**Inclination for Blumensaat's Line Influences on the Accuracy of the Quadrant Method in Evaluation for Anterior Cruciate Ligament Reconstruction**

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**Abstract**

**Purpose**

The quadrant method is used to evaluate the bone tunnel position with the grid based on the Blumensaat's line in anterior cruciate ligament (ACL) reconstruction. This study aimed to clarify the influence of variation in the Blumensaat's line on the accuracy of the quadrant method measurements.

**Methods**

A retrospective review of radiologic records of patients aged 18–30 years who underwent computed tomography (CT) scanning of the knee joint was conducted. The Blumensaat's line inclination angle (BIA), along with the most posterior point of the posterior condyle (point P) position using the quadrant method, and morphology of the Blumensaat's line were measured on true lateral transparent three-dimensional CT images of the distal femoral condyle in 147 patients. Statistical analysis was conducted to determine associations among these measurements.

**Results**

BIA was 37.5° (Standard deviation, 4.2°; range, 27°–48°). The point P position was significantly correlated with BIA in the high/low ($R^2$ = 0.590, $P$ < 0.0001) and deep/shallow ($R^2$ = 0.461, $P$ < 0.0001) directions. The morphology of the Blumensaat's line was straight in 35 knees (23.8%), whereas the remaining 112 knees (76.2%) were not straight but had some hill on the Blumensaat's line. No significant difference among the morphologic variation of the Blumensaat's line was observed in BIA and the point P position.

**Conclusion**

There was a strong correlation between BIA and the point P measured using the quadrant

method, suggesting the influence of the Blumensaat's line on the accuracy of the Quadrant method measurements in ACL reconstruction. As for the clinical relevance, surgeons should be careful in application the Quadrant method for ACL reconstruction, because the variation of the Blumensaat's line inclination influences the accuracy of this method.

## Introduction

Femoral tunnel position is an important factor to achieve success in anterior cruciate ligament (ACL) reconstruction because an inadequate tunnel position results in knee instability [18, 22, 37], poor clinical outcomes [15, 26, 31], and graft failure [24] postoperatively. Radiologic evaluations have been performed to evaluate postoperative tunnel position [11, 18, 20, 25]. The quadrant method of Bernard et al. [4, 5] is the most widely used radiologic method for evaluating femoral tunnel position [9, 10, 16, 17]. With this quadrant method, tunnel position has been evaluated using the grid based on the Blumensaat's line [4, 5], which appears as a faint condensed line on the lateral radiograph of the knee joint in the condylar massif of the femur [14]. It represents the tangentially hit part of the intercondylar roof [14]. However, the inclination of the Blumensaat's line varies [2, 3, 6, 7, 27, 28]. Moreover, in their cadaveric study on the morphology of the Blumensaat's line, Iriuchishima et al. [13] reported three types of morphologic variations in the sagittal plane, namely, straight, small hill, and large hill, and that most of the Blumensaat's line was not straight but rather had a hill. These study results indicated that the Blumensaat's line, upon which the quadrant method is based, varies considerably as to the inclination and morphology. Yahagi et al. [34] reported that the center position of the ACL footprint exhibits significant differences according to the quadrant grid placement. However, whether and how variations in the Blumensaat's line influence the quadrant method remains unclear.

Recently, several studies on the quadrant method have used three-dimensional computed tomography (3D-CT) [10, 16, 19, 26, 30, 32, 37]. However, few reports have supported the validity of the quadrant method using 3D-CT [16]. In addition, arthroscopic and magnetic resonance imaging (MRI) studies have shown that the intercondylar roof shape in the axial plane is not always symmetric [1, 6, 33]. Therefore, these studies indicated that conventional 3D-CT of the lateral half of the distal femoral condyle does not provide the Blumensaat's line.

Transparent 3D-CT (T-3DCT) is a volume-rendering protocol of CT images. Inoue et al.[12] have described the usefulness of this protocol for the precise evaluation of femoral bone tunnel position in ACL reconstruction. Briefly, by condensing the CT value, the outline of the bone remains, while the remainder of the bone is transparent [12]. Consequently, T-3DCT can provide clear observation of the bony outline and can regulate femoral condyle rotation by overlapping the posterior femoral condyle using a workstation [12]. The lateral distal femur image developed by T-3DCT was approximated to the true lateral view described by Cole et al. [8] Using this image, the Blumensaat's line morphology could be precisely evaluated in the present study.

