ORIGINAL RESEARCH

Correlation Between Preoperative and Postoperative Alignment and Kinematic Gait in Total Knee Arthroplasty

Peng Liu, MM; Huifeng Xie, MM; Yushu Chen, MD; Rixu Liu, MD; Junjie Zeng, MM; Bo Bai, MD

ABSTRACT

Objective • Maintaining the lower limb in a neutral posture following total knee arthroplasty (TKA) has long been a concept maintained by operators. This study aimed to investigate the relationship between changes in lower limb alignment and the dynamics of knee gait before and after TKA to understand the impact of alignment on gait better and offer a theoretical foundation for correcting lower limb alignment in TKA.

Methods • Our study included a group of 20 participants. The cohort consisted of 1 male and 19 females, 11 left and 9 right knees, ages 58 to 81. Using the Opti_Knee® Knee Motion Test System with infrared reflective markers and a high-speed camera, the step length and 6 degrees of freedom of the knee were recorded. Following that, we investigated the association between HKA angle and knee kinematic gait before and after surgery.

Results • For preoperative HKA angles ranging from -28° to -3°, we observed increased step length, flexion-extension rotation, and varus-valgus rotation with an increase in HKA angle. Conversely, an increase in HKA angle from -3 ° to 15° corresponded with decreased step length, flexion-extension rotation, and varus-valgus rotation. An increase in HKA angle from 1° to 3° postoperatively increased step length, flexion-extension rotation, and varus-valgus rotation. In contrast, increasing the HKA angle from 3° to 5° resulted in less flexion-extension rotation. The flexion-extension rotation was at its maximum when the HKA angle was 3°. A 3° postoperative varus resulted in improved kinematic gait. Step length, varus-valgus rotation, and flexion-extension rotation increased with increasing HKA angle in the neutral alignment group. In contrast, the non-neutral alignment group exhibited decreased flexion-extension rotation as the HKA angle increased, while step length and varus-valgus rotation increased as the HKA angle increased. The varus-valgus rotation was statistically significant ($P < .05$) in the preoperative versus early postoperative period in the 6 degrees of freedom.

Conclusions • A 3° varus alignment was found to have a superior postoperative knee kinematic gait, implying that a 3° varus alignment may be more suitable as a new gold standard for TKA than the traditional "0°" alignment. The neutral alignment group demonstrated a better knee kinematic gait than the non-neutral alignment group. During early postoperative walking, significant improvements in varus-valgus rotation were found in the 6 degrees of knee freedom. (*Altern Ther Health Med.* [E-pub ahead of print.])

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INTRODUCTION

Knee Osteoarthritis (KOA) is a common and frequent problem in the modern clinical treatment of middle-aged and elderly patients.[1] Characterized by swelling, pain, stiffness, and restricted knee joint mobility, KOA, in its severe form, can impede normal ambulation, causing significant inconvenience to patients.[2] The overall prevalence of osteoarthritis is about 15%, 10%-17% over the age of 40, 50% over the age of 60, and up to 80% over the age of 75.[3] According to national statistics, in China, the prevalence of KOA is especially pronounced, estimated at 60% in individuals over 55 and 85% in those over 65.[4]

KOA is typically categorized into early, middle, and late stages.[5] Early on, pain will be occasional and daily activities will be largely unaffected, often occurring when standing up, squatting, or going up and down stairs, with mild limitation of movement. At this time, the imaging is a slight bony encumbrance around the joint, without involving the joint space. In the middle stage, severe pain in the knee joint occurs frequently, and daily activities are limited because of the pain, which is visualized on imaging as a more pronounced bony encumbrance around the joint. There is also some narrowing of the joint space, but the joint space is still present. In the late stage, the main clinical manifestation is that the knee joint pain is very serious, daily activities are severely limited, and the imaging manifestation is that the bone spurs around the joint are particularly obvious. The joint space has basically disappeared, the joint space is obviously narrowed, and the subchondral bone is sclerotic. Without timely intervention, the disease may progress to its late stage, wherein patients experience severe pain and knee dysfunction, posing a significant global treatment challenge. With the continuous development of clinical medicine and surgical instruments, artificial joints were one of the most important advances in orthopedic surgery in the 20th century. TKA has become the main treatment for late KOA.[6] The ultimate goal of TKA is to relieve pain, restore knee function and improve the patient's quality of life.[7]

Statistically, the number of TKAs is predicted to increase 100-fold between 2005 and 2030, with an increasing number of patients undergoing TKA surgery.[8-10] Maintaining the lower limb in a neutral position (-3°<HKA<3°) following TKA has long been practiced by practitioners.[11, 12] Poor lower limb alignment restoration will result in under or over-correction of the joints, affecting biomechanics, uneven loading of the prosthesis and the bone itself, limitation of flexion and extension, pain in the operative area, and a higher rate of surgical failure, associated with aseptic loosening of the prosthesis, prosthesis subsidence, accelerated prosthesis wear, and other negative consequences.[13, 14] This study aims to determine the relationship between changes in lower limb alignment and knee kinematic gait before and after TKA to understand the impact of alignment on gait better. This comprehension is critical for developing a theoretical foundation for improving lower limb alignment in TKA operations. Traditional subjective joint scoring systems used to measure knee function are susceptible to bias, whereas static, objective imaging tests (such as X-ray, CT, and MRI) may not thoroughly understand the knee's kinematic attributes. As a result, using Gait Analysis for KOA is a popular medical and biomechanical research topic. This study employs a motion capture system and computer-aided techniques to measure kinematic gait changes, such as step length and 6 degrees of freedom of knee movement (including varus-valgus rotation, internal-external rotation, flexion-extension rotation, anterior-posterior translation, proximal-distal translation, and medial-lateral translation), to provide an objective depiction of gait alterations before and after TKA. This study aimed to investigate the relationship between changes in lower limb alignment and the dynamics of knee gait before and after TKA to understand the impact of alignment on gait better and offer a theoretical foundation for correcting lower limb alignment in TKA.

