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Different femoral origins of valgus deformity affect aspect ratios of resected distal femurs in total knee arthroplasty

Xinghua Yin, Dejin Yang, Yixin Zhou *, Hongyi Shao, Yong Huang, Xingjian Huang

Department of Orthopaedics, Beijing Jishuitan Hospital, Fourth Clinical College of Peking University, Beijing, China

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ABSTRACT

Purpose: This study aimed to evaluate the anthropometry of resected distal femurs in valgus knees at the level of standard cuts during total knee arthroplasty (TKA), and to compare these measurements to neutrally aligned knees.

Methods: Anteroposterior and mediolateral measurements of the distal femur were performed on three-dimensional computed tomography reconstructions of 57 valgus knees (34 intra-articular valgus and 23 juxta-articular valgus) and 40 neutrally aligned knees. The measured dimensions and calculated aspect ratios (ARs) were subsequently compared.

Results: Juxta-articular valgus knees had similar ARs when compared with neutrally aligned knees (1.14 ± 0.06 vs. 1.12 ± 0.05, $P = 0.103$). However, intra-articular valgus knees had smaller ARs (1.09 ± 0.07) when compared with juxta-articular valgus ($P = 0.002$) or neutrally aligned knees ($P = 0.023$).

Conclusion: Different origins of valgus deformity in the femur can significantly affect the AR values on the resected surface of the distal femur. Pre-operative evaluation of a valgus deformity may assist in estimating the morphology of the resected distal femur during TKA.

1. Introduction

Selecting a prosthesis that best fits the size and shape of the resected surface of the knee is an important factor for the outcome of total knee arthroplasty (TKA). Therefore, neglecting this may result in a number of complications: prosthesis overhang may lead to soft tissue impingement and irritation, while under-coverage of a resected surface may lead to subsidence and instability of the prosthesis [1].

Valgus deformities of the knee are observed in nearly 10% of patients undergoing TKA [2]. These deformities generally have three origins: the distal femur, proximal tibia, and medial laxity as a result of medial collateral ligament stretching [3]. Using the mechanical alignment technique during TKA, femoral resection is performed uniformly in a direction perpendicular to the mechanical axis of the femur. However, different obliquities in the distal femoral joint line may give rise to different shapes of the resected surface.

Several studies have reported distal femur configuration after standard resection in different population groups and found that females have smaller mediolateral (ML) width and anteroposterior (AP) length than males, in addition to a smaller femoral aspect

* Corresponding author at: Department of Orthopaedics, Beijing Jishuitan Hospital, Xinjiekou East Street, Xicheng District,, Beijing 100035, China.
E-mail address: orthoyixin@gmail.com. (Y. Zhou).

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ratio (AR), which is calculated by dividing the ML width by the AP length [4–9]. These studies, which included patients from different ethnic groups such as Caucasians and East Asians, showed the same gender differences within each ethnic group. Kim et al. reported that Caucasians had longer femoral AP length, but smaller femoral AR than East Asians [10]. The measurements and comparisons used in previous studies were performed on normal or varus knees, and no studies focused on valgus knees. However, the yearly growth in the population of TKA patients has resulted in more referrals of valgus knee cases to surgical centers. Thus, anthropometric understanding of valgus knees is important to find the best fit between bones and total knee implants.

The current study hypothesized that valgus knees have distinct anthropometry of the resected distal femur, including AP length, ML width and calculated ARs. This study measured these parameters and compared them with neutrally aligned knees.

Valgus knees, according to the different levels of femoral deformity origins occurring around the knee, can be classified into intra-articular valgus (IAV) and juxta-articular valgus (JAV). Valgus deformity at these two levels may require different surgical strategies: IAV knees can be realigned using TKA alone, whereas JAV may need extra-articular osteotomy if compensatory intra-articular resection during TKA is not enough to restore neutral alignment [11]. More importantly, the closer a valgus deformity is to the knee joint, the greater its effect will be upon mal-orientation of the knee joint [12]. The degree of this joint line obliquity will influence asymmetrical resection of the medial and lateral condyles, which will further affect the resected surface of the distal femur. Thus, the impact that different femoral origins of valgus deformity (IAV vs. JAV) have on anthropometry of the resected distal femur was further explored in this study.

