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Article

The Temporal-Spatial Parameters of Gait After Total Knee Arthroplasty

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Abstract: Introduction: Antalgic gait is characteristic for knee osteoarthritis. It is marked by a shortened swing phase and an extended stance phase, significantly deviating from biomechanical norms and resulting in a reduced step length. We hypothesized that total knee arthroplasty (TKA) would improve the temporal-spatial parameters of gait. Therefore, stride length, walking speed, and the relationship between gait performance changes and selected demographic features of the study group were measured, compared, and analyzed. **Material and Methods:** A total of 46 consecutive patients (24 women and 22 men) with unilateral knee osteoarthritis who underwent surgical treatment were enrolled in this prospective study. Group I (n=34) was assessed one day before surgery and again six weeks postoperatively. Group II (n=12) was evaluated preoperatively and 1.5 years after surgery. The study included three stages. In the first stage, patients were assigned to their respective groups based on the planned follow-up period. In the second stage, preoperative assessments of step length (m), walking speed (m/s), and cadence (steps/min) were conducted. In the third stage, selected gait parameters were reassessed: six weeks postoperatively in Group I and 1.5 years postoperatively in Group II. During the evaluation of step length and walking speed, gait was digitally recorded to ensure measurement precision. Cadence was assessed during a one-minute walk test. Throughout the study, patients walked naturally, in a manner reflecting their everyday locomotion. **Results:** In Group I, the mean step length slightly increased from 0.40 m (Min 0.175; Max 0.60) before surgery to 0.42 m (Min 0.21; Max 0.75) postoperatively. The stride length increased by 0.02 m, but this change was not statistically significant. The mean walking speed rose significantly from 0.41 m/s (Min 0.20; Max 0.88) preoperatively to 0.47 m/s (Min 0.23; Max 1.20) six weeks after surgery. Cadence showed a statistically significant increase from 72.9 steps/min (Min 60; Max 92) to 77.06 steps/min (Min 64; Max 92) ($p = 0.044$). In Group II, the average step length rose significantly from 0.39 m (Min 0.27; Max 0.60) before surgery to 0.52 m (Min 0.42; Max 0.68) at the 1.5-year follow-up. Walking speed also increased significantly from 0.44 m/s (Min 0.29; Max 0.82) preoperatively to 0.69 m/s (Min 0.44; Max 1.46) postoperatively. Cadence significantly improved from a mean of 73.7 steps/min (Min 60; Max 92) to 103.6 steps/min (Min 87; Max 121) at the final follow-up. Statistical analysis revealed a highly significant difference between preoperative and 1.5-year postoperative measurements all p values < 0.001. **Conclusion:** Total knee arthroplasty improves the temporal-spatial parameters of gait, measured by stride length and walking speed, both six weeks and 1.5 years after surgery.

Keywords: total knee arthroplasty; gait; stride length; walking speed; knee osteoarthritis

1. Introduction

Human gait is a complex neuromechanical process involving the synchronized activity of the central and peripheral nervous systems, the musculoskeletal structures, and sensory feedback loops. It consists of a sequence of coordinated movements that ensure stability. Central pattern generators located in the spinal cord, modulated by supraspinal signals, produce rhythmic motor patterns responsible for locomotion. Proper gait requires efficient functioning of all lower limb joints, particularly the knee joint, which acts as both a shock absorber and energy transmitter [1].

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The human gait cycle is divided into two main phases: the stance phase and the swing phase. The stance phase, accounting for approximately 60% of the gait cycle, begins with the initial contact of the foot with the ground, typically the heel. During this initial contact, the knee is extended and the hip is slightly flexed, preparing the limb to bear body weight. The loading response immediately follows, during which body weight is transferred to the supporting limb. In this phase, the knee flexes to absorb shock, and stabilizing muscles activate to maintain balance.

The mid-stance phase follows, where the body moves over the stable foot. At this point, the knee extends and the hip transitions into extension. Eccentric muscle contractions control the movement of body segments over the foot. Terminal stance, the final part of the stance phase, begins as the heel lifts off the ground and body weight shifts onto the forefoot. The hip reaches maximum extension, and the knee remains slightly flexed to prepare for limb lift-off. The stance phase concludes with pre-swing, during which the toes leave the ground and the swing phase begins. During pre-swing, the knee flexes further, and the hip starts flexing again, initiating free limb movement [2,3].

The swing phase accounts for approximately 40% of the gait cycle. It begins with the initial swing, during which the lower limb lifts off the ground. The knee flexes to about 60°, and the hip deepens its flexion. In mid-swing, the limb moves forward, achieving maximum hip flexion, while the knee extends in preparation for ground contact. The cycle ends with terminal swing, when the knee reaches full extension and the muscles responsible for limb stabilization activate in preparation for the next foot-ground contact [2,3].

The energy efficiency of gait results from the use of the double pendulum mechanism, allowing the recovery of kinetic and potential energy, thereby minimizing energy expenditure during walking [4].

