	14.9±3/9.81±1.9 mm
Elliptically calculated whole femoral ACL insertion area	113.9±4.5 mm^2
Mid-substance insertion area	61±20.2 mm^2
Length and width of mid-substance insertion	14.6±3.3/5.1±1.2 mm
Elliptically calculated mid-substance insertion area	58.4±3 mm^2

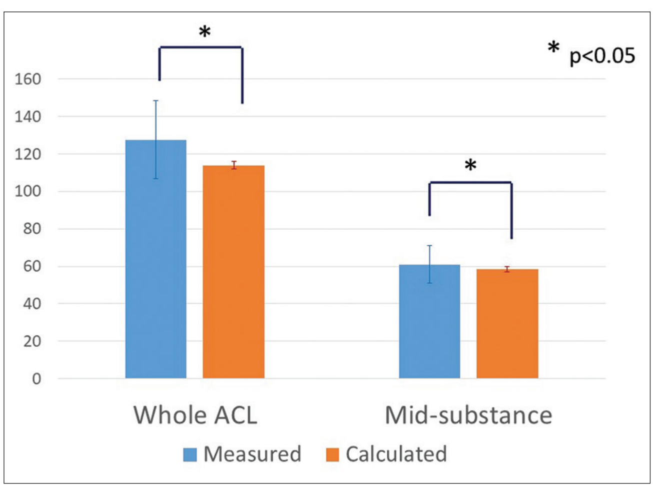

Figure 2: Comparison of the measured and elliptically calculated femoral ACL insertion. Significant difference was observed between the measured and the elliptically calculated area both in the midsubstance and the whole femoral ACL insertions. ACL = Anterior cruciate ligament

Discussion

The most important finding of this study was that the measured femoral ACL footprint area showed significant difference when compared with the elliptically calculated femoral ACL footprint area. Significant correlation was observed between the measured and the elliptically calculated midsubstance insertion area. However, significant correlation was not observed in the whole ACL insertion. These results suggest that a wide morphological variation exists in the femoral ACL footprint area and that the shape of the ACL footprint resembles an ellipse. However, calculated mathematically, it cannot be considered an accurate ellipse. Morphological correlation was observed between the measured and the elliptically calculated midsubstance insertion, suggesting that the midsubstance insertion has a relatively similar elliptical morphology. However, since the whole ACL footprint has a wider morphological variation, no correlation was observed between the measured area and the elliptically calculated area.

ACL reconstruction has conventionally been performed with single-round femoral and tibial tunnels. However, recent anatomical studies have revealed that the ACL footprint is relatively elliptical in shape and not round. This has led to numerous studies investigating the efficacy of the double-bundle technique[1,11-13,17,29-33] and the rectangular bone–patellar tendon–bone (BPTB) technique[27] in accurately reproducing the anatomical footprint in ACL reconstruction. In other words, double-bundle or rectangular BPTB techniques are methods that fill the elliptical ACL insertion with round or rectangular bone tunnels.

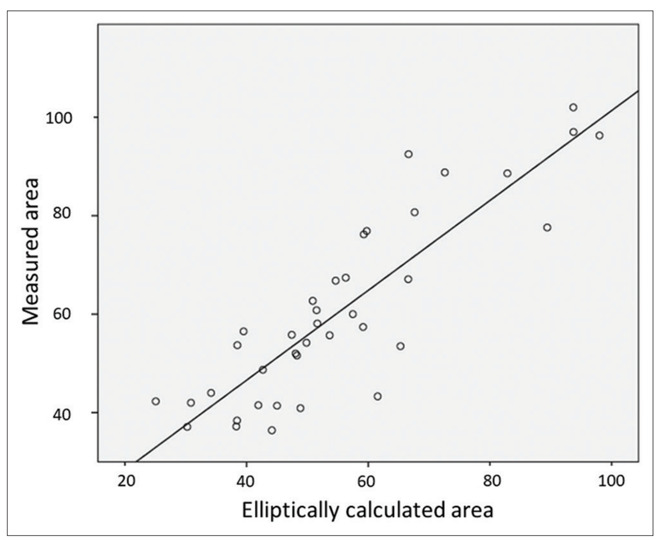

Figure 3: Correlation analysis of the measured and elliptically calculated femoral midsubstance ACL insertion. Significant correlation was observed between the measured and the elliptically calculated midsubstance femoral ACL insertion. However, no correlation was observed in the whole ACL insertion. ACL = Anterior cruciate ligament