Table 1. General information on study patients

Variable	Mean ± standard deviation	Minimum value	Maximum value
Height (cm)	154.50±4.69	145	162
Body weight (kg)	59.95±6.49	46	70
BMI	25.17±3.16	19.91	31.39

MATERIAL AND METHODS

General clinical information

This investigation enrolled 20 participants, each of whom had undergone a unilateral TKA at either the Third Affiliated Hospital of Guangzhou University of Chinese Medicine or the First Affiliated Hospital of Guangzhou Medical University between September 2019 and October 2020. For patient demographics, please refer to Table 1. Ethical approval was granted for the study. The cohort consisted of one male and nineteen female participants, with eleven left and nine right knees operated upon. The age bracket of the participants ranged from 58 to 81 years. Each participant experienced severe knee pain and dysfunction, and they were all classified as having stage IV KOA, as per the Kellgren-Lawrence classification system.[15] Preoperative and postoperative full-length photographs of the lower limbs were taken for each patient, enabling the measurement of the HKA angle and its varus-valgus rotation. These measurements and their changes were then analyzed for correlations with kinematic gait indices of the knee joint. Approximately two weeks before and after surgery, the patient's gait was captured using the Opti_Knee® Knee Motion Test System, facilitating comparative analysis of kinematic gait changes pre- and post-surgery.

Gait analysis methods

The Opti_Knee® Knee Motion Test System, made by Innomotion, was employed in this study (Figure 1). This system was affixed to the patient's femur and tibia using two straps, each equipped with four infrared reflective markers to capture motion signals. A hand-held detector fitted with four additional infrared reflective markers was used to identify the bony landmarks of the femur and tibia, specifically the greater trochanter, lateral epicondyle, medial epicondyle, lateral tibial plateau, medial tibial plateau, medial ankle, and lateral ankle. Simultaneously, a synchronized high-speed camera captured the knee joint movements as the patient walked on a treadmill. The camera recorded important characteristics of walking during the walking cycle, such as the back of the foot following the ground or the toes leaving the ground.[16] Infrared reflective markers and high-speed cameras acutely capture motion information during knee activity. On the treadmill, the patients were asked to follow the normal walking posture with the patient's normal optimal pace of three kilometers per hour or the normal pace that the patient can tolerate. The system's associated software performed real-time calculations, recording both step length and 6 degrees of freedom for the knee joint. Preoperative and postoperative gait analysis is carried out on the patient.

Figure 1. Gait Analysis diagram: A. Infrared reflective markers strapped on the femur and tibia, B. Femur and tibia with bony landmarks, C. Hand-held detector to locate bony landmarks.

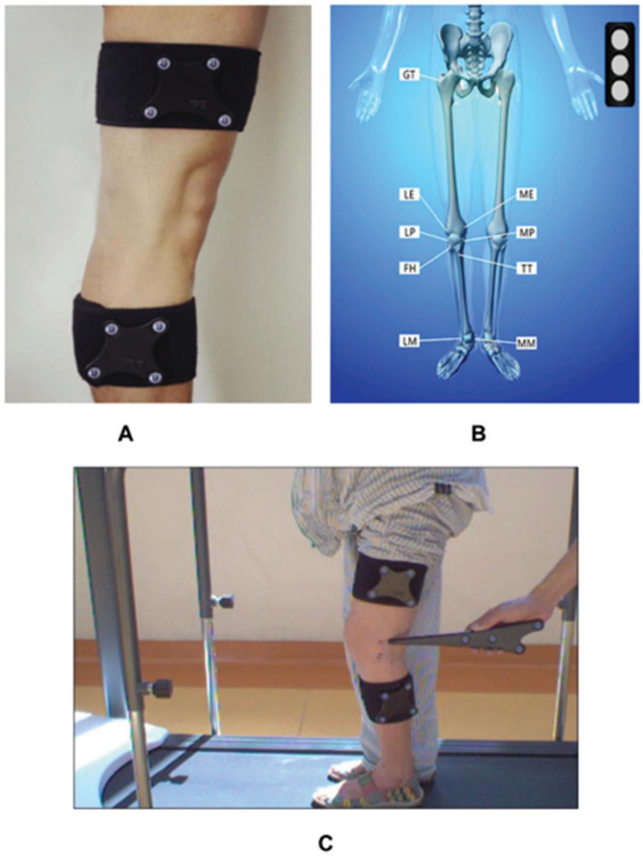


Figure 2. Preoperative HKA and step length relationship diagram.

