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RESEARCH

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Ankle alignment before and after total knee arthroplasty in patients with valgus knee deformity

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Abstract

Background The impact of Total Knee Arthroplasty (TKA) on the biomechanics of bilateral ankle joints with valgus knees remains unclear. This study aimed to evaluate how unilateral TKA affects bilateral ankle tilt, limb alignment, and biomechanics in knee valgus.

Methods Among 105 patients with end-stage knee osteoarthritis and mild-to-moderate valgus deformity who underwent TKA between January 2021 and June 2023, 86 were included in the study retrospectively. The hip-knee-ankle angle (HKA), weight-bearing line ratio (WBLR), knee joint line convergence angle (KJLCA), knee joint line obliquity (KJLO), tibial anterior surface angle (TAS), tibial plafond inclination (TPI), talar inclination (TI), and tibiotalar tilt (TT) were measured on standing full-length lower limb radiographs preoperatively and postoperatively, with postoperative follow-up averaging 10.4 months. Patients were divided into Group A (0°~5°, 25 knees), Group B (5°~10°, 40 knees), and Group C (10°~15°, 21 knees) based on the degree of lower limb alignment correction. Additionally, patients were classified into contralateral knee varus (30 knees) and valgus (56 knees) groups based on the preoperative HKA angle of the contralateral knee.

Results With changes in HKA, both TAS and TT showed concurrent change. Postoperative TAS [93.2 (86.9, 116.8)] and TT [-0.4 (-5.9, 8.1)] showed a significant increase in absolute value compared to preoperative TAS [90.3 (83.1, 100.5)] and TT [0.2 (-5.2, 6.4)] ($P < 0.05$). This suggests that TKA may alter the inclination angle of the talar articular surface by correcting the lower limb mechanical axis. Postoperative comparisons of ΔTPI and ΔTI across correction groups revealed statistically significant differences ($P < 0.05$). These findings indicate that greater knee deformity is associated with a larger preoperative angle between the distal tibial articular surface and the horizontal plane. Correction of severe deformities increases the postoperative TI angle, leading to a more inclined talar articular surface. No correlation was observed between preoperative and postoperative HKA and alignment of the contralateral ankle joint.

Conclusion Before and after TKA, concurrent changes were observed in the ipsilateral ankle's inclination angle. For severe knee valgus deformities, maintaining a residual valgus deformity postoperatively should be considered to avoid postoperative ankle complications.

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Keywords Knee valgus deformity, Ankle alignment, Total knee arthroplasty, Lower limb alignment, Knee alignment

Introduction

Knee osteoarthritis (KOA) is a common chronic joint disease in the elderly [1]. Clinical symptoms typically include joint pain, tenderness, swelling, and functional limitations. TKA has become increasingly widespread due to its ability to effectively alleviate knee pain, enhance joint function and restore patients' daily living capabilities [2–4]. Globally, the number of TKA is increasing annually. In the United States, cases increased from 38,000 in 2005 to 55,000 in 2010, with the number expected to increase sixfold by 2030 [5]. Among patients undergoing TKA, knee varus deformity is the most common condition [6]. Knee varus deformity affects approximately 60–80% of patients undergoing TKA [7]. Further studies have shown that biomechanical imbalances in joints, which refer to the alignment, joint angles, stress distribution, and dynamic load characteristics of the lower limb joints (including the hip, knee, and ankle) under specific functional or activity conditions—are disrupted, are key contributors to knee and ankle osteoarthritis [8]. These biomechanical changes often result from anatomical deformities that disrupt lower limb alignment. The alignment of the lower limb is largely influenced by the structure of the hip, knee, and ankle joints [9]. Studies have found that patients with knee varus deformities often develop ankle valgus tilting due to the compensatory capacity of the subtalar joint, which counterbalances force line deviation through eversion. However, this compensation may disrupt ankle alignment, impair joint stability and function, and accelerate the progression of both knee and ankle osteoarthritis [10]. By correcting lower limb alignment during TKA, misalignment in the ankle joint can be partially corrected, potentially improving alignment and stability of the ankle joint [11]. Some studies suggest that approximately 23.2% of patients develop new or aggravated ankle symptoms following TKA, with those who have preoperative lateralized gait or talar tilt being at higher risk of postoperative ankle pain [12, 13]. In a study by Lee et al., preoperative and postoperative imaging of the ankle joint in 128 patients with varus knee deformity revealed that approximately 28 patients developed postoperative complications or exhibited progressive worsening of ankle arthritis [12]. Kikuchi et al. reported that following TKA for the correction of varus knee deformity, significant changes were observed in the radiological parameters of the ankle joint, with the weight-bearing line at the ankle level shifting more laterally postoperatively [14]. A recent study on patients with varus knee deformity undergoing inverse kinematic alignment—a surgical philosophy designed to restore soft tissue balance, function, and native anatomy within validated boundaries to achieve restricted native kinematics—revealed that postoperative coronal knee alignment following TKA influences the coronal alignment of the ankle joint, potentially preserving or minimizing significant coronal alignment changes in the ankle [15]. However, a limited number of clinical follow-up studies have investigated changes in lower limb alignment and the ankle joint in patients with knee valgus before and after surgery. Furthermore, previous studies have not elucidated how knee valgus specifically influences lower limb alignment or the quantitative relationship between the valgus angle and ankle joint load distribution. This may be due to the relatively less common occurrence of knee valgus than of knee varus and the insufficient number of cases, which may have resulted in inadequate attention in clinical practice. This study aims to explore ankle alignment in patients with valgus knee deformities before and after TKA. We hypothesize that correcting lower limb alignment with TKA will alter the ipsilateral ankle's tilt angle, where the inclination angle refers to the degree of inclination of anatomical structures relative to a reference axis, such as the lower limb mechanical axis, joint alignment, and biomechanical properties. Furthermore, we will assess whether the contralateral ankle, which did not undergo surgery, exhibits any changes preoperatively and postoperatively, providing clinical reference data.

Materials and methods

Based on preliminary studies or literature data, we set the expected effect size to 0.8 (medium effect size), with a significance level (α) of 0.05 and a statistical power ($1 - \beta$) of 0.80. Using SPSS 27.0 statistical software for calculation, the results indicated that a minimum of 20 samples per group is required to achieve the desired statistical power.

