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Coronal shaft bowing of the femur affects varus inclination of the surgical transepicondylar axis in varus knee osteoarthritis

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Abstract

Purpose This study investigated the relationship between femoral shaft bowing and the orientation of the surgical transepicondylar axis (TEA) in the coronal plane in varus knee osteoarthritis (OA).

Methods A total of 82 knees scheduled to undergo total knee arthroplasty (TKA) for the treatment of varus knee OA were enrolled. The hip–knee-ankle angle (HKA) was measured preoperatively on anteroposterior whole-leg standing radiographs. The lateral angle between the TEA and the mechanical axis of the femur (MA-TEA) was measured in the coronal plane from preoperative computed tomography (CT) images. Femoral shaft bowing was measured on CT images. Pearson's correlation coefficient was used to examine the correlation of the MA-TEA with the HKA and femoral shaft bowing.

Results The MA-TEA correlated negatively with the HKA ($r = -0.321$, $P < 0.01$) and positively with femoral shaft bowing ($r = 0.415$, $P < 0.01$).

Conclusions The TEA changed to varus as femoral shaft bowing increased in patients with varus knee OA. This suggests that the TEA is not always the centre of the rotational axis of the femur after TKA. In addition, the TEA may not be useful as a consistent parameter in the coronal plane in patients with increasing femoral shaft bowing.

Level of evidence III.

Keywords Femoral shaft bowing · Surgical transepicondylar axis · Varus knee osteoarthritis · Computed tomography · Frontal and sagittal plane · Total knee arthroplasty

Abbreviations

TEA	Transepicondylar axis
TKA	Total knee arthroplasty
OA	Osteoarthritis
CT	Computed tomography
HKA	Hip–knee-ankle angle
ICCs	Intraclass correlation coefficients

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Introduction

The surgical transepicondylar axis (TEA) is a reliable reference in the axial plane for cutting the posterior condyle and rotating the femoral component in total knee arthroplasty (TKA). The axis is defined as the line through the sulcus of the medial epicondyle and the eminence of the lateral epicondyle [2]. The TEA represents an estimation of the functional flexion–extension axis of the knee [5].

The TEA is perpendicular to the mechanical axis of the femur in the coronal plane [3, 8]. One study indicated that this relationship could be generalized to patients with knee osteoarthritis (OA) [6]. On the other hand, another study demonstrated that the lateral angle between the TEA and the mechanical axis of the femur in the coronal plane was larger in varus knee OA than in non-varus knee OA [14]. These results seem to be controversial, and the factors affecting the orientation of the TEA in the coronal plane were unclear in previous studies.

Coronal and sagittal bowing of the femoral shaft is often seen in Asian patients with knee OA [1, 9–11, 13]. The femoral intramedullary guide angle is influenced by femoral shaft bowing in TKA [4, 12]. Femoral shaft bowing has been reported as the likely cause of inaccuracies in postoperative lower limb alignment and the femoral component angle [7]. The TEA is an useful landmark for predicting an appropriate orientation of the femoral component in the coronal plane when it is perpendicular to the mechanical axis of the femur. For example, the TEA plays an important role in patients with large bone defects or revision TKAs since the availability of the original anatomical landmarks is limited. However, the TEA may not always be perpendicular to the mechanical axis of the femur in patients with increasing femoral shaft bowing. The effect of femoral shaft bowing on the orientation of the TEA in the coronal plane has not been evaluated in previous studies. The purpose of this study was to investigate the relationship between femoral shaft bowing and the orientation of the TEA with respect to the mechanical axis of the femur in the coronal plane in patients with varus knee OA. It was hypothesized that the orientation of the TEA would change to varus and might not be useful as a consistent parameter in the coronal plane in knees with increasing femoral shaft bowing.

Materials and methods

This study was approved by the ethics committee of our hospital (B190700006), and informed consent was obtained from each patient.

Sixty-nine patients (96 knees) were scheduled to undergo TKA from June 2011 to August 2013. Anteroposterior radiographs and computed tomography (CT) images of the whole leg were preoperatively obtained for surgical planning. Radiographs were performed in a one-leg standing position, with the knee in full extension. The X-ray beam was centered on the knee with the patella facing forward. Patients with osteonecrosis of the knee (1 knee), rheumatoid arthritis (7 knees), valgus knee (5 knees) or previous surgical treatment of the lower limbs (1 knee; previous surgery for hip fracture) were excluded. Thus, 57 patients with varus knee OA (82 knees) met the inclusion criteria in the present study. The patients' demographic data are shown in Table 1.