This study aimed to clarify the influence of variation in the Blumensaat's line on the accuracy of the quadrant method using T-3DCT. It was hypothesized that variations in the Blumensaat's line affect the accuracy of the quadrant method. To the best of our knowledge, this is the first T-3DCT study to investigate the influence of the inclination and morphology of the Blumensaat's line on the accuracy of the quadrant method in ACL reconstruction.

## Materials and Methods

This clinical study was performed in ####### Hospital. Institutional review board (IRB) approval of Hokkaido University Hospital was received for this study (IRB number, 017-063).

Hospital records, including preoperative CT images of 412 consecutive patients who underwent knee surgery between 2009 and 2015 at our institution were reviewed. The inclusion criterion for this investigation was a patient aged 18–30 years old at the time of CT scanning (161 knees met the inclusion criterion). Exclusion criteria included a history of knee surgery or intra-articular knee fracture and radiographic evidence of degenerative arthritis. In patients who underwent bilateral knee surgery, only one side was used for this investigation, leaving 147 knees at the time of scanning (91 males, 56 females; 140 patients with ACL rupture, 7 with other ligamentous knee trauma; mean age, 23 years; range, 18–30 years; Fig. 1).

**Radiographic Technique and Interpretation**

Using the T-3DCT protocol described previously [12], the true lateral T-3DCT image of the distal femoral third, which was equivalent to the true lateral radiograph described by Cole et al. [8], was used. CT images were obtained using the Light Speed Ultra (8Das) Helical scan (GE, Milwaukee, WI, USA). A workstation ZIO M900 Quadra (Ziosoft, Inc., Tokyo, Japan) was used to create the T-3DCT images of the distal femur (Fig. 2A) according to the following steps: (1) select the whole distal femoral bone, including the cortex and cancellous bones; (2) create an image with 4 pixels smaller than the whole distal femur on a 2D view monitor, and (3) subtract the 4 pixels smaller image of the distal femur from the whole distal femur. Then, the axis of the distal femur of the lateral T-3DCT image was horizontally set. By controlling adduction–abduction and internal–external rotation and strictly overlapping the medial and lateral femoral condyles, the true lateral T-3DCT image was acquired (Fig. 2B).

In this study, the Blumensaat's line was defined as the most distal edge of the intercondylar roof at the true lateral T-3DCT image of the distal femoral condyle and a reference line for the quadrant method as a linear line tangent to the Blumensaat's line [10]. The inclination of the Blumensaat's line was defined as the Blumensaat's line angle (BIA) between a linear line tangent to the Blumensaat's line and the axis of the distal femoral third because the axis of the distal femoral third is the anatomical axis of the distal femur in the sagittal plane [23]. The anatomical axis of the distal femur was defined as a line connecting the middle points of the distal femur at 5 and 10 cm proximal from the distal articular surface. The most posterior point of the posterior condyle (point P; the point tangent to the posterior condyle and line parallel to the anatomical axis of the distal femur) [23] was chosen as the anatomical reference point at the lateral wall of the femoral intercondylar notch instead of the femoral bone tunnel (Fig. 3).

The following three measurements were made from each true lateral T-3DCT image: (1) BIA, (2) the point P position measured using the quadrant method, and (3) the morphology of the Blumensaat's line divided to three types, namely, straight, small hill, and large hill, according to the classification described by Iriuchishima et al. [13] (Fig. 4). The results of BIA and the point P position were reported to be one decimal.

All true lateral T-3DCT images created by a radiologist (K.T.) were evaluated in a blinded manner by two observers (K.I. and M.I.). Each examiner measured the same set of blinded T-3DCT images after 4 weeks. The averages of these measurements were used in our analysis.

In 50 randomized selected patients, at two separate time points, the following were independently measured: (1) the BIA of the same patient image created by two radiologists (K.T., H.K.) evaluated by the main observer (K.I.) to assess the radiologist reproducibility of creating the true lateral T-3DCT images, (2) BIA of the images created by a radiologist (K.T.) evaluated by the two observers (K.I., M.I.) to assess the reliability of measured BIA, (3) the point P position of the images created by a radiologist (K.T.) evaluated by the two observers to assess the reliability of the point P position measured using the quadrant method, and (4) the morphology of the

Blumensaat’s line of the images created by a radiologist (K.T.) evaluated by the two observers to assess the reliability of the morphology of the Blumensaat’s line using the Iriuchishima classification.

