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Effect of distance between the feet on knee joint line orientation after total knee arthroplasty in standing full-limb radiographs

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Abstract

Purpose Although knee joint line orientation (KJLO) after total knee arthroplasty (TKA) has been emphasized as an important factor that can affect postoperative knee kinematics, the effect of foot position on KJLO has not been fully understood. This study aimed to (1) identify the anatomical and positional factors that determine KJLO after TKA, and (2) determine the effect of foot position on KJLO after TKA. The hypothesis of this study was that the post-TKA KJLO would change depending on the distance between the feet, as well as the coronal implant positions.

Methods A total of 92 radiographs from 46 patients who underwent TKA were retrospectively reviewed. Two postoperative standing full-limb anteroposterior radiographs taken with the feet in different positions (with both feet in contact with each other or shoulder width apart) from each patient were evaluated. The correlation between KJLO after TKA and possible anatomical and positional factors, including leg length, lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), ankle joint line orientation (AJLO), mechanical tibiofemoral angle (mTFA), and distance between the feet, were analyzed, and the KJLO equation was computed using multiple linear regression. KJLO was also compared among different combinations of valgus or varus alignment of the femoral and tibial components.

Results LDFA, MPTA, AJLO, and distance between the feet were identified as determinants of KJLO after TKA, and the distance between the feet was strongly correlated with KJLO. Based on the KJLO equation (KJLO [°] = 107.548 − 0.441 × LDFA [°] − 0.832 × MPTA [°] + 0.093 × AJLO [°] + 0.037 × ITD [mm]), KJLO changes by 3.7° per 100 mm of distance between the feet. The KJLO of patients with valgus femoral and varus tibial components was more parallel to the ground than those with other combinations.

Conclusion KJLO after TKA was strongly affected by the distance between the feet when taking full-limb radiography, and the KJLO changed by 3.7° per 100 mm of distance between the feet. To assess the KJLO after TKA reproducibly, standardization of the distance between the feet is necessary.

Level of evidence IV.

Keywords Knee joint line orientation · Ankle joint line orientation · Total knee arthroplasty · Distance between the feet · Component alignment

Introduction

Restoration of native knee kinematics after total knee arthroplasty (TKA) has been proposed as a possible solution to dissatisfaction after TKA [2, 3, 8, 20]. From this point of view, knee joint line orientation (KJLO), an important factor for knee kinematics, has recently gained attention. The KJLO of normal healthy participants is known to be nearly parallel to the ground [7, 21], and recent studies have shown that a KJLO more parallel to the ground yields better clinical outcomes after TKA [10, 17]. The importance of maintaining the original KJLO is also important in high tibial

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osteotomy (HTO). A study using finite element analysis reported that excessive shear stress is applied to knee joints when the KJLO is > 5° after HTO [12]. In addition, Song et al.'s HTO study showed that joint line obliquity of ≥ 4° and 6° resulted in poorer clinical and radiological outcomes, respectively [18]. For these reasons, to avoid excessive joint line obliquity after HTO, several studies have attempted to identify factors affecting KJLO and provide a prediction model [13, 14].

However, factors that determine the KJLO after TKA have not yet been identified. Several studies have shown that valgus alignment of the femoral component and varus alignment of the tibial component in kinematically aligned (KA) TKA can provide a KJLO more parallel to the ground than mechanically aligned (MA) TKA [7, 10]. In contrast, Shin et al. reported that residual varus limb alignment after TKA can make the joint line parallel to the ground [17]. Although the ankle joint line orientation (AJLO) is known to affect KJLO after HTO [9], its effect on KJLO in TKA has not yet been investigated. In addition to anatomical factors, positional factors such as the distance between the feet also affect the KJLO value after HTO [1]. However, its effect on KJLO in TKA has not yet been clarified, and the standard distance between the feet during radiography has not yet been established.

Therefore, this study aimed to (1) identify anatomical and positional factors that determine KJLO after TKA, and (2) determine the effect of foot position on KJLO after TKA. The hypothesis of this study was that KJLO after TKA would change depending on the distance between the feet, as well as the coronal implant positions.

Materials and methods

Study subjects

Data of 93 patients who underwent TKA by a single surgeon between April 2020 and July 2020 at our hospital (a tertiary referral center) were reviewed. Among them, patients who had taken more than two standing full lower limb anteroposterior (AP) radiographs with different foot positions during the postoperative follow-up period were selected and enrolled in the study. The exclusion criteria were as follows: (1) patients who underwent total joint arthroplasty except TKA on the lower extremities before X-ray imaging, (2) who underwent TKA with prosthesis of asymmetric femoral condyle design, (3) with > 2-cm leg length discrepancy that may affect the posture when taking a radiograph, (4) bone deformity of the lower extremities due to previous fracture or bone surgery, and (5) without standing full lower limb radiograph taken with proper lower extremity rotation (patellar facing forward) or without X-ray with different distances between the feet. Finally, 46 patients were enrolled in this study, and 92 standing full lower-limb AP radiographs were evaluated. In bilateral TKAs, first operated side of the knee was included to avoid statistical bias [15]. In addition to radiologic evaluation, patient demographic data, including age, sex, height, and body mass index, were also investigated. A total of 25 standing full lower limb AP radiographs in 25 patients who underwent TKA at another institution by a different surgeon were evaluated for external validation of the equation.