Upon completion of the data analysis, we conducted a post-hoc power analysis to verify whether the actual sample size was sufficient to support the study's conclusions. The results of the analysis indicated that the actual power of this study was 83%, exceeding the predefined threshold of 80%, demonstrating that the sample size was adequate.

Ultimately, a total of 105 patients with valgus knee osteoarthritis who underwent TKA between January 2021 and June 2023 were selected at the Zhongshan Hospital of Traditional Chinese Medicine Affiliated to Guangzhou University of Traditional Chinese Medicine, with 86 cases ultimately being included in the study. The study was approved by the Ethics Committee of our institution (2024ZSZY-LL-KY-215), and informed consent was obtained before patient enrollment. Prior to the start of formal screening and measurements, all candidate patients were fully informed about the study and signed a written informed consent form. This study is classified as Level III evidence based on the Oxford Centre for Evidence-Based Medicine guidelines, as it is an observational study without a control group.

The inclusion criteria for patients were as follows: (1) patients were diagnosed with end-stage (significant joint space narrowing (joint space width < 2 mm) as observed on X-ray or MRI, accompanied by the presence of prominent osteophytes and subchondral sclerosis) knee osteoarthritis and presented with mild to moderate valgus deformity [HKA (165°–180°)]. All patients underwent primary total knee arthroplasty; (2) had clear and complete preoperative and postoperative full-length DR (Digital Radiography) images of both lower limbs in the weight-bearing position; (3) good function of surrounding knee soft tissues, including the medial and lateral collateral ligaments (Valgus and varus stress tests were conducted by applying lateral stress with the knee fully extended and at 30° flexion, assessing changes in medial and lateral joint spaces and pain response. Ligament stability was defined as joint space expansion of less than 5 mm under stress without pain); (4) knee flexion-extension range of motion ≥ 90°, flexion contracture ≤ 15°; the exclusion criteria were as follows: (1) Patients with active knee joint infection; (2) Patients with bilateral lower limb motor dysfunction caused by cerebrovascular accident; (3) Postoperative knee flexion limited to < 90° or flexion contracture > 10°, lasting for at least 3 months; (4) Lower limb deep vein thrombosis (Lower limb DVT confirmed by ultrasound); (5) Preoperative ankle instability (The anterior drawer test assesses anterior talofibular ligament (ATFL) stability, while the inversion stress test evaluates the integrity of the lateral ligament complex. Ankle instability is defined as increased joint mobility (anterior displacement > 5 mm or inversion angle > 10°) with associated pain symptoms).

Surgical procedure

The preoperative team assessed the degree of knee valgus, including X-ray imaging, to determine the osteotomy level and appropriate prosthesis to achieve neutral mechanical alignment, defined as a hip-knee-ankle angle (HKA) of 180° ± 3°. For patients with anatomical abnormalities, the surgical target may require appropriate adjustments. Intraoperative fine-tuning is performed based on the feedback from the navigation system and the surgeon's expertise to ensure maximal postoperative functionality. However, these patients were not included in the study cohort for observation. All patients received a posterior cruciate-stabilizing TKA prosthesis. The patient was positioned supine on the operating table and administered general anesthesia to ensure a pain-free and relaxed state throughout the procedure. A tourniquet was applied to the proximal thigh, and routine disinfection with iodine and alcohol was performed. Sterile drapes were placed, and a protective film was applied. The medial parapatellar approach was used, with an incision length of approximately 10–15 cm. The joint capsule was incised along the medial side of the patella to expose the knee joint. The distal femur was resected using intramedullary alignment, and the proximal tibia was resected using extramedullary alignment. The medial and lateral menisci, posterior femoral osteophytes, and tight soft tissues were subsequently debrided and released. During osteotomy, special care must be taken to maintain the lower limb alignment and joint stability. The patellar tracking is tested to ensure normal movement. The lower limb alignment and the balance between the extension and flexion gaps are assessed. The trial prosthesis is then removed, the joint is thoroughly irrigated, and the final prosthesis is implanted with bone cement. The incision was sutured layer by layer, ensuring that the wound remained clean and dry to prevent infection. Postoperatively, the patient was provided with fluid replacement and received symptomatic treatment, including anti-infection, anticoagulation, hemostasis, anti-inflammatory, and analgesic therapy. On the first postoperative day, patients began active quadriceps contraction exercises. By the second day, they performed partial weight-bearing rehabilitation with the aid of a walker. Full weight-bearing walking practice commenced after one week.

Methods for measuring lower limb angles and length

Two independent observers (radiologists or clinicians) were invited to evaluate all key measurement parameters. The intraclass correlation coefficient (ICC) was used to assess the consistency between observers. An ICC value greater than 0.75 is considered to indicate good agreement. The results showed an inter-observer ICC value of 0.79, demonstrating a high level of consistency in the measurements. The same observer repeated the measurements on the same dataset at different time points (with a 3-day interval) to evaluate their own consistency. The ICC was used to assess intra-observer reliability, and the results showed an ICC value of 0.84, indicating a high level of reproducibility in the measurements.

Standard shooting position for full-length DR images of both lower limbs in the weight-bearing position:

Patient positioning protocol: The patient remained in an upright position with feet shoulder-width apart and fully straight knees; Bilateral both tips forward to ensure natural alignment of the lower limbs; Patients evenly distribute their weight to both feet to avoid excessive weight bearing on one side.

Equipment calibration: First, we regularly calibrated the ray equipment to ensure the consistency of parameters including exposure time, ray intensity, contrast and so on. We also used standardized test objects (phantom) to verify the resolution and imaging quality of the device to detect any possible bias. In addition, the exposure time and ray intensity of the ray device are adjusted before each shoot to ensure the stable image quality of each shot. During image processing, we used standardized post-processing procedures to ensure the consistent quality of all images. All calibration and quality control processes are performed by skilled technicians and have detailed records to ensure that the ray equipment is always in optimal operation.