2. Materials and methods

A search was performed in the current database for valgus knee cases that had: AP and lateral view knee X-rays, full-length AP and lateral view lower limb X-rays, and computed tomography (CT) scan of the knee during January 2015 to December 2016. Fifty-seven Chinese patients (51 females and six males) who had valgus knees with femoral origin (see Section 2.1) were identified. All of these valgus knees had severe osteoarthritis (OA, Kellgren–Lawrence (K–L) grades III–IV) that warranted TKA. For comparison, neutrally aligned (NA) knee cases that had CT scans of the knee during the same period were searched and 40 Chinese patients (36 females and four males) who had no varus or valgus deformity in the femur were identified (see Section 2.1). Thirty-one NA knees had OA (25 with K–L grades I–II and six with K–L grades III–IV) and nine NA knees had no degenerative changes on X-ray. In both groups, the patients were excluded if they had inflammatory knee arthritis, post-traumatic knee arthritis, obvious proximal femoral deformity, and knees with previous history of TKA.

2.1. Definition of valgus knees with femoral origin and neutrally aligned knees with normal femur

Each of the included patients had full-length standing hip-to-ankle X-rays (both AP and lateral view). Malalignment in the frontal plane was analyzed via a malalignment test (MAT) in the full-length AP view X-ray [13]. Mechanical axis deviation (MAD) was defined as the distance from the center of the knee joint to the mechanical axis of the lower limb. A valgus knee deformity was defined as the weightbearing axis of the lower extremity located >10 mm lateral to the center of the knee joint (MAD >10 mm lateral). Neutrally aligned knees were defined as those with the weightbearing axis of the lower extremity located <10 mm lateral and <15 mm medial to the center of the knee joint (MAD <10 mm lateral and <15 mm medial) [13]. Joint orientation angles of the distal femur were further analyzed in the coronal plane in valgus knees and NA knees. If the mechanical lateral distal femoral angle (mLDFA) was within the standard value range (87 ± 3°), the knee was defined as having no varus or valgus deformity in the femur; if mLDFA was <84° (87 ± 3°), the femur was determined to have a valgus deformity [13]. All of the included valgus knees had >10 mm lateral MAD and <84° mLDFA, whereas all included NA knees had <10 mm lateral and <15 mm medial MAD, and mLDFA within the standard range of values.

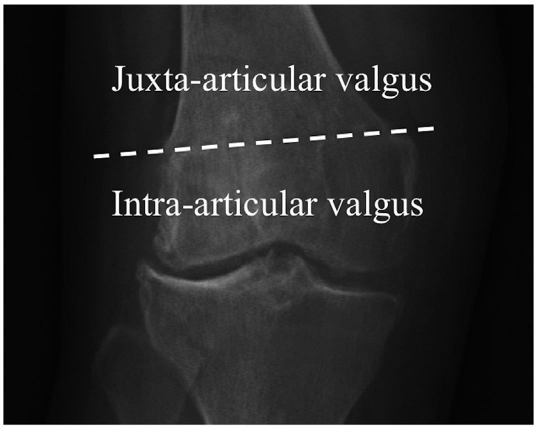

Figure 1. The dotted line tangent to the superior borders of medial and lateral posterior condyles is shown. Having a valgus deformity center of rotation of angulation (CORA) above this line was classified as juxta-articular valgus knee, and a valgus deformity CORA below this line as intra-articular valgus knee.

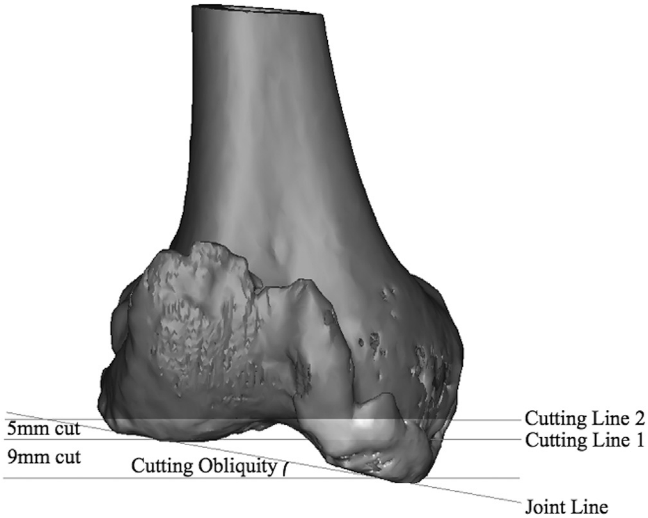

Figure 2. A valgus knee that required an additional 5 mm cut to the lateral femoral condyle after a 9 mm standard distal cut.