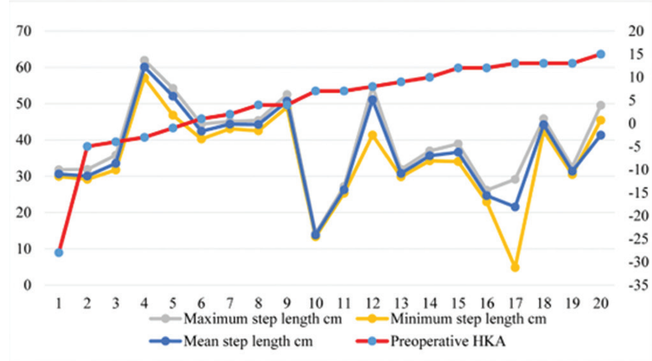
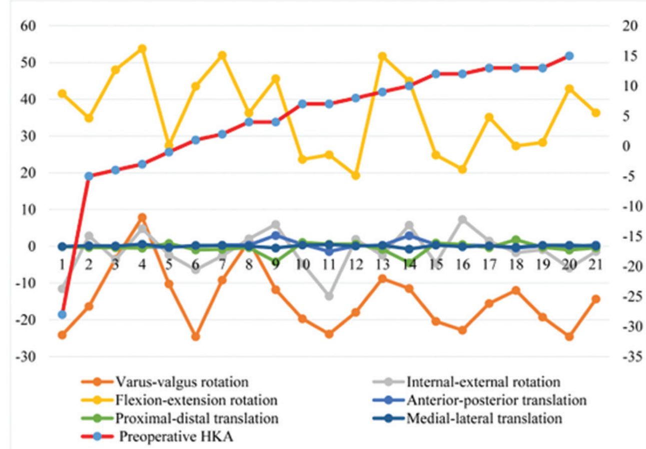


Figure 3. Preoperative HKA and 6 degrees of freedom relationship diagram.



Statistical analysis

The statistical analysis was performed using Statistical Product and Service Solutions (SPSS) 25 software (IBM, Armonk, NY, USA), where the differences in the parameters of the 6 degrees of freedom were compared before and after the operation, employing a paired *t* test. When $P < .05$ were considered significant.

RESULTS

Preoperative HKA angle and knee kinematic gait outcomes

The preoperative HKA angle measured in 20 patients ranged from -28° (valgus) to 15° (varus), with the mean being 4.5°. For an HKA angle between -28° and -3°, both the minimum and maximum step lengths and the mean increased with an increase in the HKA angle, reaching their peak at -3°. However, within the range of -3 ° to 15° for the HKA angle, the step length demonstrated a general decline. Upon inspecting the relationship between the preoperative HKA angle and the 6 degrees of freedom, certain trends became evident; for an HKA angle less than -3°, flexion-extension rotation, and varus-valgus rotation amplified as the HKA angle increased. Conversely, for an HKA angle greater than -3°, these two rotations tended to decrease with an increase in the HKA angle, peaking at -3°. The remaining parameters of internal-external rotation, anterior-posterior translation, proximal-distal translation, and medial-lateral translation fluctuated around 0° without exhibiting any clear correlation with changes in the HKA angle (Figure 2 and Figure 3).

Postoperative HKA angle and knee kinematic gait outcomes

The postoperative HKA angle measured in 20 patients ranged from 1° (varus) to 5° (varus), with a mean of 2.8°. An analysis of the relationship between the postoperative HKA angle and step length indicated a generally consistent trend among maximum, minimum, and mean step lengths, overall increasing as the HKA angle augmented. However, a "V"-shaped bottom appeared at an HKA angle of 5°. This finding was observed in patients exhibiting severe preoperative valgus with an HKA angle of -28°. In the postoperative HKA and 6 degrees of freedom relationship, the varus-valgus rotation increased circularly as the HKA angle escalated. Within the 1° to 3° range for the HKA angle, flexion-extension rotation increased as the HKA angle increased. But, within the HKA angle range of 3° to 5°, the flexion-extension rotation showed a declining trend as the HKA angle increased. The flexion-extension rotation peaked at an HKA angle of 3° (44.8°). Internal-external rotation peaked at an HKA angle of 2° (12.8°). The remaining 6

Figure 4. Postoperative HKA and step length relationship diagram.

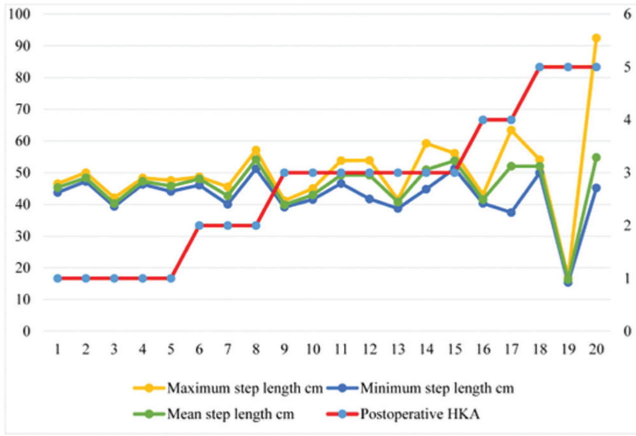


Figure 5. Postoperative HKA and 6 degrees of freedom relationship diagram.