Quality control measures: First, all radiographic equipment underwent regular calibration and maintenance to ensure stability and consistency during each imaging session. We utilized standardized phantoms to test equipment performance and continuously monitored key parameters, such as exposure levels and radiation intensity, through quality control charts. Additionally, all X-ray images were subjected to strict quality checks to ensure that resolution, contrast, and exposure levels met established standards. The post-processing of images also adhered to standardized protocols to maintain image clarity and accuracy. All operators received regular training, held relevant certifications, and followed operational guidelines. Finally, all quality control data were documented and tracked, allowing for rapid adjustments and improvements in case of any issues.

Image standardization: First, all shooting conditions (such as exposure time, ray intensity, and shooting angle) remained consistent to ensure comparable image quality. All subjects were photographed according to uniform loading standards to ensure consistency of weight bearing status. The shooting equipment was also regularly calibrated to ensure the accuracy of the equipment during each shoot. Furthermore, we used standardized positioning guidance and positioning equipment to ensure consistency in patient positioning. All images are subjected to a unified post-processing procedure to ensure the same quality of each X-ray sheet, and through the quality control and review by professional technicians to ensure the accuracy and reliability of the data.

In this study, the time interval between measurements was set to 24 h to ensure sufficient time for the intervention effects to manifest and to avoid potential interference from immediate effects on the results. The image acquisition was conducted randomly. Specifically, the timing and order of image collection were randomized using a computer program to minimize potential order effects and biases.

(1) HKA: angle between the femoral mechanical axis and the tibial mechanical axis. (2) WBLR: the intersection of the lower limb mechanical axis and the tangent line of the tibial plateau, with the ratio of the distance from the intersection to the medial edge of the tibial plateau to the tibial plateau tangent line. (3) KJLCA: The angle between the tangent to the femoral condyle cartilage and the tibial plateau. (4) KJLO: The angle formed by a line parallel to the ground and a line tangent to the tibial plateau. (5) TAS: The angle between the tibial anatomical axis and the line connecting the talar joint surface. (6) TPI: The angle between the cartilage plate of the distal tibial joint surface and the vertical line to the ground. (7) TI: The angle between the talar joint surface and the vertical line to the ground. (8) TT: The angle between the cartilage plate of the distal tibial joint surface and the talar joint surface. To enhance measurement accuracy, the angles were measured three times in a blinded manner by a professional orthopedic surgeon using the measurement tools provided by the platform www.geogebra.org (Version 6.0.873.2). This software has been widely adopted in scientific research due to its robust geometric computation and image analysis capabilities. To validate the measurement functionality of Geogebra, we utilized standard models with known geometric parameters (e.g., calibration phantoms). The measurements obtained from the software were compared against the standard values, and the error margin was found to be within 1%, indicating that its measurement accuracy meets the requirements of this study. Furthermore, the measurements from Geogebra were compared with those from other validated measurement tools (e.g., specialized medical imaging analysis software). The results demonstrated a high level of agreement between the two methods ($ICC = 0.81$, $p < 0.05$). Spatial vectors were used to measure both angles and lengths, with the average of the three measurements calculated. For the KJLCA, KJLO, and TT angles, a positive value is assigned when the two lines intersect with the opening facing outward. The detailed measurement methods are outlined in Fig. 1.

Grouping method

The change in HKA before and after surgery was used to evaluate the degree of correction of the lower limb mechanical axis. Patients were divided into three groups: Group A, with HKA correction angles ranging from 0° to 5°; Group B, with angles from 5° to 10°; and Group C, with angles from 10° to 15°. To observe the preoperative and postoperative changes in the contralateral ankle joint, patients were classified into varus and valgus groups based on the preoperative HKA angle of the contralateral knee.

Statistical analysis

Data analysis was performed using SPSS version 27.0. First, descriptive statistical analyses, including the mean, standard deviation, skewness, and kurtosis, were conducted to preliminarily assess the distribution

Fig. 1 (See legend on next page.)

(See figure on previous page.)

Fig. 1 Measurement of lower limb angles and length

Note: **vector A**-the mechanical axis of the femur; **vector B**-the mechanical axis of the tibia; **segment C**-the mechanical axis of the lower limb; **vector F**-the horizontal line to the ground; **vector D**-the subchondral plate of the femoral condyle; **vector E**-the tangent to the tibial plateau;

(1) HKA: The outward angle between vector A and vector B; (2) WBLR: The intersection of the lower limb mechanical axis (C) and the tibial plateau tangent (E) is defined as point L. The ratio of the distance between the most medial point (K) of the tibial plateau and point L to the mediolateral distance (KM) of the tibial plateau is then determined; (3) KJLCA: The angle between vector D and vector E; (4) KJLO: The angle between vector E and vector F;

Note: **vector G**-the anatomical axis of the tibia; **vector H**-the subchondral plate of the distal tibial articular surface; **vector I**-the talar dome articular surface; **vector J**-the vertical line to the ground;

(5) TAS: The angle between vector G and vector I; (6) TPI: The angle between vector H and vector J; (7) TI: The angle between vector I and vector G; (8) TT: The angle between vector H and vector I.

characteristics of the data. Subsequently, given the small sample size in this study, the Shapiro-Wilk test was employed to evaluate the normality of the data. Quantitative data are presented as x ± s for normal distributions and as the median for skewed distributions. Preoperative and postoperative comparisons of HKA, WBLR, KJLCA, KJLO, TAS, TPI, TI, and TT were conducted for all patients. Paired t-tests were used for normally distributed data, with the t-value representing the difference in changes between the paired samples. While the Wilcoxon rank-sum test was applied for skewed data, with the Z-value indicating the difference in changes between the paired samples. Correlation analysis was conducted using Pearson's correlation test for normally distributed data and Spearman's rank correlation test for skewed data. Intergroup comparisons of preoperative and postoperative differences in HKA, WBLR, KJLCA, KJLO, TAS, TPI, TI, and TT across the three groups were conducted. One-way ANOVA was used for normally distributed data, and the Kruskal-Wallis rank-sum test was applied for skewed data. Pairwise comparisons between groups were adjusted using the Bonferroni correction. A P-value of <0.05 was considered statistically significant.

