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Gradual restoration of gait following unicompartmental knee arthroplasty: a prospective study

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Abstract

Background This study investigates the gait characteristics and clinical outcomes following Unicompartmental Knee Arthroplasty (UKA) to provide scientific evidence for optimizing postoperative rehabilitation and patient management.

Methods Between December 2022 and November 2023, 34 patients with unilateral medial compartment knee osteoarthritis (KOA) underwent UKA. Preoperative and postoperative videos of patients in standing, walking (side view), squatting, and supine knee-bending positions were captured using smartphones. Gait parameters including gait cycle, swing time, swing phase, stance time, stance phase, double support time, walking speed, step time, cadence, step length, stride length, stride width, active knee flexion angle, and maximum hip and knee flexion angles during squatting were analyzed using the MediaPipe framework for human pose estimation.

Results Postoperative WOMAC scores were significantly lower than preoperative scores ($P < 0.001$), while postoperative KSS scores were significantly higher than preoperative scores ($P < 0.001$).Compared to preoperatively, postoperative affected-side gait speed, step length, step width, and active knee flexion angle all increased ($P < 0.05$). Additionally, postoperative gait cycle time and double-limb support time were reduced compared to preoperative values ($P < 0.05$). Among the 17 patients who could perform squats preoperatively and postoperatively, the maximum knee flexion angle and hip flexion angle in the squat position increased from preoperative values of $(96.41 \pm 20.65)°$ and $(113.77 \pm 22.56)°$ to postoperative values of $(110.15 \pm 20.79)°$ and $(124.84 \pm 21.13)°$.

Conclusions UKA significantly enhances knee joint kinematics, facilitating the transition from basic to advanced functional activities.

Keywords Unicompartmental knee arthroplasty, Gait analysis, Knee osteoarthritis

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Background

Unicompartmental knee arthroplasty (UKA), total knee arthroplasty (TKA) and high tibial osteotomy (HTO) are the primary surgical options for managing end-stage KOA. The research shows that, compared to HTO, the revision surgery rate for UKA is statistically significantly lower [1]. At the same time, among these, UKA has gained preference in treating unicompartmental KOA due to its advantages, including preservation of the cruciate ligaments, minimal intra-articular damage, and expedited postoperative functional recovery [2, 3]. With the rising number of UKA procedures, a more active patient population, and a younger demographic of recipients, there is an increasing demand for improved postoperative functional outcomes [4, 5]. Postoperative gait patterns serve as a key indicator of patient satisfaction and a critical measure of recovery success [6].

Gait plays a critical role in the surgical outcomes and rehabilitation process following UKA [7]. As a comprehensive reflection of human motor function, gait analysis provides valuable insights into various parameters, including gait cycle, walking speed, cadence, stride, step length, stance phase, swing phase, and double support time during walking. These parameters are essential for evaluating the functional state of the knee joint. Preoperatively, gait assessment in UKA helps clinicians assess the extent of knee joint degeneration and functional limitations, offering key information for surgical planning. Postoperatively, gait analysis guides rehabilitation, enabling the development of personalized rehabilitation plans based on gait data, which in turn enhances recovery outcomes. Postoperative gait training enables UKA patients to improve knee joint range of motion (ROM), muscle strength, and balance, ultimately restoring a normal gait pattern. Furthermore, gait training reduces postoperative complications, such as deep vein thrombosis and joint stiffness, thereby improving overall quality of life for patients [8]. Consequently, emphasizing the role of gait assessment before and after UKA surgery is crucial, and optimizing the assessment process to improve the accuracy of evaluation results is of paramount importance.

Current research in gait analysis predominantly focuses on dynamic camera-based detection and localization. More precise three-dimensional motion and gait analysis often rely on specialized motion capture systems, with optical motion capture systems regarded as the gold standard in gait analysis technology [9]. However, this approach presents several practical limitations, including the need for a dedicated gait laboratory, expensive equipment, and highly trained personnel to ensure the accuracy of data collection and processing [10]. Notably, Stenum's research underscores the potential of the human pose estimation framework for image-based quantitative gait analysis, applicable in virtually any environment. This innovative technology provides a cost-effective alternative for clinical gait analysis, significantly reducing equipment and operational costs while enhancing the accuracy and efficiency of gait evaluations [11]. Such advancements make it possible for more patients to benefit from timely and precise gait assessments, overcoming barriers to broader clinical application.