Measurement of lower limb alignment

The hip–knee-ankle angle (HKA) was measured using Fujifilm OP-A software (Fujifilm, Tokyo, Japan) on anteroposterior whole-leg standing radiographs. The HKA was defined as the angle between the mechanical axes of the femur and tibia, with positive values representing valgus alignment.

Table 1 Patients' demographic characteristics

Knees, *n*	82
Age, years	74.3 ± 8.0 (52–87)
Height, cm	151.3 ± 7.5 (137.5–171.0)
Weight, kg	59.3 ± 11.1 (39.0–87.2)
Body mass index, kg/m^2	25.9 ± 4.2 (14.6–40.6)
Side, left/right	41/41
Sex, male/female	7/75
Ahlbäck grade	Grade 1, 1; Grade 2, 5; Grade 3, 52; Grade 4, 24

Data are presented as the means ± standard deviations with range in parentheses

Measurements of femoral shaft bowing and angle between mechanical axis of the femur and surgical transepicondylar axis

Whole-leg CT images (1.5-mm thick slices) were obtained with patients lying supine in a SOMATOM Sensation 16 CT system (Siemens, Munich, Germany). Data were incorporated into Orthomap 3D (Stryker, Kalamazoo, MI), enabling the selection of anatomical landmarks and the determination of 3-dimensional linear and angular measurements by simultaneously referring to the sagittal, coronal, and axial planes [6]. The *Y*-axis was defined as the line through the centre of the femoral head and the most proximal point of the femoral notch. The *X*-axis was defined as a line perpendicular to the *Y*-axis. The *XY* plane was created to include the TEA. The *Z*-axis was defined as the cross-product of the *X*- and *Y*-axes. The lateral angle between the TEA and the mechanical axis of the femur (MA-TEA) was measured on the *XY* plane (Fig. 1). According to previous studies [1, 13], the femoral diaphysis was divided into four equal parts on the reconstructed CT. Femoral shaft bowing was defined according to the angle between the axes of the first and fourth segments of the femoral shaft on the *XY* plane (Fig. 2); a positive value represented lateral bowing. In addition, the lateral angle between the midline in the fourth segment of the femoral shaft and the TEA (Distal-TEA) was measured on the *XY* plane (Fig. 3).

Statistical analysis

Data are shown as the means ± standard deviations and were confirmed to show a normal distribution using the Shapiro–Wilk test. Pearson's correlation coefficient was used to examine the correlation between the HKA, femoral shaft bowing, or Distal-TEA, and the MA-TEA and the correlation between femoral shaft bowing and Distal-TEA. All statistical analyses were performed using SPSS (IBM

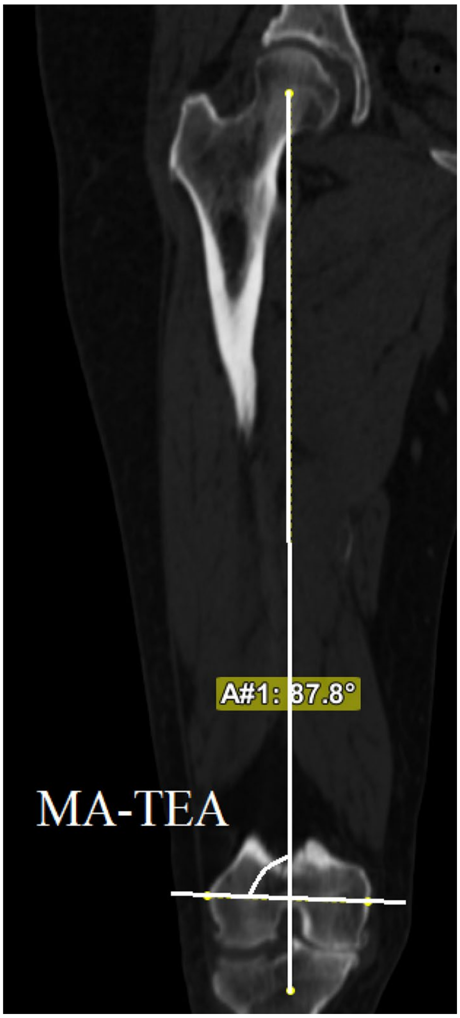

Fig. 1 Measurement of the lateral angle between the surgical transepicondylar axis and the mechanical axis of the femur (MA-TEA) on the XY plane