**Statistical Analysis**

Statistical analyses were conducted using JMP Pro 13 (SAS Institute, Inc., Cary, NC, USA). $P < 0.05$ was considered statistically significant. Data were presented as the mean (standard deviation [SD]). The Shapiro–Wilk test was used to check the normality of the BIA distribution. Intraclass correlation coefficients (ICCs) were calculated to determine the radiologist reproducibility of creating the true lateral T-3DCT image, intra and interobserver reliability in BIA, point P position measured using the quadrant method, and morphology of the Blumensaat's line. Pearson correlational analysis was conducted on comparisons of BIA and the point P position measured using the quadrant method. One-way analysis of variance was used to test for significant changes in BIA or the point P position among the three morphologic variations of the Blumensaat’s line. A sample size calculation was not performed because the patient data were retrospectively collected. The study period was 6 years, and the subjects that met the inclusion criteria were selected from the hospital records.

**Result**

BIA was 37.5° (4.2°; range, 27.0°–48.0°). The distribution of BIA over all knees is shown in Figure 5. BIA for all knees was normally distributed (n.s.).

The mean point P position evaluated using the quadrant method was at 81.8% (4.4%) in high/low and 14.3% (3.2%) in deep/shallow directions. Representative images of small and large BIA cases evaluated using the quadrant method are shown in Figure 6. There was a strong correlation between BIA and the point P position in these two directions (Fig. 7).

Regarding the morphology of the Blumensaat's line, straight, small hill, and large hill types ware observed in 35 (23.8%), 27 (18.4%), and 85 (57.8%) knees, respectively, and BIA was 36.9° (3.5°), 38.3° (4.2°), and 37.5° (4.5°), respectively. There was no significant difference in BIA among the three groups. The point P positions were 81.8% (4.4%), 82.0% (4.1%), and 82.0 (4.7%), respectively, in the high/low direction and 13.7% (3.0%), 13.5% (3.1%), and 14.8% (0.10%), respectively, in the deep/shallow direction. There was no significant difference in the point P position in either direction among the three morphologic groups (Table 1).

The ICC indexes of the radiologist reproducibility of creating the true lateral T-3DCT image, observer reliability in BIA, and point P position measured using the quadrant method were above 0.85 (Table 2).

**Discussion**

The most important finding of the present study was that the intersubject variation of BIA affected the point P position measured using the quadrant method. The comparison of bone tunnel positions measured using the quadrant method might be unreliable between the knees, when BIA of both the knees is quite different.

BIA has been assessed using various modalities (Table 2) [3, 6, 7, 28]. Previous studies obtained BIA of 35°–38° using lateral plain radiograph or CT and of 43°–44° using MRI [6]. In the present study, BIA was 37.5° using the true lateral T-3DCT image, which is similar to the result obtained in previous studies using lateral plain radiographs or CT [3, 7, 28]. However, it is considerably varied from that obtained in the study using MRI [6], which might be because lateral plain radiograph, CT, and T-3DCT could control distal femoral condyle rotation and views a tangentially hit part of the intercondylar roof, whereas MRI could not control the distal femoral condyle rotation and shows only one slice of the intercondylar roof along a specific sagittal plane. Regarding the variation in BIA, the SD of BIA was 4.2°, which is similar to the result obtained in studies using plain radiograph or CT (range, 4.76°–5.3°; Table 2)[3, 7, 28].

In the present study, a strong negative correlation was found between BIA and the point P position evaluated using the quadrant method in the high/low ($R^2$ = 0.590, $P$ < 0.0001) and deep/shallow ($R^2$ = 0.461, $P$ < 0.0001) directions. The negative correlation between BIA and the point P position suggested that variations in BIA caused the error of evaluation of the bone tunnel position using the quadrant method. Assuming the result of regression analysis of correlation between BIA and the point P position evaluated using the quadrant method ($Y = -0.7952*X + 111.7$ in high/low and $Y = -0.5212*X + 33.86$ in deep/shallow directions) and BIA [37.5° (4.3°)] quantified in the present study, the point P position evaluated using the quadrant method showed a 6.8% and 4.5% difference in these two directions, respectively, However, the difference in BIA was 8.6° (±1 SD of the mean), indicating that the difference in the point P position was 1.7, 2.3, and 2.6 mm in the high/low, deep/shallow, and total craniocaudal directions, respectively, in the normal size of the condyle [29]. The quadrant method was used not only to evaluate the postoperative femoral bone tunnel position but also to assist in intraoperative decision-making regarding femoral bone tunnel placement under fluoroscopy [21]. A previous biomechanical study reported that small changes (3 mm) in the femoral attachment site of the ACL had significant effects on laxity and tension patterns [38]. Therefore, a 2.6-mm difference in the femoral tunnel position was not considered as small in ACL reconstruction, although the point P position was not known as a femoral bone tunnel position.