2.2. Subdivision of valgus knees with femoral origin

The center of rotation of angulation (CORA) method was used to assess the femoral origin of valgus knees [13]. A line tangent to the superior borders of the medial and lateral femoral condyles on full-length AP X-ray was determined in each valgus knee (Figure 1). An anatomical projection of the posterior superior knee joint capsule on an AP X-ray is around this line and the anatomical projection of the articular cartilage of the bilateral posterior condyles is below it [14]. Thus, this line was defined as the boundary when considering whether the CORA location was in or out of the joint. Knees with CORA above this line were classified as juxta-articular valgus (JAV, 21 females and two males) knees, while CORA below this line were classified as intra-articular valgus (IAV, 30 females and four males) knees (Figure 1).

2.3. Three-dimensional reconstruction, standard cutting and measurement

Computed tomography volumetric data were collected in all 97 patients. The scans were examined with an Aquilion 64-slice spiral CT scanner (Toshiba, Otawara, Japan) with 0.5-mm thickness. Three-dimensional (3-D) image reconstructions were then performed using the Mimics medical imaging program (version 16.0, Materialize, Leuven, Belgium) for all knees, and standard cuts of the distal femur were simulated. All cutting levels were perpendicular to the mechanical axis of the femur and nine millimeters above the most distal part of the femur. If the nine millimeters did not reach the lateral condyle of the femur, an additional cut of five millimeters or even 10 mm was added (see Figure 2). All 40 NA knees completed the medial and lateral condyle cutting with nine-millimeter thickness, whereas some JAV or IAV knees required an additional five millimeters or 10 mm of cutting on the lateral condyle (see Table 1). The cutting obliquity was defined as the intersection angle between the cutting line and the joint line in the coronal plane (see Figure 2).

For each resected femur, the measurement was performed on each AP dimension of the lateral and medial condyles, the AP dimension of anterior cut (AC) on the lateral and medial condyles, the ML width of lateral and medial condyles on the resected surface, and the resected ML width, based on which the aspect ratio (AR), medial aspect ratio (mAR), AR after AC, and mAR after AC of the distal femur were calculated (Figure 3).

- AR = resected ML width/lateral condyle AP
- mAR = resected ML width/medial condyle AP
- AR after AC = resected ML width/lateral condyle AP after AC
- mAR after AC = resected ML width/medial condyle AP after AC.

A comparison of the dimensions and ARs of the JAV, IAV and NA knees was then performed.

2.4. Statistics

All statistical analyses were performed using the SPSS 16.0 statistical software package (IBM, Armonk, New York). The Kolmogorov–Smirnov test was used to assess whether the distribution of data was normal. An independent-sample *t*-test was conducted to examine the differences among continuous variables. A *P*-value of <0.05 was considered statistically significant. The kappa values for intraobserver and interobserver reliability in AR were 0.871 and 0.815, respectively.

Table 1
Parameters of distal femoral cutting that perpendicular to mechanical axis.

Parameter	NA	JAV	IAV	P NA vs. JAV	P NA vs. IAV	P JAV vs. IAV
Total number of cases	40 (4 male)	23 (2 male)	34 (4 male)	–	–	–
Average height[a], cm	159.5 ± 5.1	161.3 ± 5.8	160.1 ± 3.8	0.339	0.671	0.399
Average BMI[a], kg/m^2	24.5 ± 4.8	25.5 ± 3.0	25.7 ± 3.2	0.443	0.325	0.839
9 mm cutting of lateral condyle, cases	40	14 (2 male)	26 (3 male)	–	–	–
9 + 5 mm cutting of lateral condyle, cases	0	7	6 (1 male)	–	–	–
9 + 10 mm cutting of lateral condyle, cases	0	2	2	–	–	–
Cutting obliquity[a], degree	3.72 ± 2.14	9.45 ± 5.29	8.27 ± 4.34	<0.001*	<0.001*	0.389

NA, neutrally aligned; JAV, juxta-articular valgus; IAV, intra-articular valgus.
[a] Data are presented as mean ± SD.
* $P < 0.05$.

