The importance of Blumensaat's line morphology for accurate femoral ACL footprint evaluation using the quadrant method

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The importance of Blumensaat's line morphology for accurate femoral ACL footprint evaluation using the quadrant method

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Abstract

Purpose The purpose of this study was to evaluate the difference in the center position of the ACL footprint based on grid placement using the quadrant method according to the morphological variations of the Blumensaat's line.

Methods Fifty-nine non-paired 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, and the digital images were evaluated using Image J software. The femoral ACL footprint was periphery outlined and the center position was automatically measured. Following Iriuchishima's classification, the morphology of the Blumensaat's line was classified into straight, small hill, and large hill types. From the images, grid quadrants were placed as: Grid (1) without consideration of hill existence and not including the chondral lesion. Grid (2) without consideration of hill existence and including the chondral lesion. Grid (3) with consideration of hill existence and not including the chondral lesion. Grid (4) with consideration of hill existence and including the chondral lesion.

Results The straight type consisted of 19 knees, the small hill type 13 knees, and the large hill type 27 knees. Depending on the quadrant grid placement, significant center position difference was observed both in the shallow–deep, and high–low direction. When hill existence was considered, the center position of the ACL was significantly changed to a high position.

Conclusion The center position of the ACL footprint exhibited significant differences according to Blumensaat's line morphology. For clinical relevance, when ACL surgery is performed in knees with small or large hill type variations, surgeons should pay close attention to femoral tunnel evaluation and placement, especially when using the quadrant method.

Keywords Anterior cruciate ligament · Anatomy · Intercondylar notch · Blumensaat's line · Quadrant method

Abbreviations

ACL Anterior cruciate ligament
AM Antero-medial bundle
PL Postero-lateral bundle

Introduction

Accurate evaluation of the anterior cruciate ligament (ACL) footprint and tunnel placement is essential for the success of reproducible anatomical ACL surgery [6, 7, 10, 11, 19, 22]. In the past, femoral ACL footprint and tunnel placement were calculated using an o'clock method [1, 15, 23]. However, the o'clock evaluation is strongly influenced by knee flexion angle, and it is no longer widely used. The quadrant method was introduced by Bernard and Hertel [1], and is currently the most popular method of femoral ACL footprint and tunnel placement measurement [10, 11, 13, 17]. In the quadrant method, grid placement on the lateral wall of the femoral intercondylar notch is mainly

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determined using Blumensaat's line. In their original report, Bernard and Hertel defined the Blumensaat's line as a straight line [1]. However, if Blumensaat's line has morphological variations, these variations could affect measurement accuracy when using the quadrant method.

Farrow et al. reported that morphological variations exist in the posterior rim of the intercondylar roof [3]. Recently, Iriuchishima et al. reported that the Blumensaat's line also has morphological variations. In their study, the morphology of the Blumensaat's line was classified into straight, small hill, and large hill types [6]. No study has been performed revealing the center position difference of the femoral ACL footprint considering the morphological variations of the Blumensaat's line.

The purpose of this study was to reveal the center position difference in femoral ACL footprint using cadaveric knees according to the morphological variations of the Blumensaat's line. The hypothesis of this study was that the center position of the femoral ACL footprint would be affected by the morphological variations of the Blumensaat's line. Clarifying this issue would make it possible for surgeons to measure femoral ACL anatomy and perform reproducible anatomical ACL surgery with greater accuracy.

Materials and methods

Fifty-nine non-paired formalin fixed Japanese cadaveric knees were used (17 males, 42 females, median age 83, range 68–97). Although aged knees were used in this study, knees with severe osteoarthritic changes were excluded from this study.

Dissection

All surrounding muscles, ligaments, and other soft tissues in the knee were resected from the femoral bone. Particular care was taken to ensure that the posterior structures were accurately resected. The posterior joint capsule, menisco-femoral ligaments, posterior cruciate ligament (PCL), and synovial tissues were resected carefully. 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 split plane was parallel to the femoral shaft. The outline of the femoral ACL footprint was marked with colored ink. Antero-medial (AM) and postero-lateral (PL) bundles were not separated in this study because the purpose was to evaluate the total ACL area correctly. After marking the ACL footprint, an accurate lateral view of the femoral condyle was photographed with a Casio EXILIM S12 digital camera (Casio, Co. Ltd., Tokyo, Japan). 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) [28, 30]. The center of the femoral ACL footprint was measured automatically.