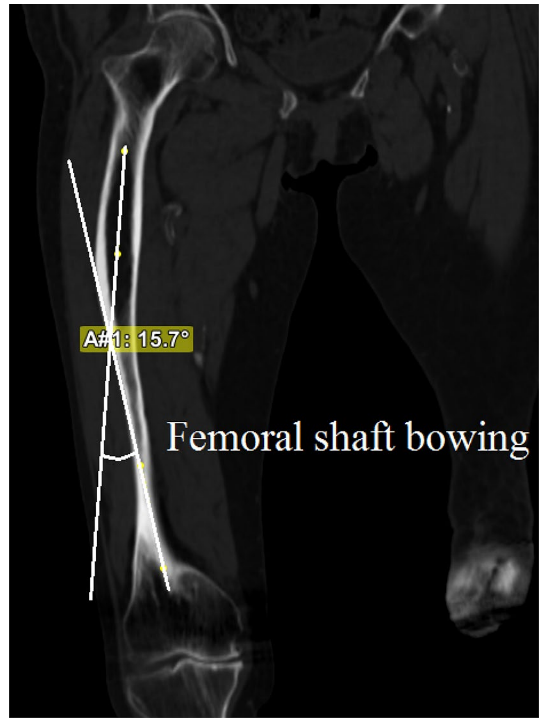

Fig. 2 Measurement of femoral shaft bowing on the *XY* plane

Corporation, Armonk, NY). Values of $P<0.05$ were considered statistically significant. Sample size calculation was performed using G*Power version 3.1.9.2 (Heinrich-Heine-Universität Düsseldorf, Germany). A priori power analysis (effect size = 0.3, significance level = 0.05, and power = 0.8) resulted in a sample size of 82. To examine the reproducibility of the measurements on CT images, 20 knees were randomly selected, and intra- and interobserver reliabilities were determined using intraclass correlation coefficients (ICCs) for each measurement.

Results

Radiographic and CT data are summarized in Table 2. MA-TEA varied widely, with a mean value exceeding 90°. MA-TEA correlated negatively with HKA ($r=-0.321$, $P<0.01$) (Fig. 4) and positively with both femoral shaft bowing ($r=0.415$, $P<0.01$) (Fig. 5) and Distal-TEA ($r=0.657$, $P<0.01$) (Fig. 6). In addition, femoral shaft bowing correlated negatively with Distal-TEA ($r=-0.287$, $P<0.01$) (Fig. 7).

The intra- and interobserver ICCs were 0.94 and 0.93 for femoral shaft bowing, 0.7 and 0.59 for MA-TEA, and 0.5 and 0.52 for Distal-TEA, respectively.

Discussion

The most important finding of this study was that the lateral angle between the TEA and the mechanical axis of the femur increased as femoral shaft bowing increased in the coronal plane. In this study, MA-TEA correlated negatively with HKA. This result supports the previous findings of Zhang et al. [14], who demonstrated that the lateral angle between the TEA and the mechanical axis of the femur in the coronal plane was larger in varus knee OA than in non-varus knee OA. It was suggested that the TEA was not perpendicular to the mechanical axis of the femur in the coronal plane when limited to cases with severe varus deformity.

In this study, MA-TEA increased with greater femoral shaft bowing. The reason why MA-TEA correlated negatively with HKA was unclear in the previous study [14]. The present study revealed that femoral shaft bowing was a contributing factor by which MA-TEA correlated negatively

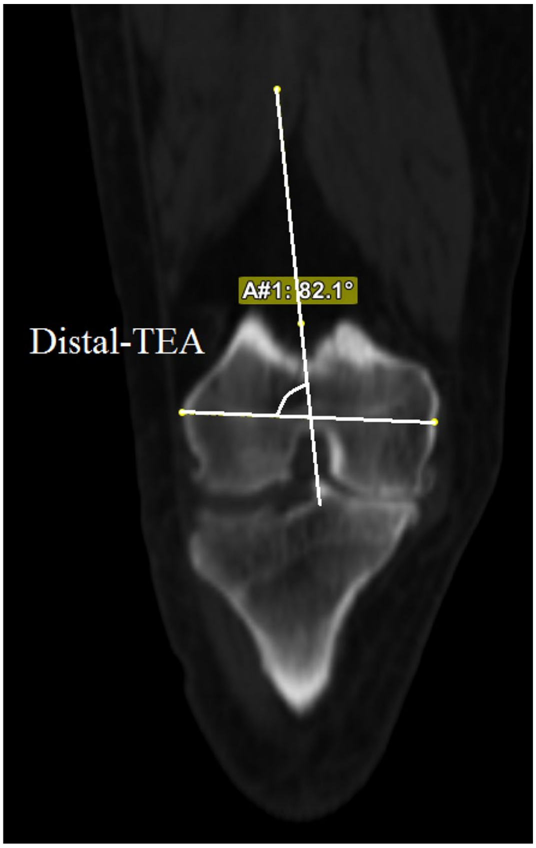

Fig. 3 Measurement of the lateral angle between the fourth segment of the femoral shaft and the surgical transepicondylar axis (Distal-TEA) on the *XY* plane