Currently, research on gait analysis following UKA is still relatively scarce. This study innovatively applies image analysis technology based on a human posture estimation framework to quantitatively analyse walking and specific movement videos of UKA patients before and after surgery. From the perspective of kinematic parameters, the study systematically evaluates the gait characteristics of patients, exploring the changes in gait parameters before and after UKA surgery. This provides important theoretical data to support the understanding of gait changes following UKA.

Methods

Participants

This was a prospective cohort study.Between December 2022 and November 2023, UKA procedures were performed by a single experienced surgeon. Initially, 65 cases meeting the preoperative gait analysis criteria were selected.Bilateral knee arthroplasty on the contralateral side may lead to significant changes in the biomechanical characteristics of both knee joints. These changes not only affect the symmetry of the patient's gait and movement patterns, but may also interfere with the functional assessment of the surgically treated knee joint through compensatory mechanisms. As a result, it becomes difficult to accurately determine whether the observed gait improvement is due to the effects of UKA surgery or the influence of the contralateral knee replacement. Based on this, 30 patients who underwent bilateral knee arthroplasty were ultimately excluded to ensure the accuracy and reliability of the study results. Additionally, one patient who did not complete the follow-up was also excluded. Ultimately, the study included 34 patients with unilateral medial compartment knee osteoarthritis, consisting of 10 males and 24 females, aged 46–82 years (mean 64.76 ± 7.78 years).

Patient inclusion criteria

Inclusion criteria were as follows: (1) Unilateral medial compartment osteoarthritis of the knee with localized tenderness limited to the medial aspect of the knee, and no or mild osteoarthritis symptoms on the contralateral side; (2) Preoperative X-rays (standing lateral view) showing osteoarthritis affecting only the medial compartment

(Kellgren-Lawrence, K-L grade ≥ 3), with normal external and patellar compartments (K-L grade ≤ 2); (3) Preoperative deformity not severe: varus deformity < 10°, tibial contracture < 10°, knee extension > 90°; (4) Normal external compartment with good cartilage, X-ray showing external rotation stress gap > 5mm; (5) Clinical examination revealing intact cruciate and lateral ligament structures; and (6) Patellofemoral joint exhibiting normal trajectory and moderate wear.

Patient exclusion criteria

Exclusion criteria were as follows: (1) Preoperative X-ray showing osteoarthritis in the lateral compartment of the knee; (2) Patients with a history of knee, hip, or ankle prosthesis; (3) Patients unable to walk independently and requiring assistance; (4) Serious medical conditions preventing tolerance to anesthesia or surgery; (5) Presence of systemic or local infectious lesions; (6) Patients who have not reached the 6-month follow-up or have not been followed up.

Gait acquisition

The assessment was performed by an orthopedic surgeon to evaluate knee joint function. Prior to testing, participants were required to wear form-fitting clothing. Smartphone videos were recorded preoperatively and six months postoperatively to capture movement patterns. Participants completed the following tasks: (1) The timed up and go (TUG) test: The participant rises from a chair, walks forward, turns around, and returns to sit back down (Fig. 1A). (2) 6-m walking: Continuous walking was recorded from a side view (Fig. 1B). (3) Supine knee flexion: The participant lies on their back and performs active knee flexion, with separate recordings for each leg (Fig. 1C). (4) Squat and stand: Multiple views (front, left side, back, and right side) of the squat and stand movement were captured (Fig. 1D).

The first three tasks assess general motor function, while the squat task serves as an advanced functional test to evaluate knee joint performance under high flexion and weight-bearing conditions. Each task was repeated at least three times, with adequate rest allowed between repetitions to ensure the participant could perform the movements at a comfortable walking speed.