Radiographic examination

Standing full lower limb AP radiographs were obtained using a 14 × 51-inch grid cassette at a source-to-image distance of 240 cm, using a UT 2000 X-ray machine (Philips Research, Eindhoven, The Netherlands) set to 90 kV and 50 mA/s. According to our routine protocol, standing full lower limb AP radiographs were obtained at two different foot positions: with both feet in contact and with feet shoulder width apart at 3 months postoperatively. During the radiographic examination, lower extremity rotation was controlled to locate the patella at the mid-point of the femoral condyle. All radiographic images were digitally acquired using a picture archiving and communication system (PACS), and radiographic measurements were performed using PACS software (INFINITT, Seoul, Korea).

Radiographic measurements

In the postoperative standing full lower limb AP radiography, the leg length, mechanical tibiofemoral angle (mTFA), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), KJLO, and AJLO were examined as anatomical factors, and the distance between the feet was measured as a positional factor using the intertalar distance (ITD).

The leg length was defined as the length from the highest point of the femoral head surface to the center of the talar dome surface. The mTFA was defined as the angle between the mechanical axis of the femur (the line from the femoral head center to the intercondylar notch center of the femoral component) and the tibia (the line from the talus center to the center of the cutting surface of the proximal tibia). A negative value was assigned to the knees in the varus alignment (Fig. 1A). The LDFA was defined as the lateral angle formed by the mechanical axis of the femur and a line tangent to the distal edge of the femoral component (Fig. 1B). The MPTA was defined as the medial angle between the mechanical axis of the tibia and the line tangent to the base plate of the tibial component (Fig. 1C). The KJLO was defined as the angle between the line tangent to the base plate of the tibial component and the ground, and the line tilted toward the medial side was set as a positive value (Fig. 1D). The AJLO was

