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Blumensaat's line is not always straight: morphological variations of the lateral wall of the femoral intercondylar notch

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Abstract
Purpose The purpose of this study was to evaluate the morphological variations of the lateral wall of the femoral intercondylar notch.
Methods Fifty-two non-paired human cadaver knees were used. All soft tissues around the knee were resected except the ACL. The ACL was cut in the middle, and the femoral bone was cut at the most proximal point of the femoral notch parallel to the plane of the femoral bone shaft. The ACL was carefully dissected, and the periphery of the ACL insertion site was outlined on the femoral side. An accurate lateral view of the femoral condyle was photographed with a digital camera, and the images were downloaded to a personal computer. The morphological variations of Blumensaat's line, the height and area of the lateral wall of the femoral intercondylar notch and the size of the femoral ACL footprints were measured with Image J software.
Results Blumensaat's line exhibited three types of morphological variations. A straight line was observed in 19 knees (37 %) (straight type). A protrusion spanning less than half of the line was observed at the proximal part of Blumensaat's line in 10 knees (19 %) (small hill type). A protrusion spanning more than half of the line was observed at the proximal part of the line in 23 knees (44 %) (large hill type). In some knees with this large hill type variation, the appearance was similar to that of anterior spur. No significant differences between these three types were observed in either the height and area of the lateral wall of the femoral intercondylar notch or the area of the femoral ACL footprint.
Conclusion In conclusion, Blumensaat's line has three types of morphological variations (straight, small hill and large hill types). For the 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 for the use of Quadrant method. The grid placement of Quadrant method would be changed in the knees of these type variations.

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

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

Introduction

Anatomical anterior cruciate ligament (ACL) reconstruction is becoming more popular due to numerous studies reporting its superior ability to restore normal knee function when compared to non-anatomical reconstruction [5, 8, 10, 14, 18, 19, 24, 25, 28, 30, 34]. With the rising frequency of anatomical ACL reconstruction, the anatomy of the ACL is being studied in greater detail [4, 6, 7, 10, 11, 17, 22, 27]. However, reports vary as to the exact anatomy of the ACL [10, 15, 20, 26, 36],

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and the optimal placement of anatomical tunnels in anatomical ACL reconstruction remains unclear.

Accurate evaluation of the ACL footprint and tunnel placement is essential for the success of reproducible anatomical ACL surgery. In the past, the femoral ACL footprint and tunnel placement were calculated using an o'clock method [1, 15, 23]. However, an o'clock evaluation is strongly influenced by knee flexion angle, and it is not widely used currently. The quadrant method was introduced by Bernard and Hertel [1]. This method is currently the most popular femoral ACL footprint and tunnel placement measurement method [11, 13, 17]. In the quadrant method, grid placement on the lateral wall of the femoral intercondylar notch is mainly 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.

Recently, Farrow et al. [3] reported that morphological variations exist in the posterior rim of the intercondylar roof. They classified the postero-lateral rim of the intercondylar roof into two types. Type 1 rims have a defined transition from Blumensaat's line to the posterior cortex, and type 2 rims have an indistinct transition. This study focused only on the posterior structure of Blumensaat's line, but it is likely that Blumensaat's line and the lateral wall of the femoral intercondylar notch also exhibit morphological variations.

To the best of our knowledge, no study has reported the morphological variations of Blumensaat's line and the lateral wall of the femoral intercondylar notch. The purpose of this study was to reveal such variations using cadaveric knees.

The hypothesis of our study was that Blumensaat's line is not always straight and that morphological variations exist based on the size and shape of the lateral wall of the femoral intercondylar notch. Revealing the detailed morphology of Blumensaat's line would make the surgeons possible to prevent the measurement error of femoral ACL anatomy and perform reproducible anatomical ACL surgery.

Materials and methods

Fifty-two non-paired formalin-fixed Japanese cadaveric knees were used (15 males, 37 females, median age 84.5, range 68–97). 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 coloured 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) [21, 24].

Measurement of the lateral wall of the femoral intercondylar notch

With the same images used in the ACL footprint evaluation, the height and area of the lateral wall of the femoral intercondylar notch were measured using Image J software. The morphological variations of Blumensaat's line and the lateral wall of the femoral interdondylar notch were evaluated using the same image.

Statistical analysis

The accuracy of the area and length measurement was less than 0.1 mm^2 [21, 24].

Data are presented as mean ± standard deviations. The average ACL footprint area, and height and area of the lateral wall of the femoral intercondylar notch were compared according to the classifications of the morphology of Blumensaat's line and the lateral wall of the femoral intercondylar notch.

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).

Considering the mean and standard deviations of the notch height, calculated sample size was 41.1. This study has been approved by the ethics committee of Nihon University School of Medicine. The IRB number was 20-14.