Morphological variation of the Blumensaat's line

Following Iriuchishima's classification [6], the morphology of the Blumensaat's line was classified into straight, small hill, and large hill types (Fig. 1).

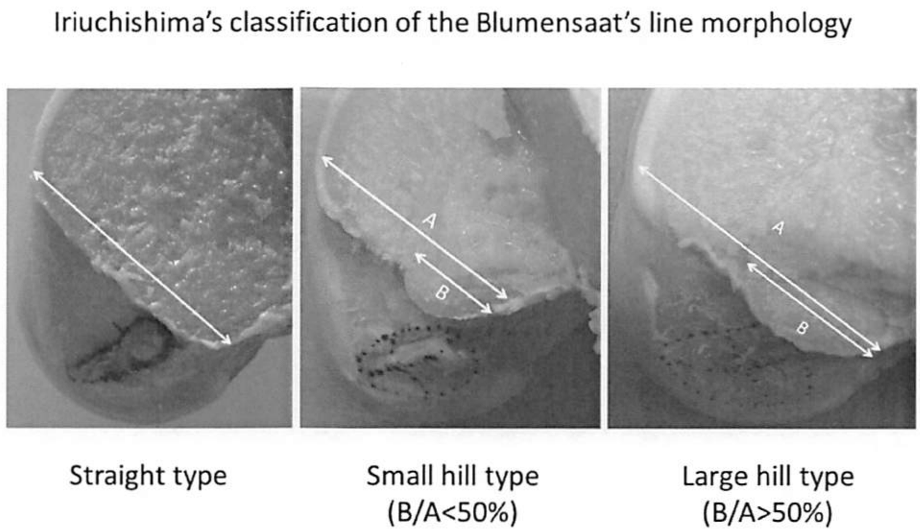

Fig. 1 Morphological variations of the Blumensaat's line. In Iriuchishima's classification, the morphology of the Blumensaat's line has three types of variations: straight type, small hill type, and large hill type

Straight type

The Blumensaat's line (intercondylar roof) appeared more or less straight, and the transition from the Blumensaat's line to the posterior cortex was clearly defined.

Small hill type

A protrusion spanning less than half of the line was observed at the posterior (proximal) part of the Blumensaat's line.

Large hill type

A protrusion spanning more than half of the line was observed at the proximal part of the the Blumensaat's line.

Grid placement in the quadrant method

In the same images used for the morphological evaluation of the Blumensaat's line, four types of quadrant grid placement were evaluated according to the morphological variations of the Blumensaat's line and the chondral lesion (Fig. 2).

Grid (1) Without consideration of hill existence and not including the chondral lesion. The baseline of the quadrant grid was matched to the anterior part of the Blumensaat's line. The lower and side line of the grid were tangential to the medial wall of the lateral femoral condyle.

Grid (2) Without consideration of hill existence and including the chondral lesion. The base line of the grid was determined as in Grid 1. The lower and side line were tangential to the articular surface.

Grid (3) With consideration of hill existence and not including the chondral lesion. The baseline of the grid was the line connecting the anterior edge of the Blumensaat's line and the top of the hill. The lower and side line of the grid were tangential to the medial wall of the lateral femoral condyle.

Grid (4) With consideration of hill existence and including the chondral lesion. The baseline of the grid was determined as in Grid 3. The lower and side line were tangential to the articular surface. The measurement accuracy of the Image J software were, 0.1 mm and 0.1 mm^2 [6, 10, 28, 30]. This study was approved by the ethics committee of the Nihon University School of Medicine. The IRB number was: 20–14.

Statistical analysis

Data are presented as mean ± standard deviations. The comparison of the ACL center position in the quadrant method according to the difference in grid placement was statistically analyzed using the Friedman Test and the Wilcoxon Signed Ranks Test for pair-wise analysis. A Bonferroni approach was used to adjust the alpha level for the pair-wise post hoc comparisons, and it was assumed that there was statistical significance when $p<0.05$ for the Friedman test and $p<0.01$ for the Wilcoxon Signed Ranks Test. All