Data analysis

We first excluded invalid videos with durations shorter than a predefined threshold. In general, the TUG, 6-m walking, and squat-and-stand tasks usually lasted for more than 10 s, and the duration threshold was set to 200 frames. The supine knee flexion task typically lasted for less than 10 s, for which the threshold was set to 60 frames. After filtering out invalid videos, the remaining videos were categorized by task type as inputs to the video analysis pipeline as illustrated in Fig. 2.

The kinematic information of participants performing movement tasks is reflected by the keypoint trajectories extracted from pose estimation models. We deployed MediaPipe [12], an open-source pose estimation framework, to track and detect 33 body keypoints for the participant in each video. Various factors, including the initialization of recording equipment, body occlusion, or the presence of multiple individuals could result in consecutive or intermittent null values in the keypoint detection outputs. Thus, a further video qualifying step was applied with a task-specific preprocessor before the calculation of motion parameters. For the supine knee flexion and squat-and-stand tasks, valid pose estimation

Fig. 1 Gait analysis of the patient: **A** The timed up and go (TUG) test, **B** 6-m walking, **C** Supine knee flexion, **D** Squat and stand

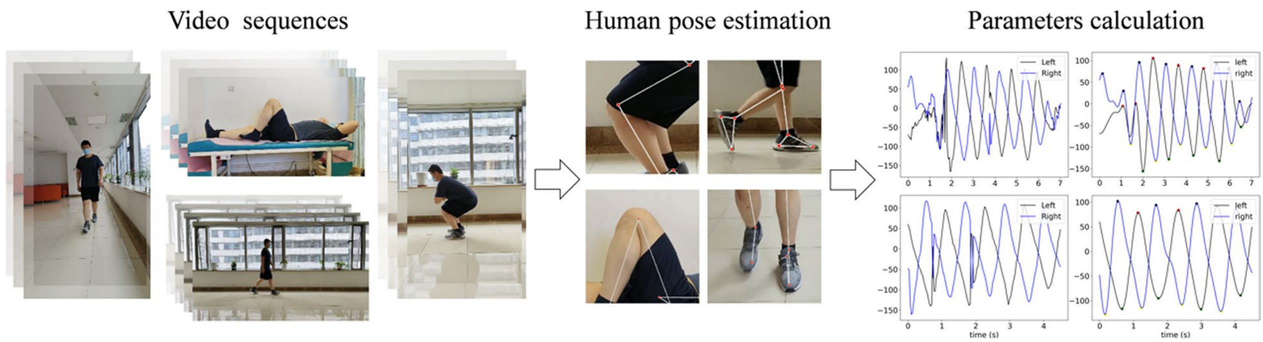

Fig. 2 Video analysis pipeline. Left: Input video sequences for four movement tasks. Middle: Body keypoints extracted with MediaPipe. Right: Demonstration of the original trajectories derived from certain keypoints (left column) and the corresponding noise-reduced trajectories with a low-pass filter (right column) used for parameter calculation (y-axis represents the keypoint coordinates in pixel value)

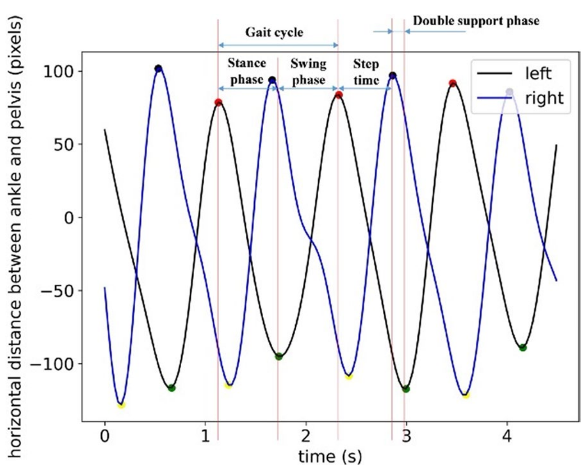

Fig. 3 Temporal parameter representations. Temporal parameters were calculated based on the time differences between maximum values (heel-strike events) and minimum values (toe-off events)

results should consist of a single continuous clip, while the TUG and 6-m walking tasks should contain two episodes of walking.Consecutive clips were then extracted, and only those lasting longer than half of the original duration were used for analysis. Turn-around points of the human body were detected to identify positional changes, enabling the differentiation of walking directions. This distinction is crucial for calculating gait parameters.