The quadrant method was reported by Bernard et al. in the 1990s [4, 5]. Although in the original method, the quadrant method used a simple lateral knee plain radiograph (2D image) to draw the Blumensaat's line and evaluate the femoral tunnel position measurement, recent studies have commonly applied the quadrant method for 3D-CT images and cadaveric knees. However, there was no definition for the Blumensaat's line on the 3D-CT image. Most studies using 3D-CT for the quadrant method described it as only the quadrant method described by Bernard et al., and did not precisely describe the Blumensaat's line as the reference line for the quadrant method grid. Forsythe et al. [10] reported that the grid is aligned with the Blumensaat's line on radiographs, which is a projection of the intercondylar roof on the radiograph; however, no such line exists on a 3D-CT mode [10]. In their cadaveric study, Iriuchishima et al. [13] stated that the Blumensaat's line is not always straight. The present study using T-3DCT revealed that a straight type was present in only one-fourth of the Blumensaat's line, whereas the remaining three-fourths had a hill at the Blumensaat's line. Forsyth et al. [10] used the most anterior edge of the femoral notch roof as the reference for grid alignment. Kim et al.[16] used the median of the most superior and inferior points of the Blumensaat's line on a simple lateral radiograph; however, there was no description regarding the Blumensaat's line on the 3D-CT image [16]. In the present study, a linear line tangent to the Blumensaat's line was used for the reference of the grid alignment, which was the same as the method described by Forsyth et al.[10] Although the result showed that BIA varied considerably, there was no significant difference in BIA among the morphologic Blumensaat's line types, and the ICC in BIA was high, indicating that a linear line tangent to the Blumensaat's line is easy and reproducible and, thus, acceptable for a reference line of the grid alignment for the quadrant method.

There are several limitations of this study. First, most patients had an ACL injury (140/147 knees); therefore, there were no normal controls. This may be attributed to the inclusion criterion of aged 18–30 years. Some studies had concerns regarding the relationship between BIA and ACL rupture. A study on skeletally immature patients demonstrated that a decreased BIA was associated with ACL rupture and that increased BIA was associated with tibial spine fracture [27]. However, a large study on adolescent patients reported no relationship between BIA and ACL rupture [6]. This finding suggested that there is no consensus on the relationship between ACL rupture and BIA variation. Second, the point P position might be influenced by the femoral sagittal axis. However, by limiting patients to those aged <30 years in this study, the variation in the femoral sagittal axis in this population was considered to be small. Third, point P was chosen as an anatomical reference point at the lateral wall of the femoral intercondylar notch. An anatomical reference point was thought necessary to assess the influence of variation in the Blumensaat's line on the evaluation of the tunnel position using the quadrant method. The actual tunnel position itself was not suitable for this reference point because the tunnel position might be influenced by surgeons; however, the point P position evaluated using the quadrant method was not influenced by surgeons. Moreover, point P itself was a reference point for aiming tunnel position [35, 36] and was, therefore, considered suitable as an anatomical reference point at the lateral wall of the femoral intercondylar notch in this study. Fourth, some measure bias existed in BIA and the point P position. Measure bias was difficult to eliminate because a true value for actual true lateral image did not exist. However, analysis for radiologist reproducibility and intra and interobserver reliability showed comparatively high reproducibility and reliability. This could secure the reliability of BIA and the point P position measured using the quadrant method. Although this study included these limitations, the results still reveal the influence that variation in BIA has on the accuracy of the quadrant method. In addition, the results reported the relationship between variation in BIA and the quadrant method measurement.

We discussed the clinical relevance of this study. This study showed that the inclination of the Blumensaat's line, which were different among patients, significantly influenced the results measured with the Quadrant method. First, although many studies reported the averaged bone tunnel location data for ACL reconstruction using the Quadrant method [10.11.19.20.21], surgeons should recognize that the location data might be influenced by the variation of the Blumensaat's line inclination. Secondly, when surgeons create a bone tunnel in ACL reconstruction at a point measured with the Quadrant method, the created tunnel location may be different among patients. Thirdly, in postoperative evaluation of the tunnel location after ACL reconstruction, surgeons cannot compare the locations with the Quadrant method among patients having a different Blumensaat's line inclination. Thus, this study suggested that surgeons should be careful in application of the Quadrant method to ACL reconstruction, because the variation of the Blumensaat's line inclination influences the accuracy of this method.