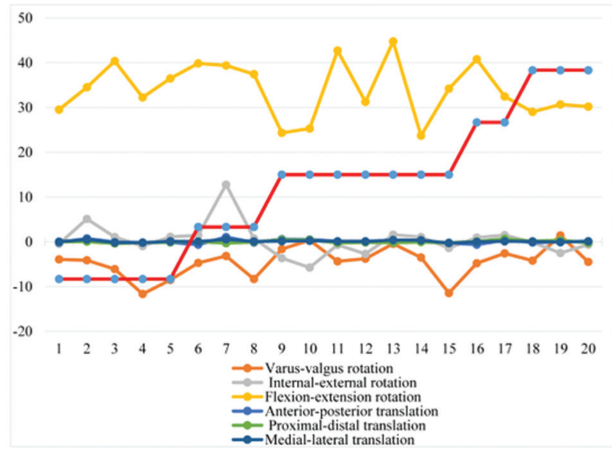


Figure 6. Neutral alignment group and step length relationship diagram.

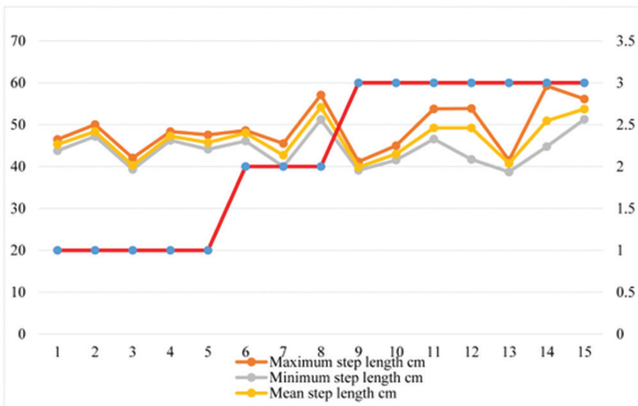
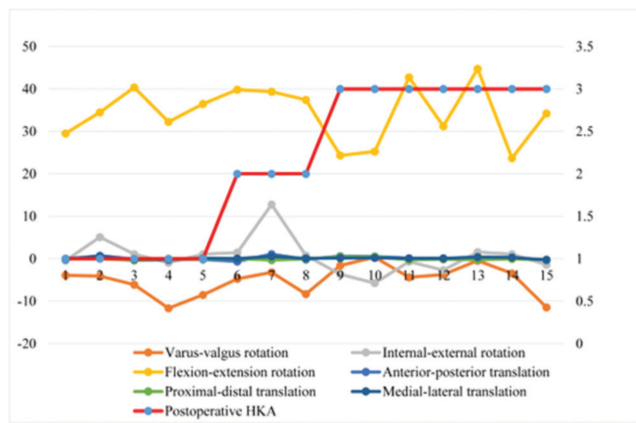


Figure 7. Neutral alignment group and 6 degrees of freedom relationship diagram.



degrees of freedom, including anterior-posterior translation, proximal-distal translation, and medial-lateral translation, showed mild fluctuations above and below 0°, suggesting no significant correlation with changes in the HKA angle (Figure 4 and Figure 5).

Neutral alignment group and non-neutral alignment group and kinematic knee gait outcomes

Based on the previous gold standard of the 0° alignment of the lower limb after surgery, we further analyzed the difference between the two groups according to the postoperative HKA angle: the neutral alignment group (-3° < HKA < 3°) and the non-neutral alignment group (HKA < -3° or HKA > 3°). Patients had a postoperative HKA angle between 1° and 5°, with 15 patients in the neutral alignment group and 5 in the non-neutral alignment group. An analysis of the relationship between the neutral alignment group and step length showed that the step length generally increased with the rise in HKA angle. The relationship between the neutral alignment group and the six degrees of freedom indicated that the varus-valgus and flexion-extension rotation increased as the HKA angle escalated. Internal-external rotation peaked at an HKA angle of 2° (12.8°). The other directions, including anterior-posterior translation, proximal-distal translation, and medial-lateral translation, fluctuated around 0° without significantly correlating with the HKA angle (Figure 6 and Figure 7).

The non-neutral alignment group also exhibited a positive correlation between the HKA angle and step length, with the three-step lengths increasing as the HKA angle increased. In the non-neutral alignment and 6 degrees of freedom relationship diagram, the flexion-extension rotation decreased with increasing HKA angle, and varus-valgus rotation increased with increasing HKA angle. The remaining degrees of freedom fluctuated around the 0° HKA angle and did not show a clear correlation with the HKA angle (Figure 8 and Figure 9).

Preoperative and postoperative knee kinematic gait outcomes

The 6 degrees of freedom of the knee joint mainly reflects the deflection direction during knee movement, as shown in Tables 2. Observing the varus-valgus rotation, a meaningful shift towards the 0° alignment can be noted when comparing the postoperative state (-4.492±3.434) with the preoperative state (-14.342±8.984), with statistical significance (*P* < .05). The internal-external rotation

Figure 8. Non-neutral alignment and step length relationship diagram.