Furthermore, we fully acknowledge that unequal sample sizes between groups may potentially influence the outcomes of statistical analyses. To ensure the reliability and validity of the results, we implemented the following measures: For parametric tests (e.g., t-tests or ANOVA), we applied correction methods suitable for unequal group sample sizes, such as Welch's t-test and Welch's ANOVA. These methods do not rely on the assumption of homogeneity of variances between groups and are effective in addressing sample size imbalances. For non-parametric tests (e.g., Mann-Whitney U test or Kruskal-Wallis test), their application to data analysis with unequal group sample sizes is straightforward, as they do not depend on assumptions regarding data distribution or sample size.

Results

Table 1 presents the comparison of baseline characteristics, including sex, age, disease duration, and body mass index (BMI), revealed no significant differences among the three groups ($P>0.05$), indicating that the baseline characteristics were comparable. The postoperative follow-up period ranged from 8 to 14 months, with a mean follow-up duration of 10.4 ± 2.6 months (The follow-up period refers to the time span from patient enrollment to the final data collection).

We defined the onset of knee osteoarthritis as the first occurrence of significant knee symptoms, such as pain, swelling, or restricted movement, or when radiographic examinations (e.g., X-rays) revealed evident pathological changes, such as joint space narrowing or osteophyte formation. Both patient self-reports and clinical diagnoses were considered valid indicators of onset. We collected this information retrospectively through patient questionnaires and confirmed it with clinical diagnoses.

The disease duration is calculated from the time when the patient first experienced symptoms or was clinically diagnosed with knee osteoarthritis. This time point is determined by clinical assessment, including physical examination and radiographic findings.

As shown in Table 2, the postoperative TAS and TT were significantly greater than preoperative values ($P<0.05$), this indicates that total knee arthroplasty (TKA) altered the angle of the articular surface of the talus, causing certain changes in the subtalar joint postoperatively; Preoperative TT [0.2° (-5.2°, 6.4°)] changed to postoperative TT [-0.4° (-5.9°, 8.1°)], indicating a shift in the direction of the TT angle from external to internal. This suggests that the correction procedure alleviated the varus state of the ankle joint. Additionally, in some patients with knee valgus, the postoperative ankle joint was left in a mild everted position.

Significant differences were observed in ΔTPI and ΔTI between the groups. For TPI: Group A: Preoperative 93.9°±4.2, Postoperative 93.5°±4.7. Group B: Preoperative 96.7°±4.4, Postoperative 95.3°±4.1. Group C: Preoperative 100.1°±5.3, Postoperative 96.5°±6.9. The ΔTPI increased with the correction angle of HKA and remained negative, showing a statistically significant difference ($P<0.05$). Postoperatively, there were no significant differences in TPI values among the three groups ($P>0.05$). This indicates that as the degree of knee deformity increased, the preoperative TPI angle with respect to the horizontal plane became larger. Although postoperative TPI values showed no significant differences among the groups,

Table 1 General characteristics of the patients

Group	Number of cases	Age (years)	Men: *n* (%)	BMI/kg/m^2	Disease duration(months)
A	25	62.1 ± 7.2	4(16.0)	23.1 ± 2.2	38.4 ± 12.4
B	40	66.3 ± 6.2	6(15.0)	23.4 ± 2.5	43.2 ± 9.7
C	21	71.6 ± 8.2	3(14.3)	23.7 ± 3.1	55.8 ± 8.3
P		0.203	0.996	0.441	0.239

Table 2 Comparison of the overall mean values of knee and ankle joint measurements preoperatively and at the final follow-up

	number	HKA (x° ± s)	WBLR (%)	KJLCA (x° ± s)	KJLO (x° ± s)	TAS (x° ± s)	TPI (x° ± s)	TI (x° ± s)	TT (x° ± s)
Pre-operative	86	171.2 ± 3.9	87.2 ± 18.1	-1.9 ± 2.6	3.5 (-2.8,18.3)	90.3(83.1,100.5)	95.8(89.3,109.3)	95.1(89.2,107.9)	0.2 (-5.2,6.4)
Post-operative	86	178.6 ± 2.7	56.7 ± 11.4	-0.5 ± 1.0	0.9 (-4.1,6.6)	93.2(86.9,116.8)	95.1(84.7,114.4)	95.7(87.9,119.2)	-0.4(-5.9,8.1)
Z(t)		-18.502	16.424	-4.467	-6.280	-6.110	-0.822	-0.213	-2.498
P		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.411	0.831	0.013

Table 3 Comparison of the preoperative and final follow-up differences in knee and ankle joint indices across different correction groups

Group	Number	ΔHKA (x° ± s)	ΔWBLR (%)	ΔKJLCA (x° ± s)	ΔKJLO (x° ± s)	ΔTAS (x° ± s)	ΔTPI (x° ± s)	ΔTI (x° ± s)	ΔTT (x° ± s)
A	25	3.1 (0.3,4.6)[1) 2)]	-10.8± 6.2[1) 2)]	0.0± 2.1[1) 2)]	-0.9 (-6.7,4.0)[1) 2)]	1.8 (-6.2,11.5)	-0.4± 4.6[1) 2)]	0.1± 5.2[1) 2)]	0.1 (-4.0,3.4)
B	40	7.4 (5.1,9.8)[3)]	-30.8± 6.3[3)]	1.1± 2.7[3)]	-2.8 (-18.6,2.7)[3)]	3.5 (-7.1,18.3)	-1.4± 3.2[3)]	2.0± 4.2[3)]	-0.5(-6.3,7.3)
C	21	12.7(10.1,14.9)	-53.3± 10.2	3.4± 2.3	-5.2 (-11.2,2.3)	3.0 (-2.0,16.3)	-3.6± 5.2	2.2± 6.1	-0.6(-8.7,2.1)
F		73.135	188.089	11.357	14.544	1.501	7.585	3.749	1.150
P		< 0.001	< 0.001	< 0.001	< 0.001	0.472	< 0.001	0.028	0.563

Note: (1) Comparison between group A and group B, $P < 0.05$; (2) Comparison between group A and group C, $P < 0.05$; 3) Comparison between group B and group C, $P < 0.05$

Data are presented as Mean ± Standard Deviation (SD) or Median [Range], depending on the distribution characteristics of the data (normal or skewed)

Table 4 Correlation between the preoperative angle of the contralateral ankle joint and the preoperative HKA on the surgical side