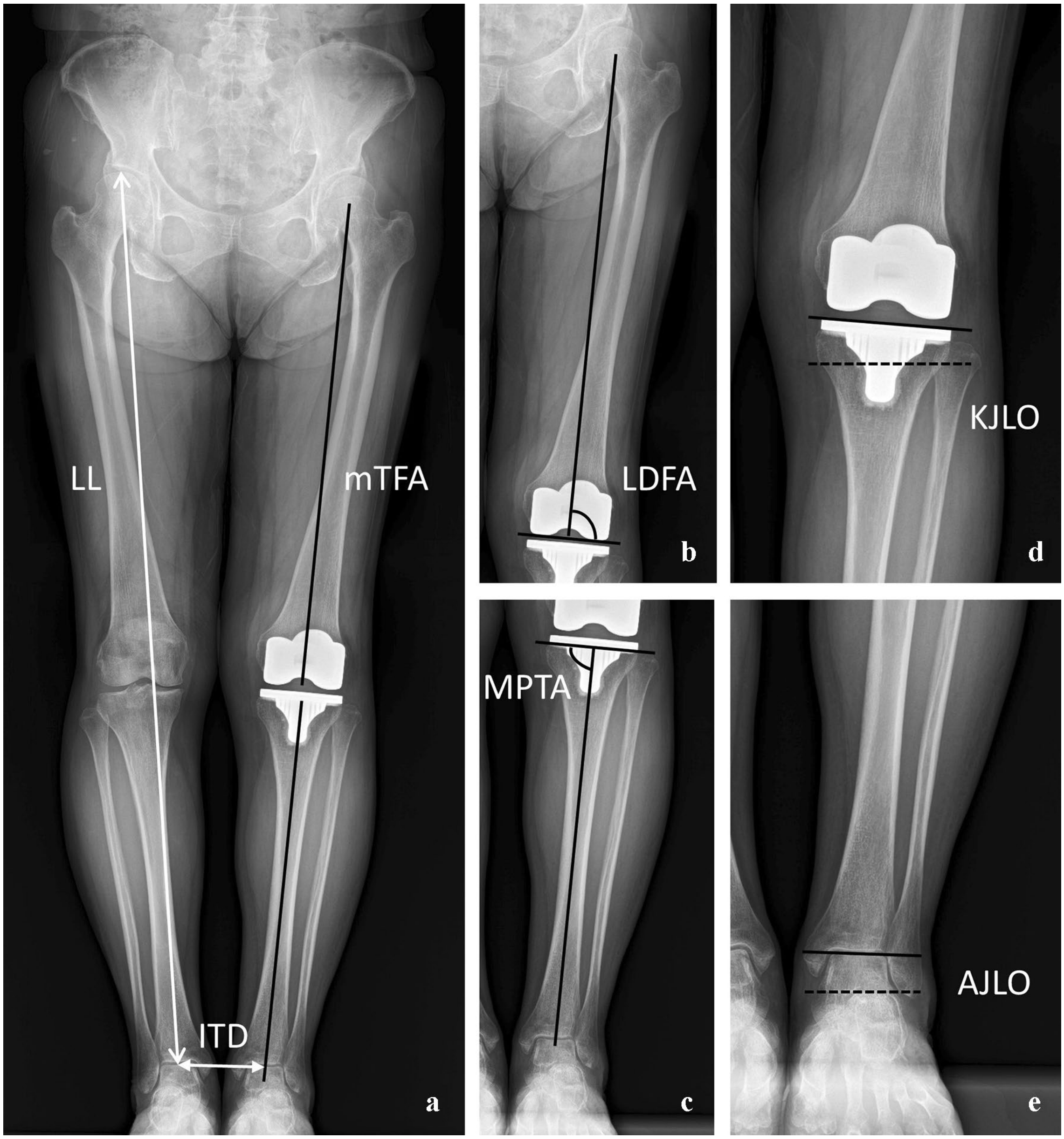

Fig. 1 Radiographic measurements. **a** The mechanical tibiofemoral angle (mTFA) is the angle between the mechanical axis of the femur and that of tibia (an angle between the black solid lines). The leg length is defined as the length from the highest point of the femoral head surface to the center of the talar dome surface (an open double headed arrow line). The intertalar distance (ITD) is distance between center of the right and left talar dome (a closed double headed arrow line). **b** The lateral distal femoral angle (LDFA) is the lateral angle between the mechanical axis of the femur and the tangential line to the distal femoral condyles of femoral component. **c** The medial proximal tibial angle (MPTA) is the medial angle between the mechanical axis of the tibia and the tangential line of the base plate of the tibial component. **d** The knee joint line orientation (KJLO) is the angle between a tangential line of the base plate of the tibia (a solid line) and a line parallel to the ground (a dotted line). **e** The ankle joint line orientation (AJLO) is the angle between the tangential line of talar dome (a solid line) and a line parallel to the ground (a dotted line)

defined as the angle between the tangent to the subchondral plate of the talus and the ground, and the tangent line of the talus surface inclined medially to the horizontal grid line was set as a positive value (Fig. 1E). The distance between the feet was defined as the distance between the centers of both talar domes and was referred to as ITD (Fig. 1A).

For the inter-observer reliability test, two orthopedic surgeons independently measured radiographic indices. Each surgeon was provided a randomly assigned number of radiographic images for measurement and was blinded to the other surgeons' measurements. For intra-observer reliability, radiologic parameters were measured twice at a 4-week interval for each examiner.

Analysis of factors related with KJLO

Determinants of KJLO were identified through correlation analysis between anatomical and positional factors and KJLO after TKA. The effects of each parameter were quantified using the equation computed for KJLO. KJLO was also compared among four different subgroups depending on the coronal alignment of the femoral and tibial components (valgus femoral–varus tibial, varus femoral–valgus tibial, valgus femoral–valgus tibial, and varus femoral–varus tibial).

Surgical technique

All surgeries were performed by a single experienced surgeon who used the modified gap technique with the same surgical protocol. All surgeries were performed through the medial parapatellar approach and MA TKA using an intramedullary guide for distal femoral cutting and an extramedullary guide for proximal tibial cutting. All prostheses were posterior-stabilized-type implants with a symmetric design and were fixed with cement.

Statistical analysis

All statistical analyses were conducted using R 3.6.2 (R Foundation for Statistical Computing, Vienna, Austria). p values of < 0.05 were considered statistically significant. As a result of power analysis for multiple regression, the sample size was measured as 85 when four independent variables had an effect size of 0.15, an alpha error of 0.05, and a power of 0.8. Descriptive statistical analysis was performed, and data normality was evaluated using the Kolmogorov–Smirnov test. Correlation analysis between KJLO and other radiographic parameters was performed using Pearson's correlation coefficient. Multiple linear regression analysis was performed to identify significant factors related to KJLO after TKA, and then a final predictive model was developed with predictors for the postoperative KJLO. The variance inflation factor was used to examine the multicollinearity between predictors in the model and exclude the predictors that caused multicollinearity. The model was validated internally and externally using a bootstrapping resampling method with 1000 iterations for calibration, and the predicted squared correlation coefficient was calculated for external validation. For subgroup analysis, analysis of variance (ANOVA) was used, and when significant differences were observed on ANOVA, Student's t test was used to determine intergroup significance. Inter- and intra-observer reliabilities were evaluated using the intraclass correlation coefficient (ICC).