Table 2 Radiographic and CT data

HKA	−15.5 ± 5.6° (−28.4° to −2.2°)
MA-TEA	91.0 ± 2.2° (86.3°–95.9°)
Femoral shaft bowing	5.5 ± 3.1° (− 2.2°–13.3°)
Distal-TEA	82.5 ± 2.0° (78.3°–88.2°)

Data are presented as the means ± standard deviations with range in parentheses. HKA, hip–knee-ankle angle, with a positive value indicating valgus alignment; MA-TEA, the lateral angle between the surgical transepicondylar axis and the mechanical axis of the femur; Distal-TEA, the lateral angle between the fourth segment of the femoral shaft and the surgical transepicondylar axis

with HKA. On the other hand, Distal-TEA decreased with greater femoral shaft bowing. It was thought that the change in Distal-TEA represented a compensatory mechanism to maintain the TEA perpendicular to the mechanical axis of the femur in the coronal plane. The joint line should be parallel to the floor in the standing position. This force may change the orientation of the TEA against femoral shaft bowing. However, deformity of the distal femoral shaft could not completely compensate for the effect of femoral shaft

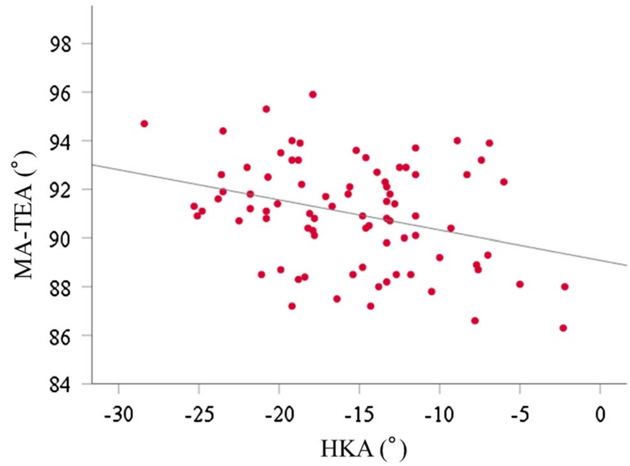

Fig. 4 Correlation between the lateral angle between the surgical transepicondylar axis and the mechanical axis of the femur (MA-TEA) and the hip–knee-ankle angle (HKA). $r = -0.321$, $P < 0.01$

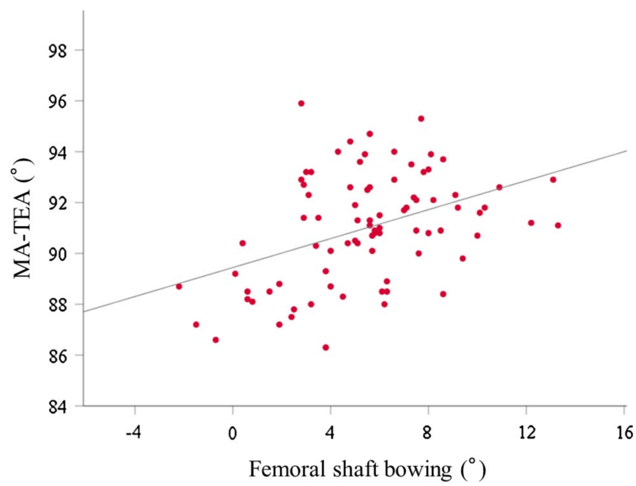

Fig. 5 Correlation between the lateral angle between the surgical transepicondylar axis and the mechanical axis of the femur (MA-TEA) and femoral shaft bowing. $r = 0.415$, $P < 0.01$

bowing on the orientation of the TEA. Measured values in this study could be affected by other factors. For example, the degree of coronal bowing of the femoral shaft may be affected by femoral torsion. If the distal femur is twisted internally, coronal bowing will increase because a portion of the sagittal bowing is added to the coronal bowing. MA-TEA may also be affected by femoral torsion. The relationship between femoral torsion and femoral shaft bowing and MA-TEA should be elucidated in a future study.