In several studies, various authors have concluded that the ACL insertion is elliptical.[18,20-26] Moreover, techniques in which intentionally created elliptical tunnels were used have also been reported.[21-23] Petersen *et al*. reported a technique involving anatomical single-bundle ACL reconstruction using elliptical tunnels. They reported that elliptical tunnels match the ACL insertion more accurately than round tunnels.[23] Noh *et al*. conducted a clinical study which compared round and elliptical tunnels in single-bundle ACL reconstruction. They reported that the Lysholm score was better in the elliptical tunnel group at the 2-year followup.[21]

Contrary to these studies advocating the use of intentionally created elliptical tunnels, other reports of recent techniques in ACL reconstruction have asserted that because creating tunnels with a precise vertical alignment to the medial wall of lateral femoral condyle or tibia plateau is impossible, the resulting tunnel outlet morphology must necessarily be elliptical in shape.[18,20,26] Hensler *et al*. reported that femoral tunnel aperture length and area in anatomical single-bundle ACL reconstruction using a transportal technique are correlated with the transverse drill angle and knee flexion angle.[18] They concluded that the most suitable transverse drill angle and knee flexion angle to the native femoral insertion are 40°and 102°, respectively.

Not only is the ACL insertion reported to be elliptical in its morphology, but the reconstructed graft cross-section has also been found to be elliptical in shape.[22,26] In light of the above studies which describe the ACL as elliptical in shape, it is essential to reveal whether ACL morphology can be accurately defined mathematically as elliptical. Such a revelation will be important for the future development of new surgical techniques and devices.

The results of this study revealed that the femoral ACL footprint morphology is close to elliptical in shape. However, mathematically, it cannot be considered an accurate ellipse. To ensure more accurate anatomical ACL reconstruction, future studies should be conducted to reveal the role and efficacy of elliptical tunnels in anatomical ACL insertion and to develop the new techniques needed to put such knowledge into practice.

The main limitations of this study were as follows: (i) ACL dissection was performed by macroscopic evaluation only. Although dissection was performed by experienced surgeons, this might allow for human error and bias. (ii) The average age of the cadavers used was significantly older than the average age of patients who undergo ACL reconstruction. Even though no specimens had severe osteoarthritic changes, the ages of the specimens should be considered in such an anatomical study. (iii) Our sample size was not large (n = 39) but was similar to a previous study.[2] Due to anatomical variation and in order to accurately define the ACL anatomy, a study with a larger sample size is needed. (iv) The ACL footprint was evaluated with a two-dimensional (2D) technique only. The ACL is attached 3D to the bone,[11] especially on the femoral side, and might be better evaluated with a 3D camera or computer graphics. (v) The relationship with intercondylar ridge and the ACL footprint is essential; however, it was not evaluated in this study. It should be revealed in the future plans.

Conclusion

The morphology of the femoral ACL insertion resembles an elliptical shape. However, due to the wide variation in morphology, the femoral ACL insertion cannot be considered mathematically elliptical. For clinical relevance, these findings may assist surgeons in their choice of technique for ACL reconstruction. The use of elliptical tunnels may not always be the best option, and surgeons should be cautious when considering such an approach.

Ethical approval

This article has been approved by the ethics committee of our institution. The number of the approval was 20-14.

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Conflicts of interest

There are no conflicts of interest.

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