We used the video of 6-m walking task to calculate temporal-spatial and kinematic gait parameters. Figure 3 illustrates the dynamics of the x-coordinate differences between the ankle and pelvis keypoints over time. The time points of the maximum values corresponded to the heel-strike events while the minimum corresponded to the toe-off events for each side. Temporal parameters were then calculated based on the time differences between heel-strike events and toe-off events. The gait cycle was defined as the time interval between two consecutive heel-strike events of the same side, with a toe-off event splitting the cycle into stance and swing phases. The step time was calculated as the time difference between consecutive heel-strike events of both sides, while the double support phase was identified as the period between heel contact and contralateral toe-off (shown in Fig. 3). Given the limited sample size of gait cycles in a single task, the median value was chosen to represent the final gait cycle duration, while the average value was used for all other parameters to provide a more robust estimation. The identified sub-phases of a gait cycle were applied in the estimation of spatial and kinematic parameters. The horizontal distances between heel keypoints were used to determine the stride (ipsilateral) and step (contralateral) length, while the knee angle was derived from the angle between vectors of the thigh (hip to knee) and the calf (knee to ankle). All spatial parameters related to length calculation were scaled according to the length of the participant's calf.

We calculated the step width based on the distance between the left and right heel keypoints during the TUG task. For the supine knee flexion and squat-and-stand tasks, we mainly focused on the knee and hip angles. The knee angle was calculated as the angle between the vector from the hip to knee and the vector from the knee to ankle. Similarly, the hip angle was defined by the angle between the vector of the thigh (knee to hip) and the vector of the upper body (from hip to shoulder). Notably, knee and hip angles were more pronounced when participants were recorded from a lateral view during the squat-and-stand task. To identify such cases, we calculated the ratio of the toe-heel distance to the knee-ankle distance. A higher ratio indicated a lateral view compared to the front or back. Low-pass filtering and interquartile range (IQR) methods were applied across all parameter calculation processes to reduce noise and outliers.

Clinical scores

The overall function and morphology of the knee joint were assessed during both preoperative and postoperative follow-ups using the Western Ontario and McMaster Universities Arthritis Index (WOMAC) [13] and the American Knee Society Score (KSS) [14]. A higher WOMAC score indicates more severe knee joint dysfunction, while a higher KSS score signifies better joint function.

Ethical considerations

The study was approved by the Ethics Committee of the Chinese People's Liberation Army General Hospital (Approval No: 2022KY127-KS001). Written informed consent was obtained from all participants, and the study adhered to the principles of the Declaration of Helsinki.

Statistical analyses

Before the study, the sample size calculation was performed using G*Power 3.1 software. The power was set at 0.80, the effect size was set at 0.5, and $\alpha = 0.05$, resulting in a calculated sample size of 34 cases. Statistical analysis was performed using SPSS version 26.0 (IBM Corp, Armonk, NY, USA). Quantitative data conforming to a normal distribution are presented as mean ± standard deviation ($\bar{x} \pm s$). Paired t-tests were used to compare preoperative and postoperative improvements.

Results

A total of 34 patients with unilateral knee osteoarthritis who underwent UKA between December 2022 and November 2023 were included in the study. The cohort consisted of 10 males and 24 females, with ages ranging from 46 to 82 years (mean 64.76 ± 7.78 years). Heights ranged from 1.55 to 1.83 m (mean 1.60 ± 0.05 m), weights ranged from 55 to 95 kg (mean 66.51 ± 9.03 kg), and BMI ranged from 22.40 to 28.40 kg/m^2 (mean 25.89 ± 2.62 kg/m^2). Follow-up time 6–17 months (mean 8.32 ± 3.77 months). The disease duration ranged from 2 to 12 years (mean 4.68 ± 2.18 years), with 14 patients having left knee involvement and 20 with right knee involvement. (Table 1).