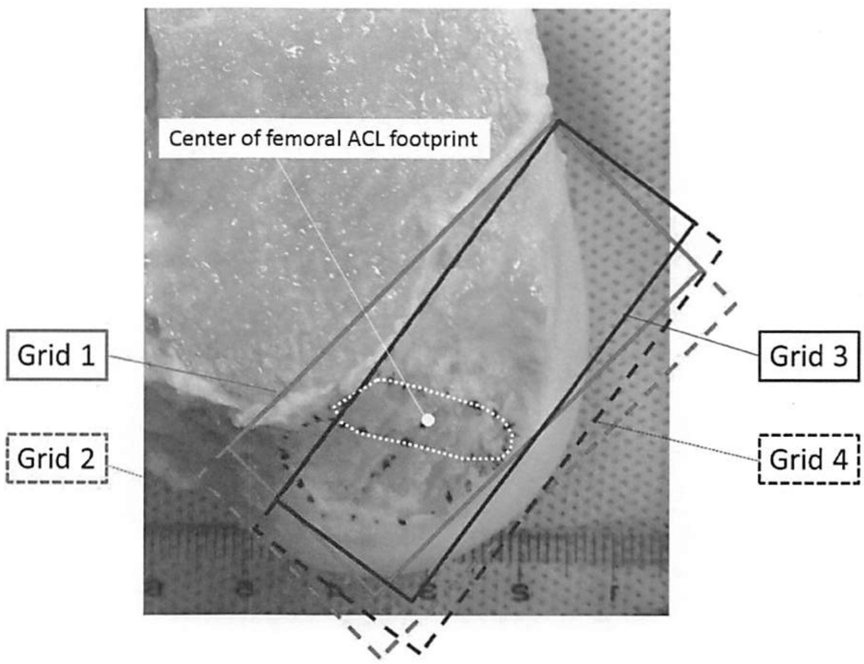

Fig. 2 Quadrant grid placement according to the morphological variations of the Blumensaat's line and the chondral lesion. According to the morphological variations of the Blumensaat's line and the chondral lesion, quadrant grids were placed as: *Grid (1)* without consideration of hill existence and not including the chondral lesion. *Grid (2)* without consideration of hill existence and including the chondral lesion. *Grid (3)* with consideration of hill existence and not including the chondral lesion. *Grid (4)* with consideration of hill existence and including the chondral lesion

statistical data were calculated with SPSS 19.0 (SPSS Inc., Chicago, IL).

Considering the mean and Standard deviations of the shallow–deep direction of straight type and hill types, the calculated total sample size was 42 (G*Power 3 software).

Results

Morphological variations of the Blumensaat's line

The morphological variations of the Blumensaat's line were: straight type in 19 knees, small hill type in 13 knees, and large hill type in 27 knees.

Difference in ACL center position according to quadrant grid placement

In straight type knees, because no hill was present, only Grids 1 and 2 were evaluated. In Grid 1, the ACL center was placed 33.7 ± 4.7% in the shallow–deep direction, and 47.6 ± 8.8% in the high–low direction. In Grid 2, the ACL center was placed 39.4 ± 4.3% in the shallow–deep direction, and 39.4 ± 7.7% in the high–low direction. Significant differences of the ACL center position were observed between Grid 1 and Grid 2 both in the shallow–deep ($p = 0.000$) and high–low ($p = 0.004$) directions (Fig. 3).

In small hill type knees, the ACL center was placed as follows: Grid (1) 37.5 ± 6% in the shallow–deep, 50.2 ± 8.3% in the high–low directions, Grid (2) 43.7 ± 5.2% in the shallow–deep, 42 ± 6.6% in the high–low directions, Grid (3) 35.7 ± 5.8% in the shallow–deep, 40.7 ± 9% in the high–low directions, and Grid (4) 40.8 ± 4.5% in the shallow–deep, 33.3 ± 7.8% in the high-low directions. In the shallow-deep direction, a significant difference was observed between Grid 1 and Grid 2 ($p = 0.027$). In the high–low direction, significant differences were observed between Grid 1 and Grid 3 ($p = 0.020$), and Grid 2 and Grid 4 ($p = 0.037$) (Fig. 4).

In large hill type knees, the ACL center was placed as follows: Grid (1) 37.1 ± 5.6% in the shallow–deep, 50.4 ± 5.8% in the high–low directions, Grid (2) 42.1 ± 5.8% in the shallow–deep, 42.6 ± 4.8% in the high–low directions, Grid (3) 34.9 ± 5.7% in the shallow–deep, 41.9 ± 7.8% in the high–low directions, and Grid (4) 40.3 ± 5.9% in the shallow-deep, 34.4 ± 6.7% in the high–low directions. In the shallow–deep direction, significant differences were observed between Grid 1 and Grid 2 ($p = 0.009$), and Grid 3 and Grid 4 ($p = 0.005$). In the high–low direction, significant differences were observed between Grid 1 and Grid 2 ($p = 0.000$), Grid 1 and Grid 3 ($p = 0.000$), Grid 2 and Grid 4 ($p = 0.037$), and Grid 3 and Grid 4 ($p = 0.000$) (Fig. 5).