Ethical approval

This study was approved by the institutional review committee of our hospital, and the requirement for informed consent was waived because of its retrospective nature (IRB No. B-2103/672-105).

Results

In this study, 92 radiographs of 46 patients (39 women and 7 men) were evaluated, and the mean age of the patients was 71.2 ± 6.2 years. Patient demographic data and radiologic measurements of each parameter are summarized in Table 1. All radiographic measurements showed satisfactory inter- and intra-observer reliability above an ICC of 0.8 (Table 2).

In the correlation analysis, ITD showed a strong positive correlation with KJLO after TKA ($r = 0.745$, $p < 0.001$) (Table 3). As the distance between the feet increases, the KJLO increasingly tilted medially (Fig. 2). In addition, postoperative LDFA ($r = -0.303$, $p = 0.003$), MPTA ($r = -0.363$, $p < 0.001$), and AJLO ($r = 0.329$, $p = 0.001$) were significantly correlated with KJLO. With increased femoral component varus, tibial component valgus, and lateral tilt of the AJLO, the KJLO is increasingly tilted laterally (Fig. 3). Similar to KJLO, AJLO also showed a positive correlation with ITD ($r = 0.218$, $p = 0.037$). mTFA and leg length were not associated with KJLO after TKA (Table 3).

Multiple linear regression analysis was used to obtain a regression equation for the KJLO: KJLO (°) = 107.548 − 0.441 × LDFA (°) − 0.832 × MPTA (°) + 0.093 × AJLO (°) + 0.037 × ITD (mm) (Table 4). The KJLO can be explained by 76.8% of the regression model ($R^2 = 0.768$). Internal validation demonstrated good calibration performance of the equation (Fig. 4A). In external validation, the equation showed satisfactory performance with a predicted correlation coefficient of 0.933 (Fig. 4B and C). In particular, the increase of 10 cm in the ITD resulted in a 3.7° change in KJLO in our study cohort.

In the subgroup analysis of KJLO depending on the coronal alignment of the femoral and tibial components, the KJLO in the valgus femoral–varus tibial group was more parallel to the ground than that in other implant positions. Although statistical significance was not observed, the varus femoral–valgus tibial group showed the largest KJLO inclination among the four groups (Table 5, Fig. 5).

Discussion

The most important finding of this study was that KJLO after TKA was strongly affected by the distance between the feet when taking full-limb radiography, and KJLO changed by

Table 1 Patient's demographics and measurements of radiologic parameters

	Test set ($n = 92$)		Validation set ($n = 25$)	
	Mean	SD (range)	Mean	SD (range)
Patient's demographics				
Age	71.17	6.21 (55 to 85)	72.08	6.91 (60 to 86)
Gender (male)	7 (15.2%)		3 (12.5%)	
BMI	26.51	3.53 (19.44 to 36.00)	26.84	4.12
Right operation	42 (45.7%)		11 (45.8%)	
Radiologic parameters				
Leg length (mm)	797.30	51.17 (653.20 to 920.56)	789.20	48.1 (661.30 to 920.56)
LDFA (°)	90.25	1.38 (47.74 to 93.33)	90.14	1.35 (87.0 to 93.0)
MPTA (°)	89.90	1.12 (87.47 to 92.94)	89.83	1.41 (87.3 to 93.9)
mTFA (°)	− 0.28	1.83 (− 5.03 to 3.38)	− 0.36	1.73 (− 5.03 to 3.38)
KJLO (°)	− 2.38	2.51 (− 8.08 to 4.37)	− 1.20	1.57 (− 4.30 to 2.20)
AJLO (°)	− 3.73	4.84 (− 15.09 to 5.03)	− 2.83	2.17 (− 8.50 to 1.00)
ITD (mm)	137.02	45.32 (72.96 to 237.77)	151.80	24.66 (111.90 to 201.30)

ITD intertalar distance, *mTFA* mechanical tibiofemoral angle, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *KJLO* knee joint line orientation, *AJLO* ankle joint line orientation

Table 2 Intraobserver and interobserver reliability of radiographic measurements

	Intraobserver reliability	Interobserver reliability
ITD (mm)	1.000 (1.000–1.000)	1.000 (1.000–1.000)
LDFA (°)	0.995 (0.991–0.997)	0.996 (0.992–0.998)
MPTA (°)	0.981 (0.966–0.989)	0.991 (0.984–0.995)
KJLO (°)	0.988 (0.980–0.993)	0.997 (0.995–0.998)
AJLO (°)	0.999 (0.998–0.999)	0.964 (0.937–0.980)

ITD intertalar distance, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *KJLO* knee joint line orientation, *AJLO* ankle joint line orientation

3.7° per 100 mm of distance between the feet. The KJLO was also affected by the combined effects of anatomical factors, such as LDFA, MPTA, and AJLO. Therefore, our hypothesis was well accepted.