## Conclusion

There was a strong correlation between BIA and the point P measured using the quadrant method, suggesting the influence of the Blumensaat's line on the accuracy of the quadrant method measurements in ACL reconstruction. For clinical relevance, surgeons should be careful in application of the Quadrant method for ACL reconstruction, because the variation of the Blumensaat's line inclination influences the accuracy of this method.


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## Authors' contribution

KI collected the data, made the analysis, and drafted the work. MI conducted this study, supervised the data analysis, and completed the draft. YK supported the data collection. KT, and HK contributed to taking special CT images. IY advised the statistical analysis. EK, NI, and KY interpreted the data and revised the draft critically.

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**Fig. 1.** Flow chart of included and excluded patients

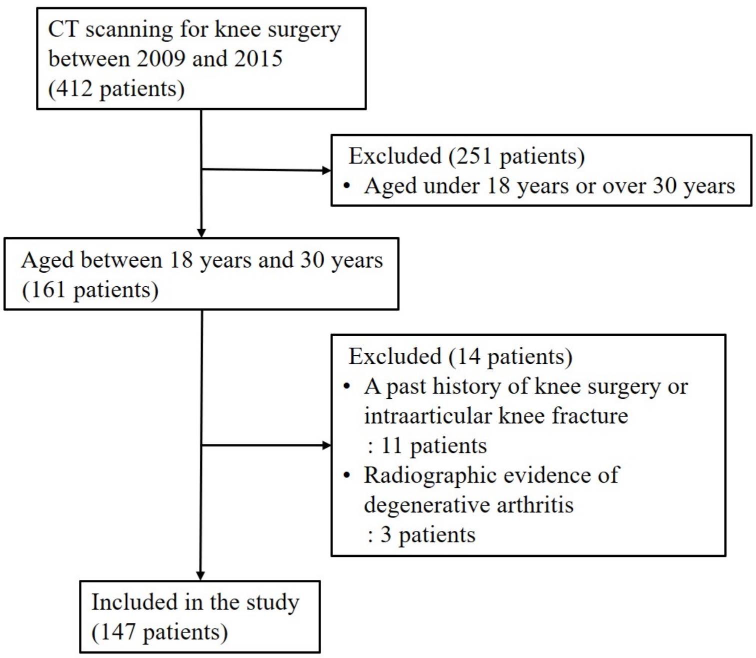


**Fig. 2.** Steps for creating the true lateral T-3DCT image (**A**) *Red area* on 2D view is the selected area on the workstation. *Left* shows 2D axial image. *Center* shows 2D sagittal image. *Right* shows 3D image. (**a**) The whole distal femur including the cortical and cancellous bones. (**b**) The image is 4 pixels smaller than the whole distal femur. (**c**) T-3DCT image generated by subtracting 4 pixels smaller image from the whole distal femur image. (**B**) True lateral T-3DCT is created by controlling a lateral T-3DCT in adduction–abduction and internal–external rotation and by strictly overlapping the medial and lateral femoral condyles. (**a**) 5° internal rotation, (**b**) 5° abduction, (**c**) true lateral, (**d**) 5° adduction, (**e**) 5° external rotation. T-3DCT, transparent three-dimensional computed tomography