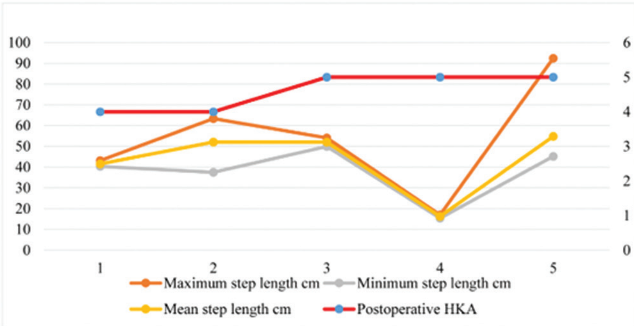


Figure 9. Non-neutral alignment and 6 degrees of freedom relationship diagram.

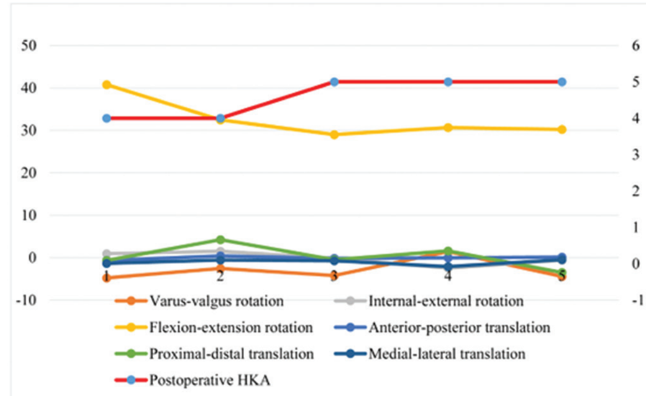


Table 2. Preoperative and postoperative knee 6 degrees of freedom

	Preoperative			Postoperative				
	Mean ± standard deviation	Minimum value	Maximum value	Mean ± standard deviation	Minimum value	Maximum value	*t* value	*P* value
Varus-valgus rotation	-14.342±8.984	-24.58	7.86	-4.492±3.434	-11.66	1.43	-4.342	.000
Internal-external rotation	-1.420±5.594	-13.54	7.31	0.430±3.710	-5.75	12.79	-1.576	.131
Flexion-extension rotation	36.358±11.204	19.31	53.8	34.615±6.411	23.71	44.75	0.982	.338
Anterior-posterior translation	0.337±0.984	-1.39	2.97	0.076±0.425	-0.64	1.07	0.959	.350
Proximal-distal translation	-0.416±1.548	-4.51	1.8	0.005±0.280	-0.36	0.66	-1.207	.242
Medial-lateral translation	0.073±0.331	-0.78	0.61	0.112±0.217	-0.29	0.55	-0.599	.556

Note: Reference range: varus-valgus rotation 6.3°~14°, internal-external rotation 10.9°~22.1°, flexion-extension rotation 55.4°~66.7°, anterior-posterior translation 1.1 cm~2.4 cm, proximal-distal translation 1.1 cm~2.1 cm, medial-lateral translation 0.7 cm~1.5 cm.

demonstrates an increase in postoperative (0.430±3.710) when compared to preoperative (-1.420±5.594), but it lacks statistical significance (*P* = .131). The difference between preoperative (36.358±11.204) and postoperative (34.615±6.411) flexion-extension rotation is not statistically significant (*P* = .338). Also, in the case of anterior-posterior translation, the postoperative state (0.076±0.425) showed a slight increase compared to the preoperative state (0.337±0.984), but the change is not statistically significant (*P* = .350). The proximal-distal translation postoperatively (0.005±0.280) is reduced when compared to the preoperative measurement (-0.416±1.548), but the change is not statistically significant (*P* = .242). Lastly, between the preoperative (0.073±0.331) and postoperative (0.112±0.217) measurements of medial-lateral translation, no significant difference is found (*P* = .556) (Table 2).

Typically, the movement from when one foot touches the ground until the same foot touches the ground again is termed a gait cycle. This cycle is split into two primary phases: the stance phase, which comprises 60% of the cycle, and the swing phase, covering the remaining 40% (Figure 10). Examining the varus-valgus rotation gait curve, both preoperative and postoperative states exhibit varus activity. Notably, the peak varus activity in the preoperative swing phase occurred at 82% of the gait cycle, recording -15.518. In the postoperative swing phase, the peak occurred slightly later, at 88% of the gait cycle, with a diminished activity level of -6.426. In the case of the internal-external rotation gait curves, the preoperative swing phase demonstrated a significant peak of internal rotation at 70% of the cycle