It is well known that limb alignment on standing full lower limb AP radiographs can be affected depending on the rotational foot positions [5, 6]. However, to the best of our knowledge, this is the first study to reveal KJLO changes after TKA, depending on the distance between the feet. Although the patellar facing forward position is regarded as the gold standard for rotational position [19], the distance between the feet for KJLO evaluation has not yet been established. Gait studies by Ro et al. [16]and Mine et al. [11] who reported the step width after TKA as 110 mm in Koreans and 119 mm in Japanese, respectively, can be considered as a reference for standardization of distance between the feet in KJLO evaluation. Hollman et al. [4] that reported different step widths between men (10.0 cm) and women (7.9 cm) aged > 70 years can help determine the appropriate distance between the feet depending on the sex.

In this study, KJLO was also affected by anatomical factors such as LDFA, MPTA, and AJLO. Although the r values for LDFA, MPTA, and AJLO were around 0.30, which is a weak correlation, this finding can be interpreted as indicating that KJLO after TKA can be determined by the combined effect of diverse anatomical factors, rather than a single strong anatomical factor. Considering that the KJLO of the valgus femoral–varus tibial group was more parallel than that of other implant positions, these results are in good agreement with previous studies on KA TKA, demonstrating a more parallel KJLO compared to MA TKA [7, 10]. The 3.3° lateral tilt of the KJLO after MA TKA in Ji et al.'s study [7] and 3.2° lateral tilt of the KJLO after MA TKA in Matsumoto et al.'s study [10] support this explanation. The interesting finding that most cases showed a lateral tilt of the

Table 3 Correlation between KJLO and other radiographic parameters

	Leg length	ITD	mTFA	LDFA	MPTA	AJLO
KJLO	− 0.019 ($p = 0.855$)	**0.745 ($p < 0.001$)**	0.056 ($p = 0.594$)	**− 0.303 ($p = 0.003$)**	**− 0.363 ($p < 0.001$)**	**0.329 ($p = 0.001$)**

ITD intertalar distance, *mTFA* mechanical tibiofemoral angle, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *KJLO* knee joint line orientation, *AJLO* ankle joint line orientation