3. Results

No significant differences in the range of demographic data, including height and body mass index (BMI), were identified among NA, JAV and IAV knees (see Table 1).

3.1. Cutting obliquity of distal femur

The average cutting obliquity in JAV and IAV knees was larger than NA knees ($P < 0.001$ and $P < 0.001$, respectively, see Table 1).

3.2. Measurement of valgus knees

The ARs of JAV and IAV knees were 1.14 ± 0.06 and 1.09 ± 0.07, respectively, with JAV being significantly larger ($P = 0.002$). Medial ARs were also measured and calculated, and the results demonstrated the same trend ($P = 0.039$). During TKA, femoral component size is determined using the AP dimension without anterior condyle thickness. To reflect this parameter, AR was measured and calculated after AC, which demonstrated the same trend (see Table 2).

3.3. Comparison between NA and valgus knees

The average AR of NA knees was 1.12 ± 0.05. When compared with NA knees, JAV knees had a larger medial condyle width ($P = 0.001$) and ML width ($P = 0.041$), but had no difference in ARs. In IAV knees, AR and medial AR were smaller than in NA knees ($P = 0.023$ and $P = 0.010$, respectively, see Table 2).

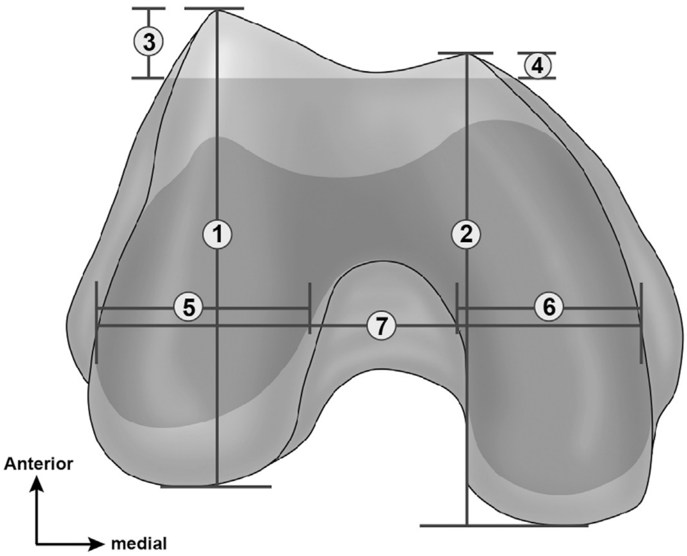

Figure 3. Measured parameters on the resected distal femur. 1. Lateral condyle anteroposterior (AP) dimension. 2. Medial condyle AP dimension. 3. Lateral anterior cut AP dimension. 4. Medial anterior cut AP dimension. 5. Lateral condyle width. 6. Medial condyle width. 7. Resected mediolateral width.

Table 2
Dimensions of distal femur in juxta-articular and intra-articular valgus knees compared with neutrally aligned (NA) knees.[a]

Parameter	NA	JAV	IAV	*P* NA vs. JAV	*P* NA vs. IAV	*P* JAV vs. IAV
Number	40 (4 male)	23 (2 male)	34 (4 male)	–	–	–
Lateral condyle AP, mm	60.93 ± 3.14	61.59 ± 3.20	62.48 ± 6.49	0.434	0.211	0.495
Medial condyle AP, mm	58.75 ± 2.78	60.62 ± 4.43	60.78 ± 6.31	0.078	0.089	0.912
Lateral AC AP, mm	7.91 ± 1.50	7.80 ± 2.61	8.66 ± 2.36	0.846	0.116	0.198
Medial AC AP, mm	3.37 ± 1.84	4.43 ± 2.74	4.92 ± 2.42	0.108	0.003*	0.485
Lateral condyle AP after AC, mm	53.02 ± 3.13	53.79 ± 3.05	53.81 ± 5.37	0.348	0.452	0.984
Medial condyle AP after AC, mm	55.38 ± 3.11	56.18 ± 4.14	55.87 ± 5.74	0.384	0.658	0.821
Lateral condyle width, mm	25.52 ± 2.45	26.26 ± 6.45	24.88 ± 5.04	0.602	0.507	0.372
Medial condyle width, mm	25.56 ± 1.85	27.98 ± 2.78	26.50 ± 5.19	0.001*	0.323	0.167
Resected ML width, mm	68.06 ± 3.97	70.31 ± 4.39	67.80 ± 7.36	0.041*	0.854	0.113
AR	1.12 ± 0.05	1.14 ± 0.06	1.09 ± 0.07	0.103	0.023*	0.002*
Medial AR	1.16 ± 0.05	1.16 ± 0.08	1.12 ± 0.08	0.844	0.010*	0.039*
AR after AC	1.28 ± 0.07	1.31 ± 0.09	1.26 ± 0.08	0.258	0.186	0.044*
Medial AR after AC	1.23 ± 0.06	1.26 ± 0.10	1.22 ± 0.09	0.252	0.390	0.102