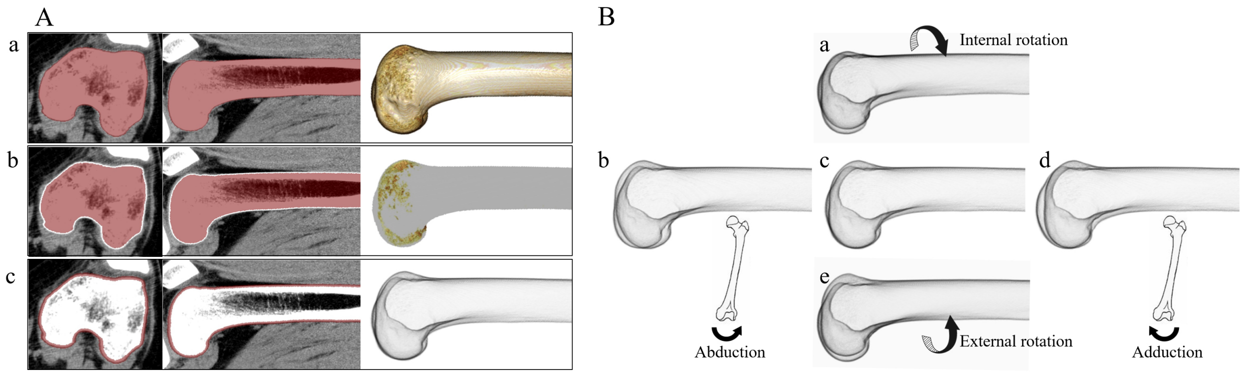


**Fig. 3.** True lateral T-3DCT images of the distal femoral condyle are created by strictly overlapping the posterior condyle of the medial and lateral femoral condyles. BIA (α) is measured between the anatomical long axis of the distal femur (**a**) and a linear line tangent to the Blumensaat's line (**b**). The anatomical long axis of the distal femur is defined as a line connecting the middle points of the distal femur at 5 and 10 cm proximal from the distal articular surface. Point P is a point tangent to the posterior condyle and the line parallel to the anatomical long axis of the distal femur (**a´**). T-3DCT, transparent three-dimensional computed tomography; BIA, Blumensaat's line inclination angle; Point P, the most posterior point of the posterior condyle

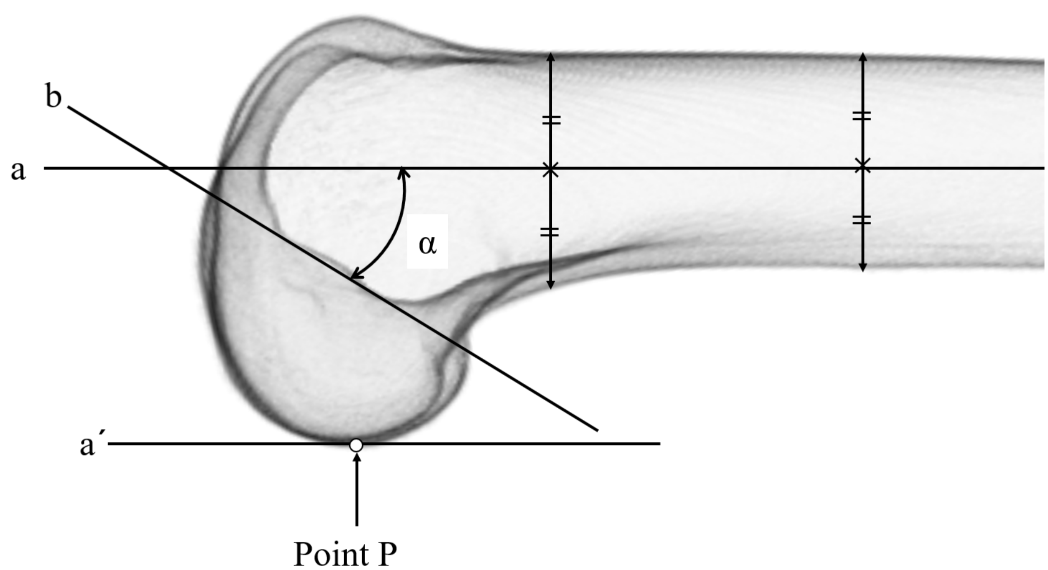

**Fig. 4.** Representative T-3DCT images of the Iriuchishima's classification [13] of the morphology of the Blumensaat's line. (**A**) Straight type. (**B**) Small hill type. (**C**) Large hill type. T-3DCT, transparent three-dimensional computed tomography