Figure 10. Gait cycle

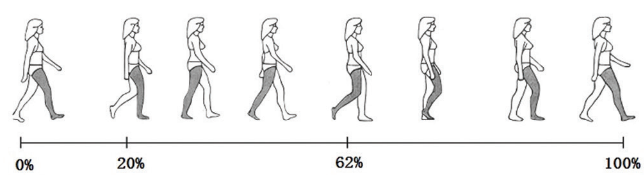
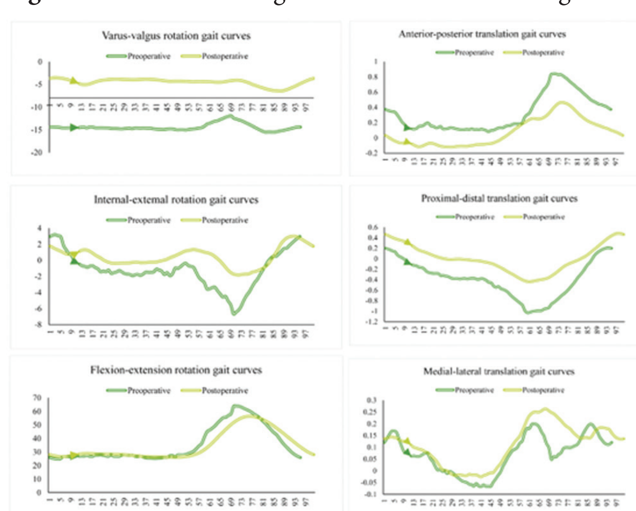


Figure 11. The knee 6 degrees of freedom curve diagram.



(-6.675). A similar peak was observed in the postoperative swing phase but with a lower activity level of -1.797 and slightly delayed at 72% of the cycle. The flexion-extension rotation gait curves also exhibit noticeable peaks. A significant peak of flexion activity was observed in the preoperative swing phase at 71% of the gait cycle (63.947), which then diminished to 56.439 at a later point, 76% of the cycle, postoperatively. The anterior-posterior translation gait curve revealed a prominent peak in anterior translation activity at 72% of the preoperative swing phase (0.841), which then decreased to 0.463 at a slightly later point (75%) during the postoperative swing phase. In the proximal-distal translation gait curves, significant downward shifting activity was recorded at the end of the preoperative stance phase (60% of the cycle, -1.030) and early in the postoperative swing phase (61% of the cycle, -0.438). Lastly, the medial-lateral translation gait curves for both preoperative and postoperative stages showed four peaks. Two peaks of internal shifting occurred during the stance and swing phases, preoperatively at 41% (-0.067) and 70% (0.048) of the gait cycle. The stance phase peak was more prominent, while postoperatively, these peaks were noted at 41% (-0.026) and 82% (0.138) of the cycle, with the stance phase still more pronounced. Additionally, two peaks of external translation were observed during the swing phase, preoperatively at 63% (0.199) and 86% (0.198) of the gait cycle and postoperatively at 68% (0.262) and 91% (0.184) of the gait cycle. Refer to Figure 11 for detailed visualization.

DISCUSSION

The knee joint, recognized as the most complex joint within the human body, is responsible for sustaining the body's weight and facilitating locomotion. With advancing age, decreased muscular strength and bone mass inevitably lead to progressive degenerative alterations within the joint, culminating in varying degrees of cartilage damage. Consequently, KOA is inherently tied to biomechanical research.[17] Knee kinematic parameters, which reflect the degree of knee mobility, reflect the patient's knee function and walking ability. This investigation delves into the following aspects.

Relationship between lower limb alignment and knee kinematic gait before TKA

In a previous study of preoperative lower limb alignment and kinematic gait in TKA, Astephen[18] found that the gait characteristics evident in osteoarthritis of the knee included changes in plane loading and alignment, increased support phase in the gait cycle in patients with KOA, the range of motion of the affected knee is reduced to the disease. Farrokhi S[19] conducted a comparative study of the gait of 14 KOA and 12 normal subjects, respectively; it was concluded that the degree of knee flexion in KOA patients was lower than normal and that varus KOA patients and valgus KOA patients showed increased knee adduction and increased knee abduction respectively. Our research revealed that when the HKA angle ranged between -28° and -3°, factors such as step length, flexion-extension rotation, and varus-valgus rotation all increased with the HKA angle increment. Conversely, when the HKA angle ranged between -3° and 15°, these same factors decreased alongside an increasing HKA angle. During the kinematic gait, elements like anterior-posterior translation, internal-external rotation, proximal-distal translation, and medial-lateral translation showed fluctuations around the 0° mark without any clear correlation with the HKA angle's change.

Relationship between lower limb alignment and knee kinematic gait after TKA

After decades of TKA development based on neutral alignment, scholars are still happy to study the relationship between alignment and kinematic gait. Vanlommel, et al.[9], who followed 143 patients with TKA for an average of more than seven years, concluded that a mild varus postoperatively resulted in higher joint function scores than neutral alignment. Kornuijt et al.[20] conducted a gait analysis study on 53 patients who underwent TKA; gait analysis was performed before, one month, six months, and one year after the surgery, and found that walking speed, step frequency, step length, and support phase were all improved after TKA. In the current investigation, 15 out of 20 participants, representing three-quarters of the entire cohort, displayed preoperative varus knees, characterized by an HKA angle >0°. During the postoperative phase, when the HKA angle was between 1° and 3°, we observed increased step length, flexion-extension rotation, and varus-valgus rotation with the HKA angle's growth. However, as the postoperative HKA angle expanded from 3° to 5°, the flexion-extension rotation decreased with the increase in the HKA angle. During the kinematic gait, the flexion-extension rotation peaked at an HKA angle of 3°. Upon reviewing the postoperative HKA and 6 degrees of freedom relationship diagram, we found that internal-external rotation peaked at an HKA angle of 2° (12.79°). In contrast, anterior-posterior, proximal-distal, and medial-lateral translations generally followed the same trajectory, illustrating minor oscillations above and below 0°. We detected no significant correlation between these measurements and variations in the HKA angle. Based on these findings, it can be inferred that KOA patients who undergo TKA might experience improved postoperative gait at 3° valgus. Consequently, we propose re-evaluating the gold standard for TKA, shifting from "0°" alignment to "3°" valgus. This alteration could potentially yield enhanced functional and kinematic gait post-surgery. However, further evidence from medical records is required to substantiate this proposition.