Results

Morphological variations of Blumensaat's line

Blumensaat's line exhibited three types of morphological variations. A straight line was observed in 19 knees (37 %)

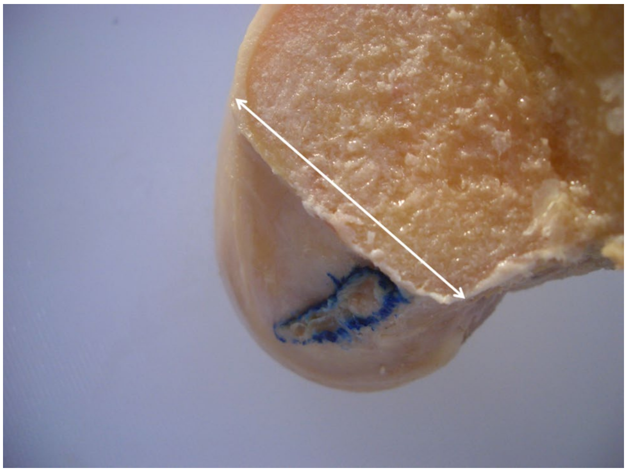

Fig. 1 Straight type. 19 knees (37 %) exhibited straight Blumensaat's line. In these knees, Blumensaat's line (intercondylar roof) appeared more or less straight, and the transition from Blumensaat's line to the posterior cortex was clearly defined

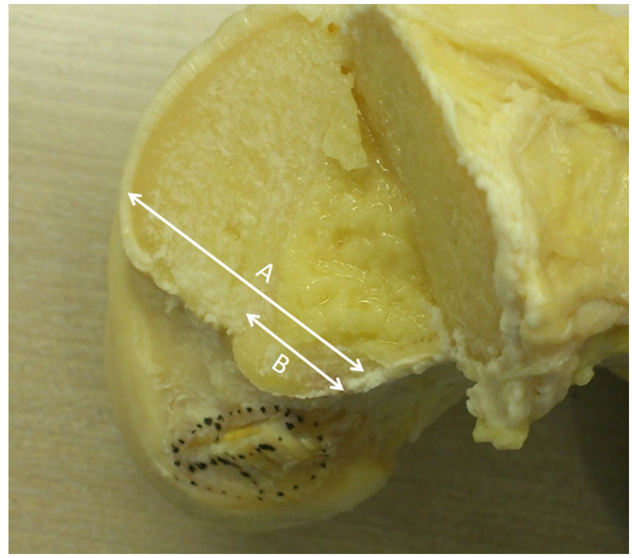

Fig. 2 Small hill type. 10 knees (19 %) exhibited a protrusion at the posterior (proximal) part of Blumensaat's line spanning less than half of the line. The ratio in length of *B*/*A* is <0.5

(straight type: Fig. 1). In these knees, Blumensaat's line (intercondylar roof) appeared more or less straight, and the transition from Blumensaat's line to the posterior cortex was clearly defined. A protrusion spanning less than half of the line was observed at the posterior (proximal) part of Blumensaat's line in 10 knees (19 %) (small hill type: Fig. 2). A protrusion spanning more than half of the line was observed at the proximal part of the line in 23 knees (44 %) (large hill type: Fig. 3). In these knees, only a short anterior section of the line appeared to be straight, and most of the line appeared protruded. In some knees with this large hill type variation, when the protrusion span was wide and low, the appearance was similar to that of anterior spur.

ACL area, height and area of the lateral wall of the femoral intercondylar notch

When the knees were divided according to these three types (straight, small hill and large hill), no significant differences were observed in the height and area of the lateral wall of the femoral intercondylar notch or in the area of the femoral ACL footprint (Table 1).

The height of the lateral wall of the femoral intercondylar notch in the straight, small hill and large hill types was 17 ± 3, 16 ± 2 and 17 ± 3 mm, respectively.

The area of the lateral wall of the femoral intercondylar notch in the straight, small hill and large hill types was 378 ± 81, 390 ± 67 and 411 ± 91 mm^2, respectively.

The femoral ACL footprint area in the straight, small hill and large hill types was 71 ± 25, 72 ± 17 and 72 ± 27 mm^2, respectively.

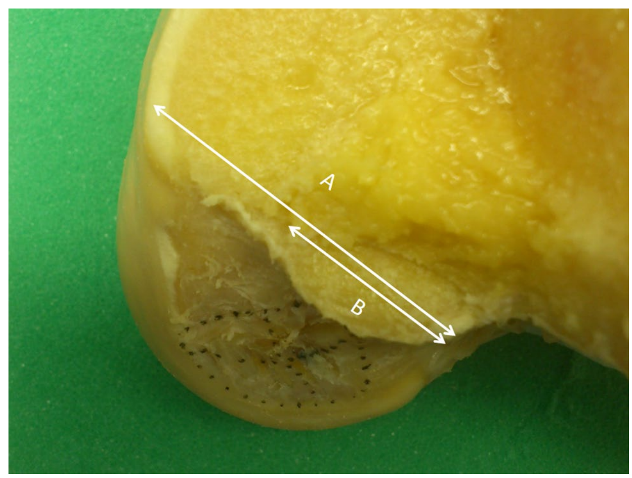

Fig. 3 Large hill type. 23 knees (44 %) exhibited a protrusion at the proximal part of the line spanning more than half of the line. In these knees, only the short anterior part of Blumensaat's line appeared straight, and most of the line appeared protruded. The ratio in length of *B*/*A* is >0.5