AC, anterior cut; AP, anteroposterior; ML, mediolateral; NA, neutrally aligned; JAV, juxta-articular valgus; IAV, intra-articular valgus.
[a] Data are presented as mean ± SD.
* $P < 0.05$.

4. Discussion

The most important finding of this study was that different femoral origins of valgus deformity affect ARs of resected distal femurs in TKA. Intra-articular valgus knees had smaller ARs than JAV knees. Another finding was that when compared with NA knees, JAV had similar ARs whereas IAV had smaller ARs.

Previous studies have measured the lateral condyle AP and resected ML widths in normal or arthritic distal femurs [5,15]. The resected ML width differs according to the degree of varus-valgus deformity of the distal femur, while lateral condyle AP dimensions are more constant if the measuring method is static. Yang et al. measured the AP dimensions of lateral condyles in a population of Chinese females, which was 61.3 ± 3.3 mm, and Yue et al. reported values of 58.8 ± 2.5 in Chinese women [5,15]. The value of the AP dimension of the lateral condyles in the current female-dominated NA knee group was 60.93 ± 3.14, which was consistent with the values reported in previous studies.

In the present study, valgus knees were divided into two groups: JAV and IAV. The ARs in these two groups were different (see Table 2), and calculated from the ML and AP dimensions which, to some extent, depend on how oblique the distal cutting is performed in relation to the joint line in the coronal plane (see Figure 2). The cutting obliquity revealed no difference between these two groups (see Table 1). However, due to the relatively normal development of the lateral condyle, oblique cutting may result in larger ML width in JAV knees. On the contrary, the relative hypo-development of the lateral condyle in IAV knees might result in less bone stock being removed from the lateral condyle, and as a result, decreased resected ML width. Thus, the AR of JAV knees was larger than that of IAV knees (see Figure 4).

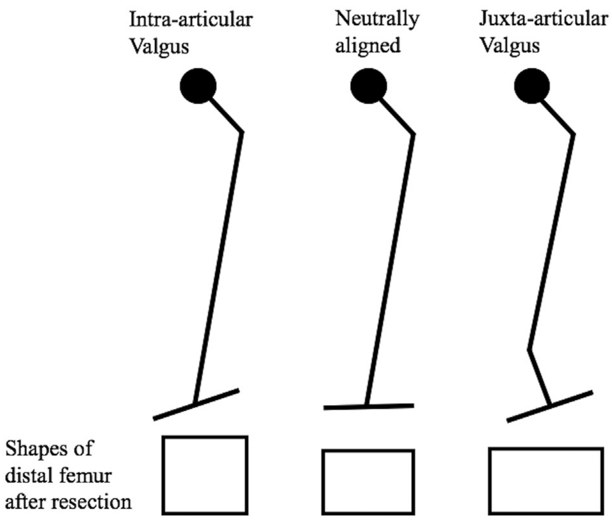

Figure 4. Schematic diagram of aspect ratios in intra-articular valgus, neutrally aligned and juxta-articular valgus knees. The aspect ratios became larger from left to right.

When compared with NA knees, the hypo-development of the lateral condyle in IAV knees resulted in a larger cutting obliquity and less bone stock being removed. Thus, a smaller ML width resulted in smaller AR in IAV knees. Regarding JAV knees, although the cutting obliquity was larger, the relatively normal development of the lateral condyle prevented the ML width of JAV knees from being smaller. Thus, the AR showed no difference between JAV and NA knees.