Relationship between neutral alignment group (-3°<HKA<3°) and non-neutral alignment group (HKA<-3°or HKA>3°) and knee kinematic gait

Step length increases with increasing HKA angle in neutral and non-neutral alignment groups. In the 6 degrees of freedom relationship, the neutral alignment group showed varus-valgus rotation and flexion-extension rotation, which increased with increasing HKA angle; in contrast, the non-neutral alignment group showed varus-valgus rotation and flexion-extension rotation, which decreased with increasing

HKA angle, while the remaining degrees of freedom did not correlate significantly with HKA angle. In conclusion, we can see that the neutral alignment group had a better postoperative kinematic gait than the non-neutral alignment group.

Study of kinematic changes preoperative and postoperative in TKA

After TKA, a neutral lower limb alignment can be obtained for better knee function and reduced knee pain. Evaluating the success of TKA objective knee joint indicators. These include prosthetic placement, lower limb alignment improvement, knee joint motion range, and the knee society score (KSS), including clinical and functional scores. Most of the abovementioned assessments provide a static evaluation, which is not fully congruent with the knee joint's kinematics and does not offer a comprehensive understanding of the knee joint's kinematic characteristics.

In contrast, gait analysis is a dynamic and objective assessment of knee motion. This study adds step length and 6 degrees of freedom of the knee joint to record gait changes before and after mechanical alignment knee arthroplasty, providing a new parameter for evaluating the efficacy of TKA. Our findings indicate varying degrees of gait's 6-degrees-of-freedom alterations pre- and post-operation. Specifically, in the early postoperative phase, the changes in varus-valgus rotation were statistically significant when comparing pre-and postoperative states ($P < .05$).

CONCLUSION

For preoperative HKA angles less than -3°, step length, flexion-extension rotation, and varus-valgus rotation show positive correlations with HKA angle. On the other hand, when the HKA angle is greater than -3°, step length, flexion-extension rotation, and varus-valgus rotation are negatively correlated with the HKA angle. A superior postoperative knee kinematic gait was seen at a 3° varus, suggesting that a 3° varus alignment could be more suitable as a new gold standard for TKA than the traditional "0°" alignment. We need to look further for the optimal HKA angle after TKA. A better knee kinematic gait was seen in the neutral alignment group (-3°<HKA<3°) as compared to the non-neutral alignment group (HKA<-3° or HKA>3°). In the 6 degrees of freedom of the knee, significant improvements in varus-valgus rotation were observed during early postoperative walking. Despite the valuable insights gained, this study is not without limitations. The study's constraints include a limited patient sample size, a short follow-up period, and a lack of comprehensiveness in the examined indicators. In the future, we intend to address these issues by expanding the sample size to ensure truer representation, lengthening the patient follow-up period to assess gait in the knee better, and developing more stringent clinical tests.[21]

CONFLICT OF INTEREST

The authors have no potential conflicts of interest to report relevant to this article.

FUNDING

This work was supported by the Scientific Research Project of Guangdong Provincial Bureau of Traditional Chinese Medicine (No.20211213), Plan on enhancing scientific research in GMU, Science and Technology Program of Guangzhou (2024A04J3317; 2024A03J1213) and Guangzhou Health Technology General Guidance Project (20241A011074).

AUTHOR CONTRIBUTIONS

PL and BB designed the study and performed the experiments, HX and YC collected the data, RL and JZ analyzed the data, PL and BB prepared the manuscript. All authors read and approved the final manuscript.

ETHICAL COMPLIANCE

The ethics committee of The First Affiliated Hospital of Guangzhou Medical University approved this study. Signed written informed consents were obtained from the patients and/or guardians.