Table 1 Basic data of UKA patients

Subject	UKA group
Age (years)	64.76 ± 7.78
Gender (male/female)	10/24
Side (left/right)	14/20
Height (m)	1.60 ± 0.05
Weight (kg)	66.51 ± 9.03
BMI (kg/m^2)	25.89 ± 2.62
Disease duration (years)	4.68 ± 2.18
Follow-up time (months)	8.32 ± 3.77

The values are presented as mean ± SD

The preoperative WOMAC score significantly decreased from 57.62 ± 7.75 to 39.12 ± 6.06 postoperatively ($P < 0.001$); Similarly, the preoperative KSS score increased from 100.97 ± 9.98 to 168.26 ± 9.50 postoperatively ($P < 0.001$),This indicates that the surgery significantly improved patients' knee joint function and satisfaction.On the affected side, walking speed, step length, stride, and active knee flexion angle improved from preoperative values of 0.79 ± 0.24 m·s^{-1},

Table 2 Comparison of preoperative and postoperative knee scores and gait parameters in UKA patients

Parameter	Preoperative	Postoperative	t	*P*
WOMAC	57.62 ± 7.75	39.12 ± 6.06	12.99	< 0.001*
KSS	100.97 ± 9.98	168.26 ± 9.50	−28.66	< 0.001*
Gait cycle/s	1.18 ± 0.15	1.12 ± 0.12	2.833	0.008*
Swing time/s	0.47 ± 0.05	0.45 ± 0.07	1.307	0.200
Swing phase/%	40.15 ± 5.05	40.96 ± 7.04	−0.602	0.551
Stance time/s	0.71 ± 0.15	0.68 ± 0.13	1.451	0.156
Stance phase/%	60.20 ± 5.82	61.64 ± 4.37	−1.419	0.165
Double support time/s	0.16 ± 0.09	0.11 ± 0.05	2.591	0.014*
Step speed/m/s	0.79 ± 0.24	0.90 ± 0.22	−3.347	0.002*
Step time/s	0.58 ± 0.10	0.56 ± 0.08	1.147	0.260
Cadence /steps/min	103.98 ± 14.41	107.06 ± 10.68	−1.541	0.133
Step length/cm	45.65 ± 11.56	50.44 ± 11.01	−3.460	0.002*
Stride Length/cm	90.73 ± 20.22	100.18 ± 18.88	−4.511	< 0.001*
Step width/cm	12.39 ± 3.52	12.09 ± 2.35	0.702	0.488
ROM /°	118.91 ± 12.63	125.05 ± 8.55	−3.347	0.001*

The values are presented as mean ± SD. * Significant differences in gait parameters between pre- and postoperative patients ($p < 0.05$)

45.65 ± 11.56 cm, 90.73 ± 20.22 cm, and 118.91 ± 12.63°, respectively, to postoperative values of 0.90 ± 0.22 m·s^{-1}, 50.44 ± 11.01 cm, 100.18 ± 18.88 cm, and 125.05 ± 8.55° (P < 0.05),These improvements in the data clearly reflect a significant enhancement in the patients' walking ability and knee joint range of motion postoperatively. The gait cycle duration and double-limb support time decreased from preoperative values of 1.18 ± 0.15 s and 0.16 ± 0.09 s to postoperative values of 1.12 ± 0.12 s and 0.11 ± 0.05 s (P < 0.05),This change suggests that patients' gait has become smoother, and their walking efficiency has improved. No significant changes were observed in swing time, swing phase, support time, support phase, step time, cadence, step width, or maximum hip flexion angle during squatting between pre- and postoperative measurements (P > 0.05) (Table 2).