The increased cutting obliquity in valgus knees requires special consideration in cutting and measuring the ML width. In cases with a large cutting obliquity, an additional five millimeters or 10 mm of cutting on the lateral condyle was performed. Since the ML width of the commonly used augment is consistent with the lateral condyle width of the femoral component, the additionally resected surface of the lateral condyle was projected onto the nine-millimeter cutting plane of the medial condyle, and AP and ML dimensions were measured on it.

Gender differences in distal femoral morphology have been previously reported [4–9]. In this regard, women have smaller ARs than men among various races [10]. These differences have stimulated the design of female-specific femoral components with narrower femoral condyles that can reduce the ML overhang in women undergoing TKA [6,16]. Although it is unknown whether the use of female-specific femoral components results in improved clinical outcomes in women, researchers continue to investigate the osseous morphology of different populations as a means of potentially pursuing optimal matching between the bone and desired implant. Yang et al. reported the resected femoral ARs of women and men in the Chinese population (1.16 ± 0.05 vs. 1.18 ± 0.06, $P = 0.031$) [5]. The present study found that the resected femoral ARs were 1.12 ± 0.05 and 1.14 ± 0.02 in NA female and NA male knees, respectively. In addition to confirming a smaller AR in females with NA knees, the same trend was also identified in valgus knees. However, this was a real cohort representing predominantly female valgus knee patients undergoing TKA; thus, further studies that include an equal male:female ratio would be beneficial when investigating gender differences in valgus knees.

Currently, component fit in patients with altered ARs can be improved in different ways. A component design family that has multiple ML/AP shape offerings and an increased number of available sizes can be chosen [17]. If the AR is expected to be narrow, as in IAV cases, a narrow or 'female knee' component can be selected pre-operatively. The TKA can be performed in a conventional, PSI-assisted or navigation-assisted way to improve the accuracy of femoral component positioning [6,18,19].

This study had several limitations. First, the sample size of valgus knee patients was limited due to the natural distribution of pathology among patients who need TKA. Valgus knee patients in this study were predominantly female. Thus, there were not enough data to further study gender difference within valgus knees. For comparison, a group of NA knees that had CT scans, which could be identified from the database during the same period, were included. Although the ratio between female and male patients with valgus knees was not perfect, this impact was minor due to most NA knee patients being female, and the difference in the mean BMI and height was minimal compared with valgus knee patients.

Another limitation was that the CORA method was used to define the location of valgus deformity. This method may become less accurate when other deformities coexist at the level of the proximal femur. Thus, in the current study, cases with obvious proximal deformity, such as coxa vara or coxa valga, were excluded.

The third limitation was that anatomical landmarks were followed and parameters were measured on 2-D X-rays to guide distal femoral cutting on 3-D reconstruction. The anatomical mechanical angle (AMA) was measured on full-leg X-ray in the coronal plane and used to confirm distal femur cuts made perpendicular to the mechanical axis in a 3-D reconstruction of local knee CT data. In the sagittal plane, it was confirmed that all knees had similar posterior distal femoral angles (PDFA) without any obvious outliers. Distal cutting was performed perpendicular to the anterior cortex of the distal femur. Measurement error may have occurred during these processes: after distal cutting especially, macroscopic judgment was made as to the true osseous margin, and CT-based 3-D reconstructions cannot automatically subtract osteophytes. To reduce these errors, all knees were measured separately by two orthopedists, and both of them completed the measurement twice, with four weeks apart. The average values of each dimension in all knees were used in the final statistical analysis.

The clinical importance of this study is that femoral resection during TKA may produce different morphologies in valgus knees depending on the level of deformity origin. Juxta-articular femoral valgus knees have similar ARs to NA knees and a 'routine' femoral component may achieve a fit with the resected surface, whereas intra-articular femoral valgus knees have 'narrower' ARs than NA knees. Thus, it is reasonable to prepare a 'narrower' or so-called 'female knee' femoral component pre-operatively for IAV. If the routine femoral component cannot fit the altered AR of IAV intra-operatively, a smaller femoral component can be used and placed in a more flexed position to avoid ML overhang or anterior notching.

5. Conclusions

Different origins of valgus deformity in the femur can significantly affect the AR values on the resected surface of the distal femur. Pre-operative evaluation of a valgus deformity may assist in estimating the morphology of the resected surface of the distal femur during TKA.

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Declaration of Competing Interest

We, the authors, declare the following conflict of interest.
Yixin Zhou has consultancy agreements with Johnson & Johnson and Smith Nephew.

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