Contralateral knee varus or valgus	Knee varus				Knee valgus			
	TT	TI	TPI	TAS	TT	TI	TPI	TAS
r	-0.279	-0.080	-0.080	0.028	-0.106	-0.039	-0.085	0.108
P	0.135	0.675	0.675	0.885	0.439	0.778	0.535	0.426

Table 5 Correlation between the angle of the contralateral ankle joint measured at the final follow-up and the HKA on the surgical side

Contralateral knee varus or valgus	Knee varus				Knee valgus			
	TT	TI	TPI	TAS	TT	TI	TPI	TAS
r	0.110	0.174	0.231	0.163	0.089	0.043	0.052	0.175
P	0.562	0.357	0.220	0.388	0.512	0.755	0.701	0.197

all postoperative values were lower than preoperative values, indicating that the distal tibial articular surface became more parallel to the ground after surgery. For TI: Group A: Preoperative 93.9°±4.8, Postoperative 94.0°±5.5. Group B: Preoperative 96.6°±4.7, Postoperative 98.6°±4.8. Group C: Preoperative 97.2°±7.7, Postoperative 99.4°±5.1. The ΔTI increased with the HKA correction angle and was positive, showing a statistically significant difference ($P < 0.05$). Both preoperative and postoperative TI values showed significant differences among the three groups ($P < 0.05$). This indicates that as the deformity angle increased, the preoperative and postoperative TI angles relative to the horizontal plane became larger, with postoperative mean TI values exceeding preoperative values in each group. (Table 3).

Neither the preoperative nor the postoperative angles of the contralateral ankle joint showed a significant correlation with HKA ($P > 0.05$) (Tables 4 and 5).

Discussion

This study revealed that, in patients with knee valgus, deformity correction led to concurrent changes in the mechanical axis of the affected lower limb, the inclination angles of the ankle joint, joint alignment, and biomechanical status. However, no significant differences were observed in the angle of the contralateral ankle joint.

Effect of correction of valgus knee deformity by TKA on the inclination angles of both ankle joints

One of the aims of this retrospective study is to evaluate changes in the bilateral ankle tilt angle after TKA in valgus knee joints. Kim et al. [16] noted that patients who undergo TKA for the correction of knee varus exhibit compensatory changes in the alignment and inclination angles of ankle joints. Kwon et al. [17] conducted a multiple linear regression analysis on knee varus patients and found that both TKA and high tibial osteotomy affected the subtalar and ankle joints postoperatively. However, their study did not address the effect of valgus knee on the ankle joint. Our study found that, postoperatively, the TAS and TT angles of the same-side ankle joint were significantly increased compared to preoperatively ($P < 0.05$), suggesting that TKA was associated with changes in the angle of the talar articular surface by correcting the mechanical axis of the lower limb, thereby inducing compensatory biomechanical changes in the subtalar joint over the medium to long term. The author suggests that a potential reason is that TKA not only modifies the alignment of bony structures but may also disrupt the balance of surrounding soft tissues (e.g., ligaments, tendons, and joint capsules). Such alterations in soft tissue balance may further impact the biomechanical properties of the ankle joint, resulting in increased TAS and TT angles. Therefore, during the perioperative period, it is essential to thoroughly assess the balance of soft tissues surrounding the knee and ankle joints, particularly to identify postoperative excessive laxity or tightness. If such conditions are present, soft tissue balance should be promptly restored through rehabilitation training or surgical intervention. Although no significant differences were observed in the TI angle between the preoperative and postoperative measurements, as shown in Table 2, the TI angle increased compared to preoperatively, which may, to some extent reflect concurrent changes and suggest that biomechanical reorganization may occur in the subtalar joint. Regarding the postoperative change in the TI angle, Shichman's conclusion aligns with ours. However, in contrast to their study, which only assessed the preoperative and postoperative TI angles in patients with a valgus deformity greater than 10°, our study included a wider range of valgus deformities (0–15°) and a larger sample size, allowing us to observe a broader range of associations between deformities [18]. As shown in Table 2, we further observed that the TPI decreased compared to preoperatively, suggesting that the degree of tibial distal joint surface inclination can be corrected with surgical correction of knee valgus deformity, making it more parallel to the ground. This result contrasts with previous studies, which found that in the knee varus correction group, surgery corrected the varus deformity and altered the TPI angle, whereas no such changes was observed in the knee valgus group [19]. The author suggested that the primary cause for this phenomenon may be related to the size of the correction angle. Shichman et al. [18] focused on patients with knee valgus greater than 10°, and it is possible that the compensatory changes in the TPI angle that occurred preoperatively in this population became irreversible postoperatively due to the longer duration of the condition. Table 3 further demonstrates that preoperatively, as the deformity angle increased, the distal tibial articular surface became increasingly misaligned with the horizontal plane. Regarding the TT angle, we observed that it was positive preoperatively, indicating that patients with knee valgus often present with a certain degree of ankle varus before surgery. The author suggests that a potential reason is that the subtalar joint, a critical regulator of lower limb biomechanics, may compensate for abnormal lower limb alignment induced by knee valgus through adaptive changes. Further analysis of the postoperative TT data revealed that, following correction, the ankle varus was alleviated, some patients exhibited a mild eversion position of the ankle. Based on the change in the TT angle, we concluded that in patients with knee valgus, the ankle was positioned in varus, while knee varus led to a certain degree of ankle valgus. Scholars including Norton et al. [10, 20, 21] have drawn similar conclusions in their research on the effects of correcting knee varus on the ankle joint. Regarding the effects on the contralateral ankle joint, our study found no significant differences in the TT, TI, TPI, and TAS angles of the contralateral side between preoperative and postoperative HKA values, regardless of whether the contralateral knee was varus or valgus ($P > 0.05$). Gao et al. [22] also assessed the alignment of the contralateral ankle joint after TKA, their finding was consistent with ours: TKA did not significantly affect the alignment of the non-operative ankle joint, further support for the results of the present study. The author suggests that this may be because TKA primarily restores the lower limb mechanical axis by correcting the alignment of the surgical side knee joint (HKA), whereas the alignment of the contralateral lower limb remains unaffected. Consequently, the biomechanical properties of the contralateral ankle joint (e.g., TT, TI, TPI, and TAS angles) may remain relatively stable, with no significant changes observed. However, in contrast to their study, we conducted a subgroup analysis by dividing the contralateral knee joint into varus and valgus groups to investigate potential differences. The analysis revealed no significant correlation. Although the mechanism linking knee deformities to degenerative changes in the ankle joint remains unclear, the association between knee deformities and ankle osteoarthritis has been established [23]. Muehleman et al. discovered in a cadaveric study of severe knee deformities that these individuals often exhibited significant degenerative changes in the ankle joint [24].