p values of < 0.05 were considered statistically significant

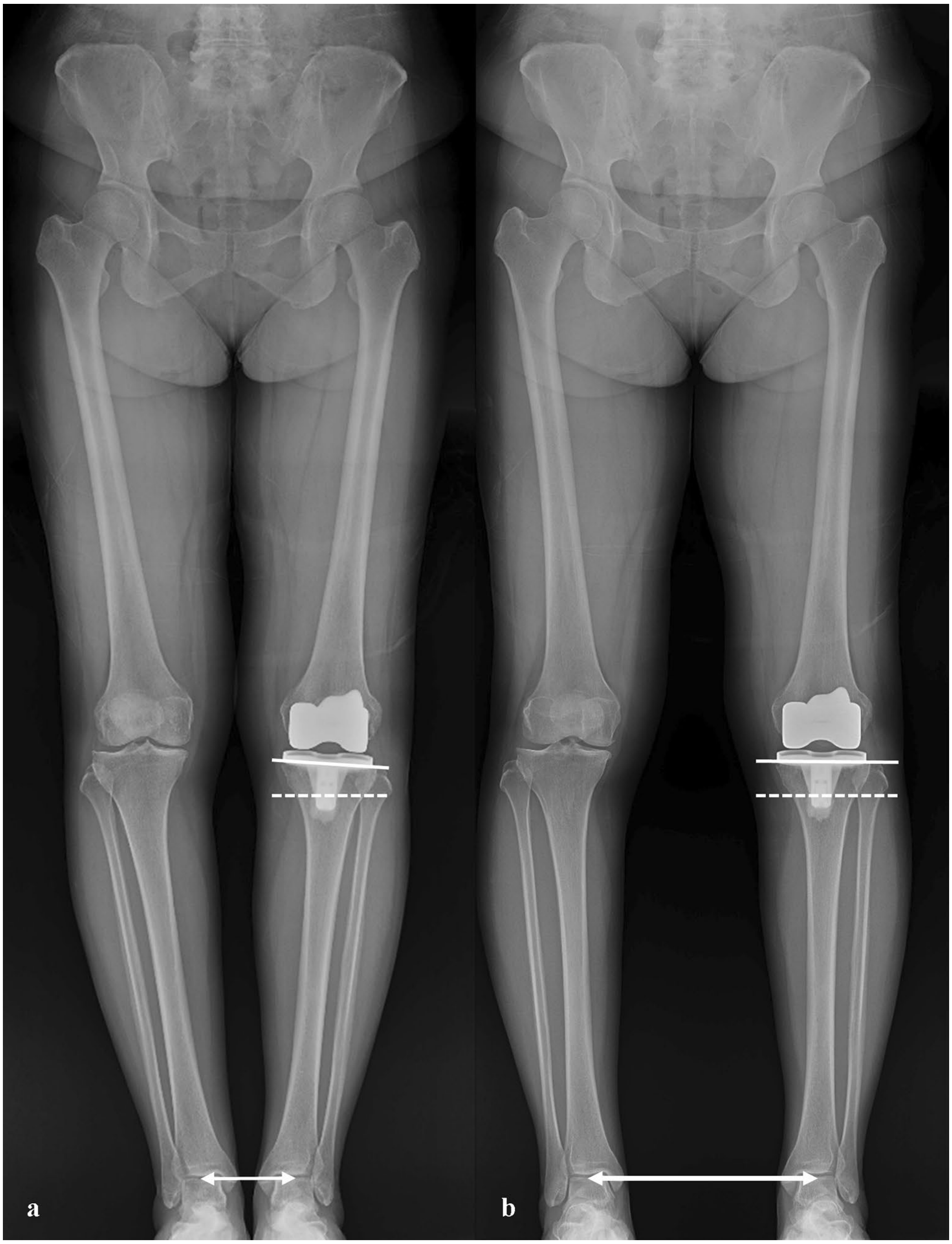

Fig. 2 Comparison of KJLO between two different foot positions. **a** The standing full lower limb AP radiograph of a patient with narrow ITD. **b** The standing full lower limb AP radiograph of the same patient with wide ITD. The KJLO is tilted further medially when the ITD is increased

KJLO regardless of component positions (Fig. 5) can also be explained by the fact that, in this study, all operations were performed with MA TKA with some degree of varus or valgus outliers.

In this study, AJLO was also identified as a determinant of KJLO after TKA ($r = 0.329$, $p < 0.001$). Lee et. al. [9] revealed that the KJLO after HTO can be compensated by AJLO changes. Our results support that KJLO can be affected by AJLO after TKA, as well as HTO. However, based on the equation, the effect of AJLO on KJLO was relatively small compared to other factors in this study (approximately 8°, 4°, and 1° KJLO change per 10° MPTA, LDFA, and AJLO changes, respectively). In addition, similar to KJLO, AJLO showed a positive correlation with ITD. Standardization of the distance between the feet might be necessary for the appropriate assessment of AJLO as well as KJLO.

This study has some limitations. First, the sample size in this study was relatively small. Although power analysis was performed in this study, these data cannot completely reflect