Among the study participants, 18 patients were able to successfully perform the squat-to-stand movement preoperatively, and this number increased to 25 postoperatively. Seventeen patients demonstrated consistent proficiency in performing the movement both preoperatively and postoperatively. For these 17 patients, a significant improvement was observed in their maximum knee flexion angle during squatting, which increased from 96.41 ± 20.65° preoperatively to 110.15 ± 20.79° postoperatively. Similarly, the maximum hip flexion angle showed a notable increase, rising from 113.77 ± 22.56° preoperatively to 124.84 ± 21.13° postoperatively. The detailed squatting flexion angles for these 17 patients are provided in Table 3.

Discussion

The variation in gait cycle duration is a valuable indicator of gait functionality [15]. During postoperative follow-up after UKA, a significant shortening of the gait cycle was observed compared to preoperative measurements. This phenomenon can be attributed to several factors. First, the successful execution of UKA significantly alleviated the chronic pain associated with unicompartmental knee osteoarthritis [16]. The marked reduction in postoperative pain not only improved patients' willingness to engage in daily activities but also encouraged a faster and smoother gait pattern, thereby shortening the gait cycle. Second, as postoperative rehabilitation progressed, muscle strength around the knee joint gradually recovered, accompanied by a substantial improvement in neuromuscular control. This facilitated better gait control, reducing unnecessary pauses and hesitation, which in turn enhanced the efficiency of the gait cycle. Therefore, the shortening of the gait cycle following UKA is likely the result of a combination of factors, including pain relief, muscle strength and neuromuscular control recovery and biomechanical changes.

Recovery of walking speed is a key indicator for evaluating health status and functional recovery [17]. In our observations, patients showed significant

Table 3 Comparison of flexion angles in squatting position preoperatively and postoperatively for 17 patients able to perform the squat-to-stand movement

Patients	Maximum knee flexion Angle in preoperative squat posture (°)	Maximum knee flexion Angle in postoperative squat position (°)	Maximum hip flexion Angle in preoperative squat posture (°)	Maximum hip flexion Angle in postoperative squat position (°)
1	98.48	133.91	111.91	126.26
2	136.97	139.28	132.81	136.07
3	96.59	114.62	138.92	136.94
4	121.63	131.54	135.76	143.4
5	106.91	119.30	115.49	136.49
6	85.16	102.33	94.6	128.2
7	84.10	147.98	114.61	146.55
8	93.91	91.82	101.25	114.63
9	127.43	114.35	130.51	135.75
10	78.80	86.46	76.11	76.41
11	60.82	83.67	73.53	112.47
12	87.45	104.96	84.47	99.02
13	123.61	121.31	142.11	82.77
14	88.47	115.85	126.84	137.99
15	79.04	92.75	133.9	140.41
16	93.32	96.33	127.36	143.04
17	76.25	76.13	93.98	125.9

improvements in both WOMAC and KSS pain scores following surgery, along with noticeable enhancements in gait speed and knee joint ROM. However, it is important to note that, according to existing literature, the walking speed of healthy elderly individuals typically ranges from 0.94 to 1.34 m/s [18]. In contrast, the preoperative walking speed of patients in this study was (0.79 ± 0.24) m/s, which improved to (0.90 ± 0.22) m/s postoperatively. Despite this improvement, both preoperative and postoperative speeds remained below the standard walking speed for healthy elderly individuals. Several factors may explain the gap between postoperative walking speed and the benchmark for healthy adults. First, the patients in this study were generally older, and it is well-documented that gait speed naturally declines with advancing age [19]. Second, according to Fary's research [20], full recovery of walking speed may require a recovery period of at least 22 weeks. In our study some patients had not yet reached the 22-week mark required for complete recovery. Consequently, while walking speed improved after UKA, the knee joint's walking function had not fully recovered to the level typical for healthy adults. Future plans include extending the follow-up period to enable continuous monitoring and evaluation of further improvements in walking speed. Stride length is another critical parameter for assessing functional recovery after UKA [21]. Research indicates that after UKA, pain relief, improved joint alignment, and enhanced quadriceps contraction efficiency work together to increase the motion speed of the affected limb during walking, which in turn increases stride length [22–24]. It is hypothesized that the increase in stride length directly reflects improved hip flexion and knee extension functions in the affected limb. Chronic knee osteoarthritis often leads to knee flexion deformities, which severely restrict the ROM during walking. However, effective treatment through UKA improves knee flexion deformity. Postoperatively, as rehabilitation progresses, quadriceps strength gradually recovers, allowing for a greater knee extension angle during the mid-stance phase. This improvement is critical because it enhances knee joint stability by allowing the knee to lock effectively with the ground during walking, thereby promoting better forward propulsion. The enhanced propulsion from this improved knee extension contributes to the ability to cover greater distances and naturally increases stride length, further improving walking efficiency.