The link between knee valgus, lower limb alignment, and biomechanics

The knee joint, one of the largest and most structurally complex joints in the human body, is crucial for supporting body weight and facilitating daily movement. Due to its unique structure, the knee joint must bear significant loads while maintaining flexibility, which accelerates cartilage wear and contributes to the development of knee osteoarthritis [25]. Postoperatively, both KJLCA (-0.5° ± 1.0) and KJLO [0.9° (-4.1°, 6.6°)] angles were reduced compared to preoperative values, with statistically significant differences ($P < 0.05$). This led to an increase in the lateral knee joint gap and a reduction in lateral stress, indicating that medial and lateral stresses became more balanced after valgus knee correction surgery. In addition, this study divided the patients into three groups based on the severity of lower limb mechanical axis valgus deformity, with the aim of comparing the degree of ankle joint tilt relative to the ground under different preoperative valgus conditions. The results revealed that after the lower limb mechanical axis was corrected, changes in the TPI, TAS, TI, and TT values were observed to varying degrees. It suggested that in order to adapt to different degrees of valgus deformity, the distal tibial joint surface, the subtalar joint surface, and the tibio-talar joint surface all underwent corresponding tilting changes. This indicates that the mechanical distribution in the weight-bearing position of the ankle joint differs under various degrees of valgus deformity across the groups.

TKA in patients with severe knee valgus deformity

The mechanical axis alignment has long been regarded as the "gold standard" technique for alignment in TKA. Positioning the prosthesis perpendicular to the mechanical axes of the tibia and femur ensures a balanced distribution of shear forces and stresses in the tibiofemoral compartment, restores neutral alignment of the lower limb, and optimizes biomechanics for the prosthetic knee [26–28]. However, studies suggest a different perspective for patients with severe knee valgus deformity: complete correction of the lower limb alignment may cause the ankle joint to fail to adapt to the overcorrection, potentially resulting in postoperative issues such as foot and ankle pain. Graef's team [29] conducted a follow-up study with 91 patients with knee valgus deformity (mTFA ≥ 15°; mechanical tibio femoral angle) who underwent TKA, assessing their ankle joints under both standing and walking conditions before and after surgery. Their study concluded that excessive emphasis on achieving neutral alignment of the lower limb mechanical axis could cause the ankle joint, already significantly altered, to fail to adapt to the post-surgical correction. This is likely the primary cause of aggravated ankle symptoms following surgery. Despite significant advancements in surgical techniques and prosthetic materials, studies indicate that TKA still has a dissatisfaction rate of approximately 11–25% [30–32]. This includes postoperative ankle stability. Gursu et al. assessed the ankle morphology and alignment in 78 patients with knee deformities exceeding 10° who underwent TKA. Their study concluded that overcorrection of knee deformities can disrupt ankle alignment, resulting in postoperative ankle pain [33]. Our study also confirmed this finding. In our study, patients with knee valgus were divided into three groups based on the degree of lower limb mechanical axis correction, and a comparative analysis was conducted. The results showed that after the surgery, the HKA correction value was directly proportional to the TPI, TI, and TT values. With the correction of the lower limb mechanical axis, there were no significant differences in postoperative TPI, TI, and TT values between the three groups. This suggests that the ankle joint needs to adjust its tilt angle relative to the ground in response to changes in the mechanical axis, even in patients with severe valgus knees. This indicates that the biomechanical state of the ankle joint changes under weight-bearing X-ray examination, which can lead to alterations in the tension of the medial and lateral joint capsules and ligaments of the ankle joint. Consequently, this may cause postoperative discomfort or joint instability, especially in patients with a history of ankle trauma, such as ligament injuries. As knee deformity increases and is corrected, the postoperative TI angle increases (TI: Group A: Preoperative 93.9°±4.8, Postoperative 94.0°±5.5. Group B: Preoperative 96.6°±4.7, Postoperative 98.6°±4.8. Group C: Preoperative 97.2°±7.7, Postoperative 183 99.4°±5.1), causing the alignment of the talar articular surface to become more inclined. This may lead to abnormal biomechanical conditions in the tibiotalar joint in some postoperative patients. Therefore, as surgeons, we should assess the ipsilateral ankle joint in patients with severe knee valgus deformity prior to surgery. Retaining a certain degree of knee valgus may be beneficial to prevent excessive correction of the lower limb mechanical axis, which could reduce ankle joint discomfort after surgery and potentially improve clinical outcomes and patient satisfaction. With advancements in technology and the growing adoption of robot-assisted system, for patients with severe knee valgus, the robot-assisted system can be utilized intraoperatively to monitor lower limb alignment and joint load distribution in real-time, ensuring the accurate achievement of surgical objectives [34]. Additionally, for these patients, intraoperative adjustments to lower limb alignment or combined ankle correction surgery may be considered. Will residual valgus deformity after TKA affect the lifespan of the prosthesis? Batailler et al. [35] conducted a follow-up study on 94 patients with severe knee valgus, comparing those with residual valgus angles greater than 3° after correction to those who achieved normal neutral alignment. They found that both groups achieved similarly good functional recovery outcomes, with no significant difference in clinical efficacy. Multiple studies have confirmed that residual valgus or varus does not affect the prosthesis's long-term survival rate. A follow-up study by the Mayo Clinic team [36, 37] involving approximately 400 patients who underwent TKA showed that, compared to the neutral alignment group, there was no significant difference in the prosthesis's long-term survival rate when the postoperative mechanical axis deviation exceeded ± 3°. Therefore, in patients with severe knee deformities, maintaining a residual valgus deformity during correction may not only preserve the long-term survival of the knee prosthesis but also delay degenerative changes in the ankle joint. However, there is currently insufficient data to define the specific range, so further research is needed on the range of maintaining alignment in patients with concomitant ankle symptoms on the same side. Furthermore, if excessive correction of the knee joint causes the postoperative ankle tilt to worsen compared to the preoperative condition, interventions such as adjusting insoles or physical therapy during rehabilitation may be considered to alleviate ankle discomfort. Braga et al. [38] conducted a study involving 19 patients with ankle varus deformity and found that custom-made wedge insoles could modify the movement and torque patterns of the ankle joint, thereby enhancing the biomechanical environment of the foot and ankle. In conclusion, the human body functions is an integrated system. While the surgeon focuses on the realignment of the lower limb axis, restoration of knee joint mobility, and balance of surrounding soft tissues, a tailored rehabilitation plan for the knee and ankle joints of each patient should also be developed postoperatively to minimize postoperative complications.