REFERENCES

1. Mercurio M, Gasparini G, Sanzo V, Familiari F, Castioni D, Galasso O. Cemented Total Knee Arthroplasty Shows Less Blood Loss but a Higher Rate of Aseptic Loosening Compared With Cementless Fixation: An Updated Meta-Analysis of Comparative Studies. *J Arthroplasty*. 2022;37(9):1879-1887.e4. doi:10.1016/j. arth.2022.04.013
2. Yuan T, Cai D, Hu B, Zhu Y, Qin J. Therapeutic Effects of Curcumin on Osteoarthritis and Its Protection of Chondrocytes Through the Wnt/Β-Catenin Signaling Pathway. *Altern Ther Health Med*. 2022;28(5):28-37.
3. Pei Y, Yang W, Wei S, et al. Automated measurement of hip-knee-ankle angle on the unilateral lower limb X-rays using deep learning. *Phys Eng Sci Med*. 2021;44(1):53-62. doi:10.1007/s13246-020-00951-7
4. Iwasaki K, Ohkoshi Y, Hosokawa Y, et al. Higher Association of Pelvis-Knee-Ankle Angle Compared With Hip-Knee-Ankle Angle With Knee Adduction Moment and Patient-Reported Outcomes After High Tibial Osteotomy. *Am J Sports Med*. 2023;51(4):977-984. doi:10.1177/03635465221150513
5. Altman RD. Classification of disease: osteoarthritis. *Semin Arthritis Rheum*. 1991;20(6)(suppl 2):40-47. doi:10.1016/0049-0172(91)90026-V
6. Lahm A, Mrosek E, Spank H, et al. Changes in content and synthesis of collagen types and proteoglycans in osteoarthritis of the knee joint and comparison of quantitative analysis with Photoshop-based image analysis. *Arch Orthop Trauma Surg*. 2010;130(4):557-564. doi:10.1007/s00402-009-0981-y
7. Shirinsky IV, Kalinovskaya NY, Filatova K, Shirinsky VS; Pleiotropic Effects of Comarum palustre L. in Patients with Osteoarthritis and Diabetes Mellitus with High Comorbidity Burden: An Exploratory Study. *Altern Ther Health M*. 2021;27(80-84.
8. Lostak J, Gallo J, Zapletalova J. Patient Satisfaction after Total Knee Arthroplasty. Analysis of Pre-Operative and Peri-Operative Parameters Influencing Results in 826 Patients. *Acta Chir Orthop Traumatol Cech*. 2016;83(2):94-101. doi:10.55095/achot2016/014
9. Vanlommel L, Vanlommel J, Claes S, Bellemans J. Slight undercorrection following total knee arthroplasty results in superior clinical outcomes in varus knees. *Knee Surg Sports Traumatol Arthrosc*. 2013;21(10):2325-2330. doi:10.1007/s00167-013-2481-4
10. 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):1217-1222. doi:10.1302/0301-620X.93B9.26573
11. Wang SQ, Gao YQ, Zhang C, Xie YJ, Wang JX, Xu FY; A Bibliometric Analysis Using CiteSpace of Publications from 1999 to 2018 on Patient Rehabilitation After Total Knee Arthroplasty. *Med Sci Monitor*. 2020;26(e920795. doi:10.12659/MSM.920795
12. Kim C, Bin SI, Kim JM, Lee BS, Park JG, Yoon GW. Postoperative alignment but not femoral coronal bowing is a significant longevity factor after total knee arthroplasty. *Orthop Traumatol Surg Res*. 2020;106(3):435-442. doi:10.1016/j.otsr.2019.12.001
13. Huang T, Long Y, George D, Wang W. Meta-analysis of gap balancing versus measured resection techniques in total knee arthroplasty. *Bone Joint J*. 2017;99-B(2):151-158. doi:10.1302/0301-620X.99B2.BJJ-2016-0042.R2
14. Vandekerckhove PJ, Lanting B, Bellemans J, Victor J, MacDonald S. The current role of coronal plane alignment in Total Knee Arthroplasty in a preoperative varus aligned population: an evidence based review. *Acta Orthop Belg*. 2016;82(1):129-142. doi.
15. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. *Ann Rheum Dis*. 1957;16(4):494-502. doi:10.1136/ard.16.4.494
16. Gao J, Lu Y, Gokulnath P, et al. Benefits of Physical Activity on Cardiometabolic Diseases in Obese Children and Adolescents. *J Transl Int Med*. 2022;10(3):236-245. doi:10.2478/jtim-2022-0041
17. Petersen W, Ellermann A, Zantop T, et al. Biomechanical effect of unloader braces for medial osteoarthritis of the knee: a systematic review (CRD 42015026136). *Arch Orthop Trauma Surg*. 2016;136(5):649-656. doi:10.1007/s00402-015-2388-2
18. Astephen JL, Deluzio KJ, Caldwell GE, Dunbar MJ. Biomechanical changes at the hip, knee, and ankle joints during gait are associated with knee osteoarthritis severity. *J Orthop Res*. 2008;26(3):332-341. doi:10.1002/jor.20496
19. Farrokhi S, Tashman S, Gil AB, Klatt BA, Fitzgerald GK; Are the kinematics of the knee joint altered during the loading response phase of gait in individuals with concurrent knee osteoarthritis and complaints of joint instability? A dynamic stereo X-ray study. *Clin Biomech*. 2012;27(4):384-389. doi: 10.1016/j. clinbiomech. 2011. 10.009
20. Kornuijt A, Kuijer PPFM, van Drumpt RA, Siebelt M, Lenssen AF, van der Weegen W. A high physical activity level after total knee arthroplasty does not increase the risk of revision surgery during the first twelve years: A systematic review with meta-analysis and GRADE. *Knee*. 2022; 39:168-184. . knee.2022.08.004 doi:10.1016/j.knee.2022.08.004
21. Eymir M, Unver B, Karatosun V. Relaxation exercise therapy improves pain, muscle strength, and kinesiophobia following total knee arthroplasty in the short term: a randomized controlled trial. *Knee Surg Sports Traumatol Arthrosc*. 2022;30(8):2776-2785. doi:10.1007/s00167-021-06657-x