Stride length has been extensively studied as a key parameter in the analysis of pathological gait patterns [25]. Preoperatively, it was anticipated that postoperative improvements—such as enhanced stability, and better lower limb support capacity—would enable patients to shift their body weight more towards the affected side and maintain this shift for a longer duration during walking, thereby promoting an increase in stride length. However, it is important to note that actual gait improvements may be influenced by multiple factors, including the success of the surgery, individual patient characteristics, adherence to rehabilitation protocols, and the presence of potential complications. Therefore, a comprehensive evaluation of changes in stride length requires consideration of these factors to ensure an accurate understanding of postoperative gait recovery. Moreover, an increase in stride length not only reflects the functional recovery of the affected lower limb but may also positively impact overall gait symmetry, stability, and efficiency. Future research could further explore the relationships between changes in stride length and gait variability, and how these factors collectively influence the overall walking ability of patients.

The significant functional advantages of UKA lie in its ability to effectively promote the postoperative recovery of knee joint ROM while maintaining normal motor function [26]. In this study, the observed improvement in postoperative ROM among UKA patients is believed to be primarily attributed to the meticulous design of the UKA procedure. This design emphasizes the preservation and optimization of the knee's natural kinematics [27]. These features not only alleviate acute symptoms but also foster tissue repair and functional reconstruction, directly accelerating joint mobility recovery. Additionally, the precise correction of lower limb alignment post-UKA plays a pivotal role in ROM recovery [28]. Alignment optimization is not only essential for the biomechanical balance of the knee joint but also directly affects the distribution of stress on the joint surface and the efficiency of its motion trajectory. In this study, fine adjustments to the tibial resection angle ensured that postoperative lower limb alignment achieved an optimal state, facilitating smooth joint motion and significant improvements in ROM. This mechanism effectively reduces abnormal stress concentrations within the joint, slows joint degeneration, and creates highly favorable conditions for the long-term enhancement of ROM.

This study examined the effects of surgical intervention on the maximum knee flexion angle during squatting in patients. The results revealed a significant increase in the knee flexion angle, from a preoperative value of (98.17 ± 24.40)° to a postoperative value of (110.15 ± 20.79)°. This improvement underscores the surgery's efficacy in restoring knee flexion function, which has direct implications for patients' ability to perform daily activities, particularly those involving stair climbing and squatting. Such enhancements notably improve their quality of life and self-care capabilities. Moreover, the study observed adaptive changes in hip joint function following UKA, which is particularly noteworthy. Specifically, the maximum hip flexion angle during squatting increased from (113.77 ± 22.56)° preoperatively to (124.84 ± 21.13)° postoperatively. This change reflects a natural adjustment in the hip flexion strategy during movements like squatting, allowing patients to better adapt to the new functional state of their knee joint post-surgery. It also highlights the positive impact of the surgery on the overall biomechanics of the lower limb, promoting increased hip joint flexibility and a broader range of motion.

The results of this study indicate that there were no significant differences in step frequency and swing time after UKA surgery compared to pre-surgery ($p > 0.05$). This phenomenon may be attributed to the following factors: firstly, UKA surgery preserves the normal anatomical structure of the knee joint, thus maximizing the retention of proprioception and neuromuscular control capabilities of the knee joint [29]. Cadence and swing time, as basic gait parameters, are mainly regulated by the central nervous system and are relatively insensitive to changes in local joints [30]. The results of this study are consistent with the research of Peng Hao et al. [31], which also showed that the step frequency of patients remained stable after UKA surgery. However, it should be noted that this study only evaluated gait parameters 6 months after surgery. Given the long-term nature of neuromuscular adaptation, extending the follow-up period may reveal potential changes in these parameters. Therefore, it is suggested that future studies conduct longer follow-up observations to comprehensively assess the long-term effects of UKA on patients' gait parameters.