This study also has several limitations: Firstly, DR full-length lower limb images are two-dimensional, while patients are three-dimensional beings, which introduces certain limitations in X-ray imaging. Secondly, due to the relatively low incidence of knee valgus, the number of cases included in this study was limited. Consequently, it may also be influenced, to some degree, by potential disparities in group size. In addition, more long-term follow-up is needed to assess the long-term effects of TKA on the ankle joint. Finally, the above data lack functional outcome measures and control group, only assessing ankle alignment changes exclusively through static radiographic measurements. Future studies should incorporate larger sample sizes and multicenter data to enhance the generalizability and reliability of the findings. Additionally, long-term follow-up (e.g., 5 or 10 years) should be performed, integrating assessments of soft tissue balance, gait analysis, and dynamic imaging parameters to comprehensively evaluate changes in lower limb biomechanics. For patients with ankle valgus, further research is needed to determine whether ankle correction surgery should be combined with TKA and to identify the optimal timing for such interventions.

Conclusion

TKA may alter the inclination angle of the talar articular surface by correcting the lower limb mechanical axis. Therefore, before and after TKA, surgeons should assess changes in the ankle joint angle and alignment on the same side, but excessive focus on changes in the non-surgical side ankle joint is not required. Greater knee deformity is associated with a larger preoperative angle between the distal tibial articular surface and the horizontal plane. Correction of severe deformities increases the postoperative TI angle, leading to a more inclined talar articular surface. So for severe knee valgus deformities, maintaining a residual valgus deformity postoperatively should be considered to avoid postoperative ankle complications.