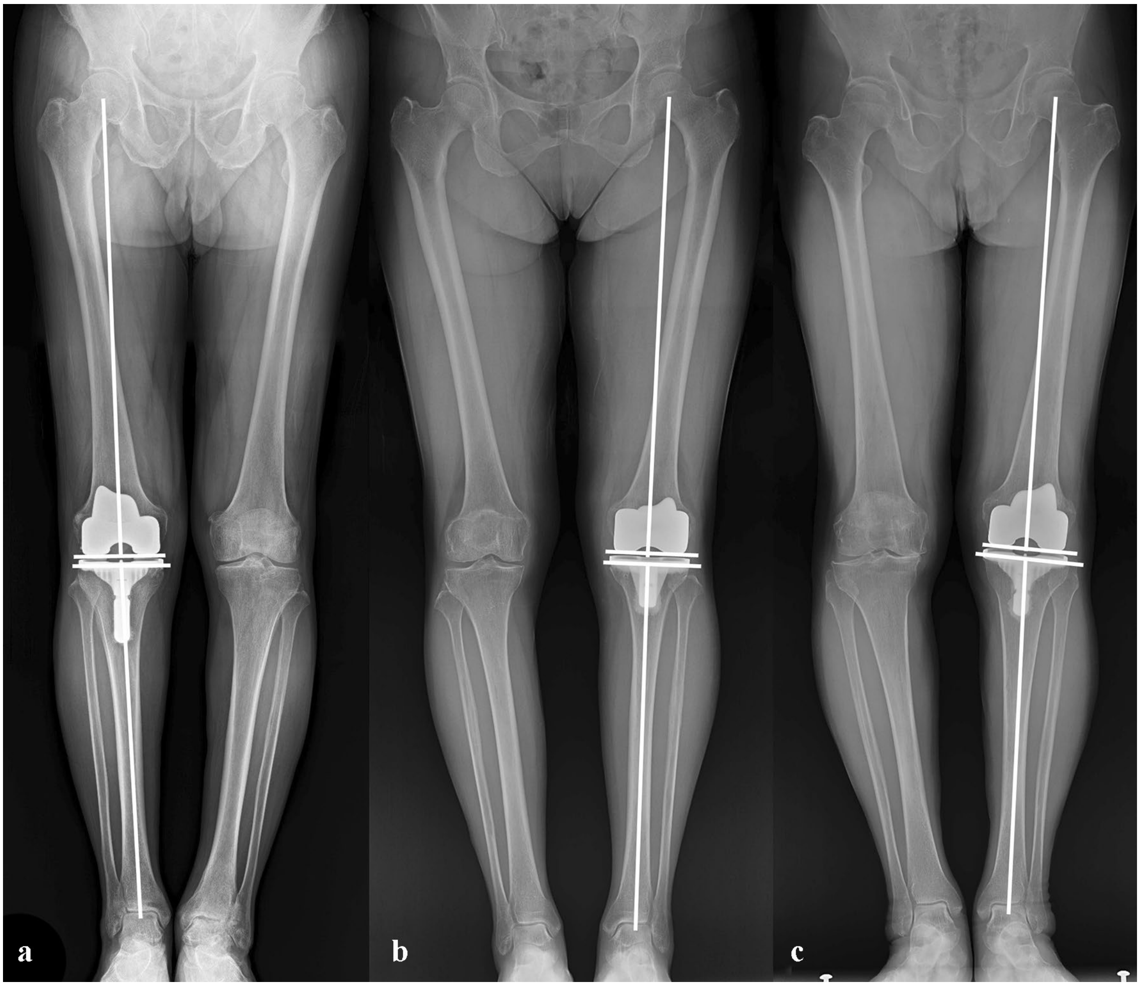

Fig. 3 Anatomical factors affecting the KJLO. **a** Parallel KJLO to the ground in patient with valgus femoral (LDFA < 90), and varus tibial (MPTA < 90) components. **b** 2° lateral tilt of KJLO in patient with neutral femoral (LDFA = 90), and neutral tibial (MPTA = 90) components. **c** 5° lateral tilt of KJLO in patient with varus femoral (LDFA > 90), and valgus tibial (MPTA > 90) components

Table 4 Multiple linear regression analyses of factors affecting postoperative KJLO after TKA

	Non-standardized		Standardized beta	*t*	*p* value
	B	Standard error			
LDFA	− 0.441	0.095	− 0.243	− 4.660	< 0.001
MPTA	− 0.832	0.116	− 0.372	− 7.185	< 0.001
ITD	0.037	0.003	0.671	12.597	< 0.001
AJLO	0.093	0.027	0.180	3.396	0.001

R^2 0.768, *KJLO* knee joint line orientation, *LDFA* lateral distal femoral angle, *MPTA* medial proximal tibial angle, *AJLO* ankle joint line orientation

all variations in anatomical and positional factors. Therefore, the effect of each determinant on KJLO can differ between the study populations. Nevertheless, considering the strong correlation between KJLO and ITD ($r = 0.745$, $p < 0.001$), we believe that the main finding would be similar even with an increased number of patients. Second, we assumed that the mediolateral soft tissue balance in the knee extension status was almost perfect. Therefore, the results of this study cannot be applied to patients undergoing TKA in which the joint of the femoral and tibial components are not parallel because of incomplete mediolateral ligament balancing. In these patients, the joint line convergence angle can also be considered as a determinant of KJLO after TKA. Third, in this study, various TKA implants were used in this study. However, all implants were of the posterior stabilized type and had a symmetrical design, so it was thought that the effect of implant type would be minimal in this study.

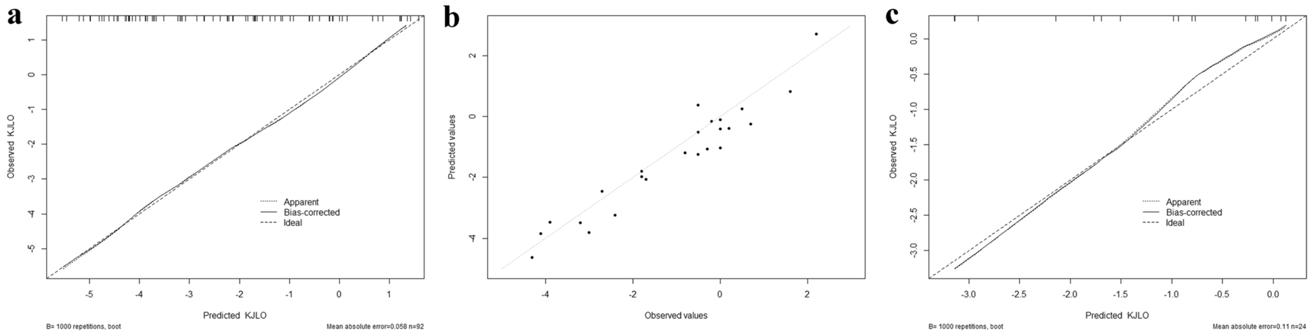

Fig. 4 Internal and external validation of the equation for the KJLO after TKA. **a** Internal validation showing satisfactory performance of the equation. **b** and **c** External validation demonstrating satisfactory performance of the equation

Table 5 Sub-group analysis of KJLO after TKA depending on the coronal alignments of femoral and tibial components