In clinical practice, the TEA is a useful landmark for predicting an appropriate orientation of the femoral component in the coronal plane when it is perpendicular to the mechanical axis of the femur. For example, the TEA plays an important role in patients with large bone defects or revision TKAs

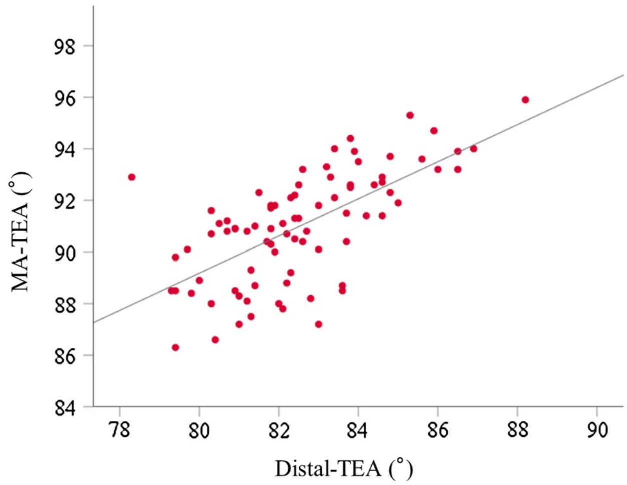

Fig. 6 Correlation between the lateral angle between the surgical transepicondylar axis and the mechanical axis of the femur (MA-TEA) and the angle between the fourth segment of the femoral shaft and the surgical transepicondylar axis (Distal-TEA). $r = 0.657$, $P < 0.01$

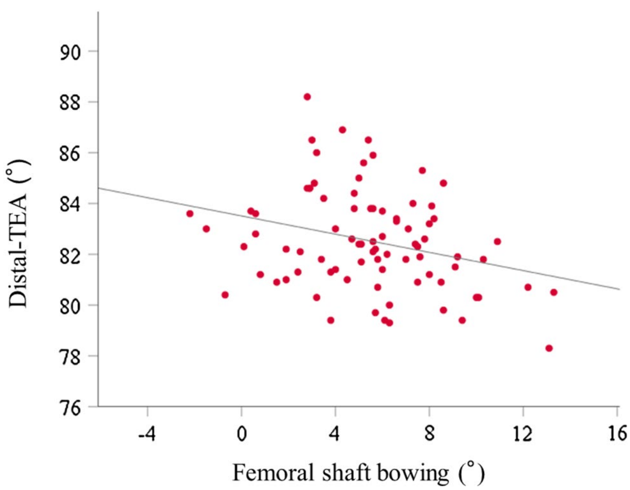

Fig. 7 Correlation between femoral shaft bowing and the lateral angle between the fourth segment of the femoral shaft and the surgical transepicondylar axis (Distal-TEA). $r = -0.287$, $P < 0.01$

since the availability of the original anatomical landmarks is limited. However, the TEA changed to varus as femoral shaft bowing increased in this study. The TEA may not be useful as a consistent parameter in the coronal plane in such knees. In addition, the functional flexion–extension axis of the knee after TKA would correspond to the TEA determined using the mechanical alignment method in cases with the TEA perpendicular to the mechanical axis of the femur. In contrast, the postoperative functional flexion–extension axis in knees with severe femoral shaft bowing may differ from the TEA, indicating a possible factor affecting clinical outcomes after TKA. Whether this discrepancy should be taken into account in procedures for TKA remains to be elucidated.

Various limitations to the present study need to be considered when interpreting the results. First, most patients in the present study were Japanese females who underwent TKA for moderate to severe varus knee OA, meaning that the present study provides more information on TKA in Japanese female patients with varus knee OA than in the general population. Second, both knees in 25 patients were analyzed in the present study. In the same patient, the measured values may be the same, although there is no literature on this issue. This could bias the results in the present study. Third, patients with flexion contracture were not excluded from the present study. This might affect HKA. Fourth, the values from a weight-bearing radiograph were compared to those of a non-weight- bearing CT. This might affect the results of this study. Fifth, the correlations were often quite fair. Finally, the statistical power of this study was slightly weak. The sample size should ideally be increased.

Conclusions

The MA-TEA increased with greater femoral shaft bowing in the coronal plane in patients with varus knee OA. This suggests that the TEA is not always the centre of the rotational axis of the femur after TKA. In addition, the TEA may not be useful as a consistent parameter in the coronal plane in patients with increasing femoral shaft bowing.

Author contributions SN: study design, data collection, interpreting the data and writing the paper. KK, HK: data collection. SY, TA, TO, MS, YI: interpretation. All authors read and approved the final manuscript.

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Compliance with ethical standards

Conflict of interest There are no conflicts of interest.

Ethics approval Ethical approval for the study was obtained from the institutional review board of Yokohama City University Hospital (B190700006).

Consent to participate Informed and written consent was obtained from all patients.

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