Discussion

The most important finding of this study was that the morphology of the Blumensaat's line significantly affected ACL center position evaluation using the quadrant method. According to the consideration of hill existence (Grid 1 vs. Grid 3, and Grid 2 vs. Grid 4), significant differences were found in the ACL center position. In the grids in which hill

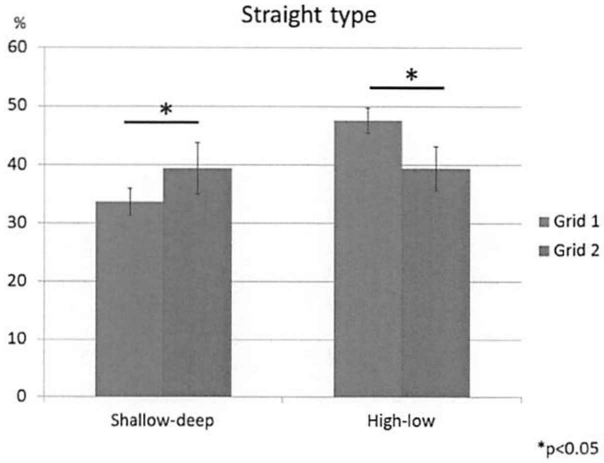

Fig. 3 ACL center position difference based on quadrant grid placement in straight type knees. When the chondral lesion was included in the quadrant grid placement (Grid 2), ACL center position was changed to a significantly shallow and high position

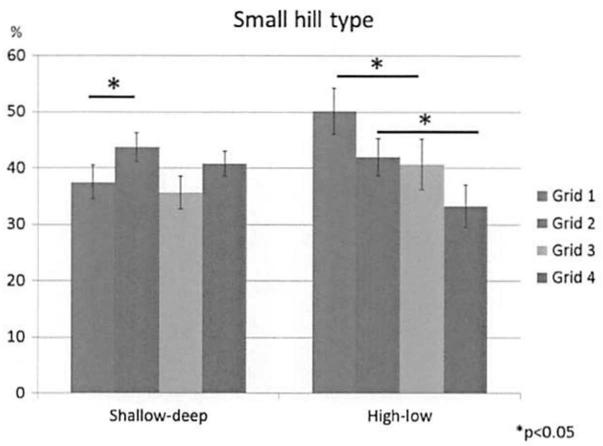

Fig. 4 ACL center position difference based on quadrant grid placement in small hill type knees. When hill existence was taken into consideration in the quadrant grid placement (Grid 1 vs. Grid 3, Grid 2 vs. Grid 4), the ACL center was significantly changed to a high position. When the chondral lesion was included in the quadrant grid placement (Grid 1 vs. Grid 2, Grid 3 vs. Grid 4), ACL center position was significantly changed to a shallow position

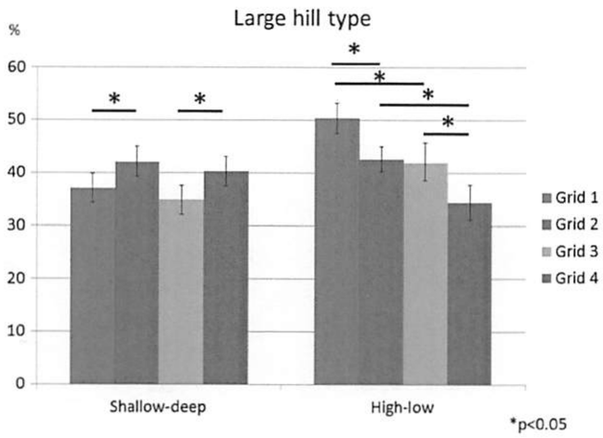

Fig. 5 ACL center position difference based on quadrant grid placement in large hill type knees. When hill existence was taken into consideration in the quadrant grid placement (Grid 1 vs. Grid 3, Grid 2 vs. Grid 4), the ACL center was significantly changed to a high position. When the chondral lesion was included in the quadrant grid placement (Grid 1 vs. Grid 2, Grid 3 vs. Grid 4), ACL center position was significantly changed to a shallow position

existence was considered, the ACL center position was measured at a high position. In addition, the inclusion of the chondral lesion in the quadrant method evaluation also affected the ACL center position (Grid 1 vs. Grid 2, and Grid 3 vs. Grid 4). These results suggest that it is problematic to adopt the original quadrant method uniformly for all knees for femoral ACL footprint or tunnel placement evaluation.