Discussion

The most important finding of this study was that the morphology of the lateral wall of the femoral intercondylar notch, especially Blumensaat's line, exhibited variations. Blumensaat's line was not always straight, and both small and large hill type variations were observed. The existence of such small and large hill type variations could affect the measurement accuracy in ACL footprint and tunnel position evaluation when using the quadrant method, and

Table 1 ACL area, height and area of the lateral wall of the femoral intercondylar notch

	Straight	Small hill	Large hill
Height of the notch (mm)	17 ± 3	16 ± 2	17 ± 3
Area of the notch (mm^2)	378 ± 81	390 ± 67	411 ± 91
Area of femoral ACL footprint (mm^2)	71 ± 25	72 ± 17	72 ± 27

When the knees were divided into three types (straight, small hill and large hill), no significant differences were observed in the height and area of the lateral wall of the femoral intercondylar notch, or in the area of the femoral ACL footprint

surgeons should pay close attention when using an over the top guide in ACL reconstruction.

A serious concern for ACL surgeons is graft roof impingement [9, 11]. When the reconstructed ACL graft is misplaced in the knee, the graft is impinged to the intercondylar roof of the femur. It is believed that graft impingement could be the cause of anterior knee pain, knee effusion and loss of range of knee motion. Continuous graft impingement can cause graft deterioration or re-rupture, and finally result in consistent knee instability [11]. Recently, strategies of ACL reconstruction are shifting towards "anatomical" reconstruction. In anatomical ACL reconstruction, the potential risk of graft roof impingement is higher than in non-anatomical reconstruction because the tibial tunnel is placed at a more anterior portion on the tibia [9, 11]. As with tunnel misplacement, graft-notch size mismatch and notch shape can be causes of graft roof impingement [11]. Therefore, to prevent graft roof impingement, anatomical evaluation of the intercondylar notch is essential.

A significant correlation between notch width and ACL size has been reported by several authors [2, 29, 31, 32, 34]. Stijak et al. [29] conducted a cadaveric study and found that ACL width was in positive correlation with the intercondylar notch width in male subjects. In the cadaveric study by Muneta et al. [20], the notch width was correlated with the cross-sectional area of the ACL. Davis et al. [2] also reported that the width of mid-substance ACL had a significant correlation with the notch width. Previously, the outlet morphology of the intercondylar notch has been the main focus of many studies [2, 29, 31]. Notch width and notch width index can also be considered in morphological evaluations of the outlet [2, 29]. However, regarding the sagittal plane of the intercondylar notch, although the angle of the intercondylar roof has been evaluated [26, 29], morphological variations have not been well investigated.

This study revealed that Blumensaat's line exhibits the following morphological variations: straight type, small hill type and large hill type. In the human body, the existence of a straight line is rare. However, since its original identification and description, Blumensaat's line has always been considered a straight line [1, 12, 16, 29]. In the evaluation of ACL femoral footprint and tunnel position, the quadrant method is widely used [1]. In the quadrant method, Blumensaat's line determines the base line of the grid. In the original study documenting this method, Blumensaat's line was regarded as completely straight line [1]. As revealed in this study, Blumensaat's line is not always straight, and the existence of small or large hill type variations affects the accuracy of grid placement when using the quadrant method. For effective reproducible anatomical surgery, these morphological variations should be considered when surgeons use the quadrant method. Considering the results of this study, how to place the grid of quadrant method in the small and large hill types of the knees should be discussed in the future plans.

Farrow et al. [3] stated that the use of an over the top guide for the creation of femoral tunnels in ACL surgery would be influenced by the morphology of 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 Blumensaat's line to the posterior cortex. When using an over the top guide, these types of knees would require a different tunnel position than knees with straight Blumensaat's line.

The main limitations of this study were as follows: (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 severe osteoarthritic changes, the ages of the specimens should be considered in such an anatomical study. (3) Our sample size was not large ($n = 52$). Due to anatomical variation, a study with a larger sample size is needed. (4) The ACL footprint was evaluated with a two-dimensional technique. The ACL is attached three-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 lateral wall of the femoral intercondylar notch, especially that of Blumensaat's line. Using a lateral radiographic or 3D CT view of the knee, preoperative evaluation of anatomical variety 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

In conclusion, Blumensaat's line is not always straight and often exhibits small and large hill type variations. The area of the femoral ACL footprint, and the area and height of the lateral wall of the femoral intercondylar notch show no correlation with these morphological variations.

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