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Author contributions

YXY: Writing– original draft. XBB: Data curation, Formal analysis, Writing– review & editing. HNT: Conceptualization, Validation, Writing– review & editing. WZG: Investigation, Project administration, Writing– review & editing. HJY: Data curation, Resources, Validation, Writing– review & editing. LC: Data curation, Project administration, Writing– review & editing. TJB: Supervision, Validation, Writing– review & editing.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This study was approved by the Ethics Committee of Zhongshan Hospital of Traditional Chinese Medicine Affiliated to Guangzhou University of Traditional Chinese Medicine.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Liu Y, Xing Z, Wu B, Chen N, Wu T, Cai Z, et al. Association of MRI-based knee osteoarthritis structural phenotypes with short-term structural progression and subsequent total knee replacement. J Orthop Surg Res. 2024;19(1):699.
2. Li X, Lai J, Yang X, Xu H, Xiang S. Intra-articular injection of vancomycin after arthrotomy closure following gentamicin-impregnated bone cementation in primary total knee arthroplasty provides a high intra-articular concentration while avoiding systemic toxicity: a prospective study. J Orthop Surg Res. 2024;19(1):856.
3. Yu Z, Cai H, Liu Z. Factors that impact the patellofemoral contact stress in the TKA: a review. Arthroplasty. 2023;5(1):44.
4. Zhao C, Liao Q, Yang D, Yang M, Xu P. Advances in perioperative pain management for total knee arthroplasty: a review of multimodal analgesic approaches. J Orthop Surg Res. 2024;19(1):843.
5. Verbeek JFM, Hannink G, Defoort KC, Wymenga AB, Heesterbeek PJC. Age, gender, functional KSS, reason for revision and type of bone defect predict functional outcome 5 years after revision total knee arthroplasty: a multivariable prediction model. Knee Surg Sports Traumatol Arthrosc. 2019;27(7):2289–96.
6. Ahn JH, Lee SH, Kang HW. Quantification of the effect of vertical bone resection of the medial proximal tibia for achieving soft tissue balancing in total knee arthroplasty. Clin Orthop Surg. 2016;8(1):49–56.
7. Engseth LHW, Grønsund J, Aunan E, Brattgjerd JE, Schulz A, Moatshe G, et al. A novel instrument for ligament balancing: a biomechanical study in human cadaveric knees. J Exp Orthop. 2023;10(1):83.
8. Boesen M, Ellegaard K, Henriksen M, Gudbergsen H, Hansen P, Bliddal H, et al. Osteoarthritis year in review 2016: imaging. Osteoarthritis Cartilage. 2017;25(2):216–26.
9. Hubbard TJ, Hicks-Little C, Cordova M. Changes in ankle mechanical stability in those with knee osteoarthritis. Arch Phys Med Rehabil. 2010;91(1):73–7.
10. Xie K, Han X, Jiang X, Ai S, Dai K, Yu Z, et al. The effect of varus knee deformities on the ankle alignment in patients with knee osteoarthritis. J Orthop Surg Res. 2019;14(1):134.
11. Kunugiza Y, Tomita T, Hirao M, Hamada M, Hosono N. Amelioration in ankle pain and improvement in function after total knee arthroplasty for ipsilateral knee and ankle osteoarthritis: a report of two cases. Arthroplast Today. 2020;6(4):925–30.
12. Lee JH, Jeong BO. Radiologic changes of ankle joint after total knee arthroplasty. Foot Ankle Int. 2012;33(12):1087–92.
13. Rühling M, Kirschbaum SM, Perka C, Graef F. Increased ankle pain after total knee arthroplasty is associated with a preoperative lateralized gait and talar tilt, but not with ankle laxity or the range of motion of the subtalar joint. Bone Joint J. 2023;105–b(11):1159–67.
14. Kikuchi N, Kanamori A, Okuno K, Yamazaki M. Weight-bearing line at the ankle joint level shifted laterally after total knee arthroplasty for varus knee osteoarthritis: evaluation of the hip-to-calcaneus line. Orthop Traumatol Surg Res. 2024;110(2):103690.
15. Shichman I, Hallak A, Ashkenazi I, Warschawski Y, Gold A, Snir N, Correction. Effect of inverse kinematic alignment total knee arthroplasty on coronal alignment of the ankle joint in patients with varus knee deformity. Arch Orthop Trauma Surg. 2025;145(1):133.
16. Kim JG, Suh DH, Choi GW, Koo BM, Kim SG. Change in the weight-bearing line ratio of the ankle joint and ankle joint line orientation after knee arthroplasty and high tibial osteotomy in patients with Genu varum deformity. Int Orthop. 2021;45(1):117–24.
17. Kwon SS, Yoo JD, Lee SY. Linear mixed modeling on the effects of varus knee surgery on the ankle joint weight-bearing axis. Foot Ankle Surg. 2022;28(1):114–8.
18. Shichman I, Ben-Ari E, Sissman E, Oakley C, Schwarzkopf R. Effect of total knee arthroplasty on coronal alignment of the ankle joint. J Arthroplasty. 2022;37(5):869–73.
19. Shichman I, Hallak A, Ashkenazi I, Warschwaski Y, Gold A, Snir N. Effect of inverse kinematic alignment total knee arthroplasty on coronal alignment of the ankle joint in patients with varus knee deformity. Arch Orthop Trauma Surg. 2024;144(9):4455–61.
20. Norton AA, Callaghan JJ, Amendola A, Phisitkul P, Wongsak S, Liu SS, et al. Correlation of knee and hindfoot deformities in advanced knee OA: compensatory hindfoot alignment and where it occurs. Clin Orthop Relat Res. 2015;473(1):166–74.
21. Shih HT, Liao WJ, Tu KC, Lee CH, Tang SC, Wang SP. Poor correction capacity of preexisting ankle valgus deformity after total knee arthroplasty. J Clin Med. 2021;10(16).
22. Gao F, Ma J, Sun W, Guo W, Li Z, Wang W. Radiographic assessment of knee-ankle alignment after total knee arthroplasty for varus and valgus knee osteoarthritis. Knee. 2017;24(1):107–15.
23. Xie K, Jiang X, Han X, Ai S, Qu X, Yan M. Association between knee malalignment and ankle degeneration in patients with end-stage knee osteoarthritis. J Arthroplasty. 2018;33(12):3694–e81.
24. Muehleman C, Margulis A, Bae WC, Masuda K. Relationship between knee and ankle degeneration in a population of organ donors. BMC Med. 2010;8:48.
25. Trad Z, Barkaoui A, Chafra M, Tavares JMR. Finite element analysis of the effect of high tibial osteotomy correction angle on articular cartilage loading. Proc Inst Mech Eng H. 2018;232(6):553–64.
26. Karasavvidis T, Pagan CA, Debbi EM, Mayman DJ, Jerabek SA, Vigdorchik JM. No difference in limb alignment between kinematic and mechanical alignment robotic-assisted total knee arthroplasty. J Arthroplasty. 2024;39(8s1):S200–5.
27. Charaya H, Gill HS, Bhan R. Functional outcome based on mechanical axis alignment following total knee arthroplasty. Cureus. 2022;14(2):e22553.
28. Oussedik S, Abdel MP, Victor J, Pagnano MW, Haddad FS. Alignment in total knee arthroplasty. Bone Joint J. 2020;102–b(3):276–9.
29. Graef F, Hommel H, Falk R, Tsitsilonis S, Zahn RK, Perka C. Correction of severe valgus osteoarthritis by total knee arthroplasty is associated with increased postoperative ankle symptoms. Knee Surg Sports Traumatol Arthrosc. 2022;30(2):527–35.
30. Yang J, Li X, Liu P, Liu X, Li L, Zhang M. The impact of patellofemoral joint diseases on functional outcomes and prosthesis survival in patients undergoing unicompartmental knee arthroplasty: a systematic review and meta-analysis. J Orthop Surg Res. 2024;19(1):840.
31. Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KD. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res. 2010;468(1):57–63.
32. Franklin PD, Lewallen D, Bozic K, Hallstrom B, Jiranek W, Ayers DC. Implementation of patient-reported outcome measures in U.S. Total joint replacement registries: rationale, status, and plans. J Bone Joint Surg Am. 2014;96(Suppl 1Suppl 1):104–9.
33. Gursu S, Sofu H, Verdonk P, Sahin V. Effects of total knee arthroplasty on ankle alignment in patients with varus gonarthrosis: do we sacrifice ankle to the knee? Knee Surg Sports Traumatol Arthrosc. 2016;24(8):2470–5.
34. Xing P, Qu J, Feng S, Guo J, Huang T. Comparison of the efficacy of robot-assisted total knee arthroplasty in patients with knee osteoarthritis with varying severity deformity. J Orthop Surg Res. 2024;19(1):872.
35. Batailler C, Lording T, Libert T, Servien E, Lustig S. Achieving better clinical outcomes after total knee arthroplasty in knees with valgus deformity: the role of alignment strategies. J Bone Joint Surg Am. 2025;107(2):152–62.
36. Abdel MP, Ollivier M, Parratte S, Trousdale RT, Berry DJ, Pagnano MW. Effect of postoperative mechanical axis alignment on survival and functional outcomes of modern total knee arthroplasties with cement: a concise follow-up at 20 years. J Bone Joint Surg Am. 2018;100(6):472–8.
37. Bonner TJ, Eardley WG, Patterson P, Gregg PJ. The effect of post-operative mechanical axis alignment on the survival of primary total knee replacements after a follow-up of 15 years. J Bone Joint Surg Br. 2011;93(9):1217–22.

38. Braga UM, Mendonça LD, Mascarenhas RO, Alves COA, Filho RGT, Resende RA. Effects of medially wedged insoles on the biomechanics of the lower limbs of runners with excessive foot pronation and foot varus alignment. Gait Posture. 2019;74:242–9.

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