In the human body, the existence of a straight line is rare. However, since its original identification and description, the Blumensaat's line has always been considered a straight line [1, 11, 16, 29]. Historically, the concept of the Blumensaat's line was reported in 1930s for the evaluation of patella height using the radiography techniques of the time [6, 12]. The limitations in technology made it difficult to observe the morphology of the Blumensaat's line in the same detail in which is it now possible.

In the quadrant method [1], the Blumensaat's line determines the baseline of the grid. In the original study documenting this method, the Blumensaat's line was regarded as a completely straight line. As revealed by Iriuchishima et al. [6], Blumensaat's line is not always straight. As shown in this study, the existence of small or large hill type variations affects the accuracy of grid placement and ACL center position evaluation when using the quadrant method. For reproducible anatomical surgery, these morphological variations should be considered when surgeons use the quadrant method. Considering the results of this study, optimal placement of the grid using the quadrant method should be evaluated in greater detail. It is the authors' opinion that in order to perform a reproducible evaluation using the quadrant method, Grid 1 placement is preferable. The reasons for this are: (1) if hill existence is taken into consideration, a significant error is likely to occur between straight and hill type knees. (2) When the chondral lesion is included in the quadrant method evaluation, grid placement is strongly affected by knee rotation. Unlike the original quadrant method report, in which radiographs were used, ACL tunnel placement is now commonly evaluated using 3D-CT. Using an accurate lateral view knee radiograph, the affect of knee rotation is small. However, determining detailed tunnel position is difficult. In 3D-CT, although the tunnel placement can be clearly detected, the affect of knee rotation has to be considered. Therefore, in 3D-CT evaluation, the quadrant method should be modified, and only the medial wall of the lateral femoral condyle, not including the chondral lesion, should be evaluated.

Farrow et al. stated [3] that the use of an over the top guide for the creation of femoral tunnels in ACL surgery is influenced by the morphology of the Blumensaat's line. In knees with small and large hill type variations (Type 2 in Farrow's classification), it is difficult to identify the transition from the Blumensaat's line to the posterior cortex. When using an over the top guide, these types of knees require a different tunnel position than knees with a straight Blumensaat's line.

Iriuchishima et al. mentioned that in large hill type knees, when the protrusion span was wide and low, the appearance was similar to that of anterior spur [6]. In those knees, the occurrence of graft impingement is feared. As with tunnel misplacement, graft-notch size mismatch and notch shape can be causes of graft roof impingement [15]. Therefore, to prevent graft roof impingement, anatomical evaluation of the intercondylar notch, and accurate grid placement in the quadrant method are essential.

The main limitations of this study were (1) the dissection was performed by macroscopic evaluation only. Although dissection was performed by experienced surgeons, this might allow for human error and bias, (2) the average age of the cadavers used was significantly older than the average age of patients that undergo ACL reconstruction. Even though no specimens had osteoarthritic changes, the ages of the specimens should be considered in such an anatomical study, (3) our sample size was not large ($n=59$). Due to anatomical variation, a study with a larger sample size is needed, (4) the ACL footprint was evaluated using a 2-dimensional technique. The ACL is attached 3-dimensionally to the bone [7] and might be better evaluated with a 3D camera or computer graphics.

For clinical relevance, surgeons should consider the morphological variations of the Blumensaat's line as factors that significantly affect femoral ACL footprint evaluation. Pre-operative evaluation of the anatomical variety of the Blumensaat's line should be performed in order to prevent grid misplacement when using the quadrant method or miscalculations when using an over the top guide in knees with small and large hill type variations.

Conclusion

The center position of the ACL footprint exhibited significant differences according to variations in Blumensaat's line morphology. To increase the accuracy of grid placement in the quadrant method using 3D-CT, hills in the Blumensaat's line should not be regarded, and only the medial wall of the lateral femoral condyle should be evaluated.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interests.

Ethical approval This study was performed in accordance with ethics principles of the Declaration of Helsinki and was conducted with the institutional review boards of Nihon University School of Medicine.

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Informed consent For this type of formal consent is not required.

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