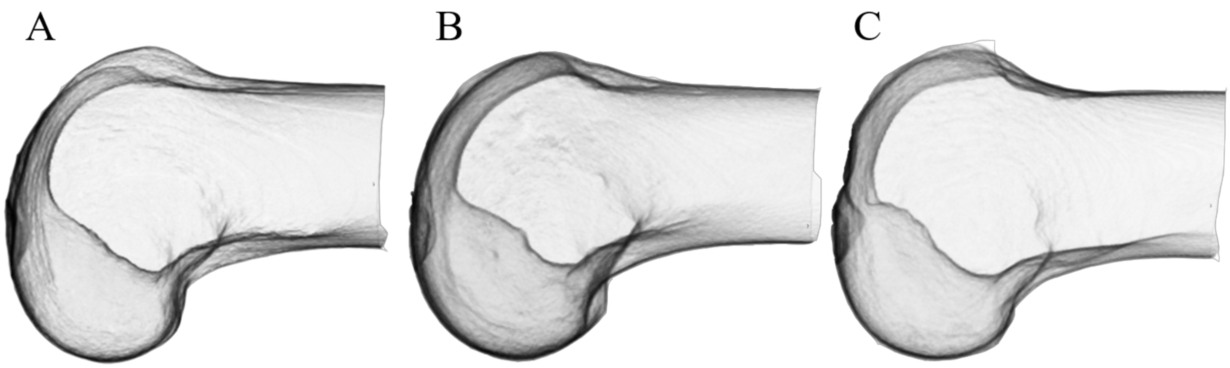


**Fig. 5.** Histogram showing the distribution of BIA of the knees. BIA, Blumensaat's line inclination angle

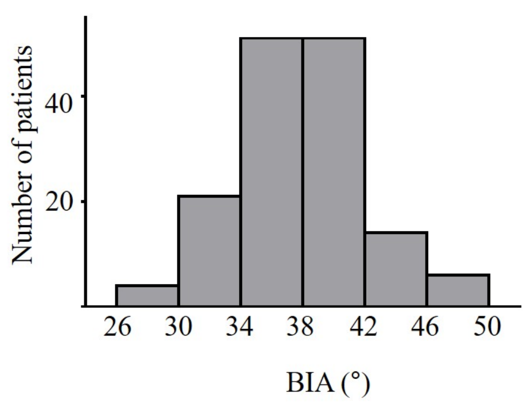


**Fig. 6.** Representative true lateral T-3DCT images evaluated using the quadrant method in small and large BIA cases**.** (**A**) BIA is 31°. The point P position is 83.3% and 20.7% in the high/low and deep/shallow directions, respectively. (**B**) BIA is 44°. The point P position is 75.5% and 13.5% in both directions, respectively. *White dot* is point P. T-3DCT, transparent three-dimensional computed tomography; BIA, Blumensaat's line inclination angle; Point P, the most posterior point

of the posterior condyle

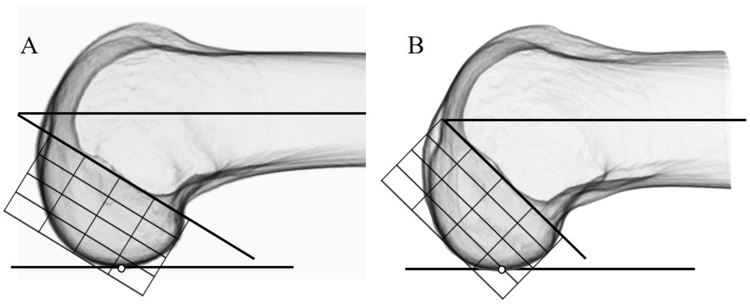


**Fig. 7.** Relationship between BIA and the point P position using the quadrant method. (**A**) BIA and the point P position in the high/low direction: Pearson correlation analysis showing a significant negative correlation between BIA and the point P position in the high/low direction (Pearson $r$ = −0.77; $P$ < 0.0001, $n$ = 147). *Line* represents linear regression of data ($y = -0.8x + 111.7$; $R^2$ = 0.59). (**B**) BIA and the point P position in the deep/shallow direction: Pearson correlation analysis shows a significant negative correlation between BIA and the point P position in the deep/shallow direction (Pearson $r$ = −0.68; $P$ < 0.0001, $n$ = 147). *Line* represents linear regression of data ($y = -0.52x + 33.9$; $R^2$ = 0.46). BIA, Blumensaat's line inclination angle; Point P, the most posterior point of the posterior condyle