	(Group 1) VgF-VrT (*n* = 29)	(Group 2) VrF-VgT (*n* = 21)	(Group 3) VgF-VgT (*n* = 23)	(Group 4) VrF-VrT (*n* = 19)	*p* value						
					Total	Gr1 vs Gr2	Gr1 vs Gr3	Gr1 vs Gr4	Gr2 vs Gr3	Gr2 vs Gr4	Gr3 vs Gr4
KJLO (°)	−0.05 ± 2.31	−3.74 ± 2.51	−3.05 ± 1.65	−2.65 ± 2.15	.000	.000	.000	.000	.554	1.000	1.000
mTFA(°)	−0.07 ± 0.85	0.05 ± 1.16	1.72 ± 0.88	−2.23 ± 1.25	.000	1.000	.000	.000	.000	.000	.000
AJLO (°)	−2.55 ± 4.81	−4.06 ± 5.73	−3.75 ± 4.90	−4.35 ± 4.25	.619						
ITD (mm)	150.2 ± 47.2	133.5 ± 45.6	129.2 ± 45.4	135.9 ± 44.0	.466						

The data are presented as means and standard deviations for continuous variables. Statistical significance was set at $p < .05$

Vg valgus, *Vr* varus, *F* femoral component, *T* tibial component, *Gr* group, *ITD* intertalar distance, *mTFA* mechanical tibiofemoral angle, *KJLO* knee joint line orientation, *AJLO* ankle joint line orientation

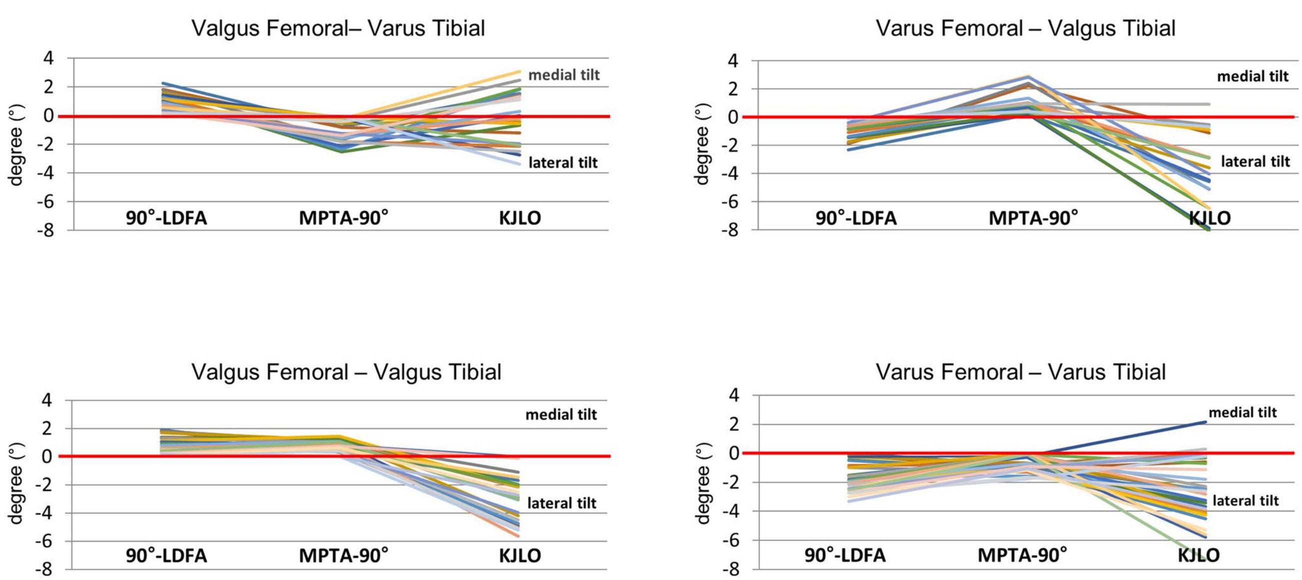

Fig. 5 Analysis of the KJLO between subgroups classified according to the coronal alignment of the femoral and tibial components. The KJLO of the valgus femoral-varus tibial group was more parallel to the ground than the other three groups

Conclusions

KJLO after TKA was strongly affected by the distance between the feet when taking full-limb radiography, and KJLO changed by 3.7° per 100 mm of distance between the feet**.** To assess the KJLO after TKA reproducibly, standardization of the distance between the feet is necessary.

Author contributions The authors have made the following contributions: (1) the conception and design (NKL, TWK, CBC), analysis and interpretation of the data (NKL, TWK, SL, YSC, CBC), (2) drafting of the article (NKL, TWK), critical revision of the article for important intellectual content (SHL, YSC, SBK, CBC), (3) Final approval of the article (NKL, TWK, SL, YSC, SBK, CBC).

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Declarations

Conflict of interest The authors have no competing financial interests.

Ethical approval This study was approved by the local ethical committee in Seoul national university Bundang hospital, Gyenggi-do, Korea (B-2013/672-105).

Informed consent The requirement for informed consent was waived due to the retrospective nature of the study.

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