Accurate measurement of double-limb support time is a valuable indicator of both gait stability and pain sensitivity [32]. Prolonged double-limb support time typically signals reduced walking stability and diminished gait smoothness [8, 9]. In this study, a significant reduction in double-limb support time was observed postoperatively, indicating improved lower limb muscle efficiency and optimized joint stability during the gait cycle. More importantly, the decreased double-limb support time signifies that patients can more quickly transfer their center of gravity during walking, which leads to a more natural, fluid gait and enhanced balance. This improvement in "smoothness" and "balance" not only contributes to higher patient satisfaction postoperatively but, in the long term, may reduce fall risks associated with unstable gait. Consequently, this could lower the incidence of complications such as periprosthetic fractures, ligament injuries, and prosthetic wear. Traditional evaluation systems often fall short in quantifying these "smoothness" and "balance" characteristics. However, our innovative testing approach allows for the quantitative assessment of these critical motion parameters, offering a more comprehensive and accurate perspective for clinical evaluation. This approach effectively addresses the limitations of conventional scoring systems.

The study has some limitations. (1) The main limitation of this study lies in the short follow-up period, which may limit the comprehensiveness and long-term reference value of the results. Although most patients can achieve significant functional improvements within 3–6 months after UKA surgery, full adaptation of gait parameters may require a longer time.Therefore, the 6-month follow-up period may have only captured early postoperative gait changes and may not reflect the dynamic process of long-term gait adaptation. Moreover, the short-term follow-up may have underestimated the ultimate improvement potential in gait symmetry and coordination, and some gait indicators may still show significant changes over a longer period, suggesting that the results of this study may only represent the early recovery phase post-surgery. Nevertheless, this study provides valuable insights into early gait recovery after UKA, and the 6-month follow-up data have significant guiding importance for early rehabilitation interventions. Future research should extend the follow-up period to more comprehensively clarify the temporal characteristics of gait adaptation. At the same time, expanding the sample size and conducting subgroup analyses to explore the impact of factors such as age and gender on postoperative recovery will help more thoroughly assess the clinical efficacy of UKA and provide more reliable evidence for personalised rehabilitation plans and clinical decision-making. (2) While this study assessed various movement modes, such as squatting, side-view walking, sit-to-stand, and supine knee flexion, other essential activities—such as stair climbing and running—could not be evaluated due to space constraints. To enhance the comprehensiveness of our research, future studies will aim to expand the patient cohort, broaden the range of assessed motion tasks, and extend the follow-up period in future studies, providing a more thorough analysis of gait recovery outcomes.

Conclusions

UKA surgery can improve the kinematic characteristics of the knee joint, encompassing both basic and advanced functional activities.

Abbreviations

OA	Osteoarthritis
KOA	Knee osteoarthritis
TKA	Total knee arthroplasty
UKA	Unicompartmental knee arthroplasty
HTO	High tibial osteotomy
BMI	Body Mass Index

ROM Range of motion
KSS Knee society score
WOMAC Western Ontario and McMaster Universities Arthritis Index

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Author contributions
MZ, WC and XL conceived the idea of the study. MZ, YZ, HW, HZ, QZ, and XZ made significant contributions to the data analysis and interpretation. MZ, HW and YZ developed the statistical analysis plan and conducted statistical analyses.MZ contributed to the interpretation of the results. MZ drafted the original manuscript. WC and XL supervised the conduct of this study. All authors reviewed the manuscript draft and revised it critically on intellectual content. All authors approved the final version of the manuscript to be published.

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Availability of data and materials
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was approved by the Ethics Committee of the Chinese People's Liberation Army General Hospital (Approval No: 2022KY127-KS001). Written informed consent was obtained from all participants, and the study adhered to the principles of the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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