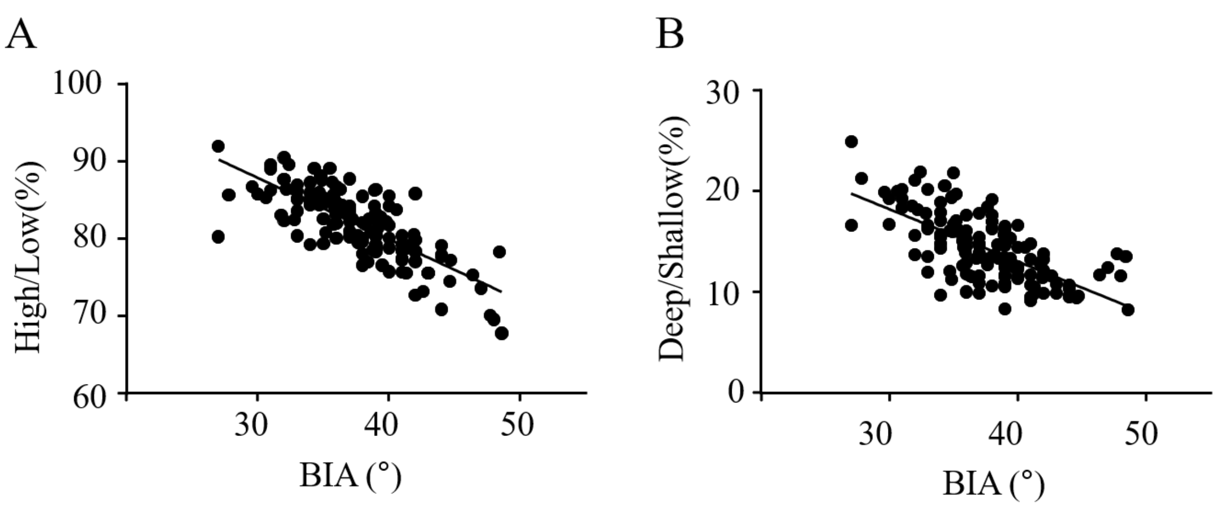


**Table 1.** BIA and the point P position in the Iriuchishima's classification[13] of the morphology

of the Blumensaat's line

| | All | Straight type | Small hill type | Large hill type | *P* value |
|---|---|---|---|---|---|
| Number of cases | | 35 (23.8%) | 27 (18.4%) | 85 (57.8%) | |
| BIA **(°)** | 37.5 (4.2) | 36.9 (3.5) | 38.3 (4.2) | 37.5 (4.5) | n.s |
| Point P position (%) | | | | | |
| High/low | 81.8 (4.4) | 82.0 (4.1) | 81.5 (4.0) | 82.0 (4.7) | n.s |
| Deep/shallow | 14.3 (3.2) | 13.7 (3.0) | 13.5 (3.1) | 14.8 (3.3) | n.s |

BIA, Blumensaat's line inclination angle; Point P, the most posterior point of the posterior condyle; n.s., not significant

**Table 2.** Analysis of the reproducibility of T-3DCT and reliability of BIA and the point P position measured using the quadrant method

BIA, Blumensaat's line inclination angle; Point P, the most posterior point of the posterior condyle; T-3DCT, transparent three-dimensional computed tomography; X, co-ordinate point in the deep/shallow direction; Y, co-ordinate point in the high/low direction.

| | | Intraclass Correlation Coefficient | |
|---|---|---|---|
| Reproducibility of true lateral T-3DCT creation | Intracreator | 0.95 | |
| | Intercreator | 0.94 | |
| Reliability of BIA measurement | Intraobserver | 0.91 | |
| | Interobserver | 0.91 | |
| Reliability of point P position measurement | | X | Y |
| | Intraobserver | 0.90 | 0.89 |
| | Interobserver | 0.89 | 0.88 |
| Reliability of the morphology of the Blumensaat's line | Intraobserver | 0.91 | |

| | |
|---|---|
| Interobserver | 0.87 |

**Table 3.** Summary of studies investigating the Blumensaat's line inclination angle

| Study (Year) | Modality | Rotation controlled? | BIA **(°)** |
|---|---|---|---|
| Buzzi et al.[7] (1999) | Plain radiograph | Yes | 37.3 (5.3) in normal knees<br>37.6 (5.0) in ACL-deficient knees |
| Scheffel et al.[28] (2013) | Plain radiograph | Yes | 34.7 (5.2; range, 23–48) |
| Anderson et al. [3] (1987) | CT | Yes | 38 (4.76) |
| Bouras et al.[6] (2017) | MRI | No | 43 (4) in normal knees<br>44 (3) in ACL-deficient knees |
| Current study | T-3DCT | Yes | 37.5 (4.2; range, 27–48) |

ACL, anterior cruciate ligament; CT, computed tomography; MRI, magnet resonance imaging; T-3DCT, transparent three-dimensional computed tomography.