Key gait parameters include step length, stride length, cadence, walking speed, duration of gait phases (stance and swing phases), double support time, and step width. Step length is defined as the distance between the contact points of one foot with the ground and the subsequent contact of the opposite foot. In healthy adults, step length typically ranges from 0.60 to 0.80 meters. Stride length, the distance between two consecutive ground contacts of the same foot, usually measures about 1.2–1.6 meters [5].

Average step length depends on factors such as height, sex, and gait technique. Cadence—the number of steps taken per minute—typically ranges from 90 to 120 steps/min, depending on age, sex, and physical condition [6]. Walking speed, calculated as stride length multiplied by cadence and divided by two, averages between 1.11 and 1.66 m/s in healthy adults. Walking speed is considered a key functional indicator, strongly associated with independence and quality of life [7,8].

Maintaining balance during gait is crucial and is achieved through coordinated movements of the pelvis, hips, knees, and ankles. For example, during the stance phase, the knee flexes slightly (approximately 15°) to absorb shock and facilitate smooth movement. During the swing phase, the knee flexes up to 60°, allowing the limb to move freely [9].

Knee osteoarthritis (KOA) is a degenerative process that leads to joint deformity, structural damage, and functional impairment. It affects all joint components, including cartilage, bone, ligaments, the joint capsule, and synovial membrane [10]. The prevalence of KOA increases with age, with radiographic features observed in 19.2–27.8% of individuals aged 45 years and older [11]. KOA causes pain, joint stiffness, and muscle weakness.

The knee joint plays a central role in all phases of gait, especially in shock absorption and control of limb movement. In normal gait, the knee flexes during the swing phase and extends just before heel strike. In KOA patients, these patterns are disrupted, with reduced ranges of flexion and extension, increased muscle coactivation, and decreased peak joint moments, leading to inefficient, antalgic gait patterns [12].

Antalgic gait, a hallmark of KOA, is characterized by a shortened swing phase and a prolonged stance phase. This deviation from biomechanical norms results in reduced step length and an increased number of steps. Shortening of the single-limb support phase on the affected side is typical. Incomplete knee extension reduces gait efficiency through functional limb shortening, with increased flexor strength relative to quadriceps strength, often compensated by forward trunk lean. Persistent knee flexion leads to secondary changes in the muscular system, including prolonged activation of the biceps femoris, semimembranosus, semitendinosus, and rectus femoris muscles during the stance phase. These changes significantly impact gait biomechanics.

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Patients with KOA typically exhibit reduced walking speed, shorter step length, and longer double support time. Additionally, joint instability resulting from degenerative changes often leads to altered kinematics and asymmetric loading during gait [10–12].

2. Aim of the Study

The aim of this study was to analyze changes in temporal-spatial gait parameters, specifically step length, cadence, and walking speed, before and after surgical treatment of knee osteoarthritis using total knee arthroplasty (TKA).

The primary objective was to assess the degree of improvement in locomotor function during the early postoperative period (six weeks) and the long-term follow-up (1.5 years) after the procedure. The study also aimed to examine the relationship between the extent of gait parameter changes and selected demographic characteristics of the patient group.

Given the role of the knee joint in gait biomechanics and the characteristic gait disturbances observed in advanced osteoarthritis, we hypothesized that TKA would improve the analyzed gait parameters. Additionally, we assumed that therapeutic effects might vary depending on the postoperative observation period and individual patient characteristics.

3. Materials and Methods

The research was approved by the Bioethics Committee at the Pomeranian Medical University in Szczecin (No. KB-0012/81/17). The study was conducted at the Department of Orthopedics, Traumatology, and Musculoskeletal Oncology at the Pomeranian Medical University in Szczecin (Poland). It included 46 consecutive patients with knee osteoarthritis (grades III and IV according to the Kellgren-Lawrence classification) who underwent surgical treatment, comprising 24 women (52.2%) aged 55–84 years and 22 men (47.8%) aged 59–82 years [13].

The participants were divided into two groups. Group I included 34 patients (18 women and 16 men), and Group II included 12 patients (6 women and 6 men). All participants had no degenerative changes exceeding grade I on the Kellgren-Lawrence scale in the contralateral knee. Radiographic assessments were performed in standing anteroposterior and lateral views and evaluated by radiology specialists. The statistical characteristics of the study group are presented in Table 1.

Table 1. Statistical features describing the study groups.

	Group I n=34			Group II n=12		
Number	Total n=34	Women n=18	Men=16	Total n=12	Women=6	Men=6
Parameter	X (SD)	X (SD)	X (SD)	X (SD)	X (SD)	X (SD)
Age (years)	71 (7,12) Min:55; Max: 84	70,5 (7,26) Min:55; Max: 84	71,9 (6,98) Min:59; Max:80	68,33 (6,43) Min:56 Max: 82	69 (5,87) Min:56; Max: 78	68,67 (7,53) Min:59; Max:82
Body weight (kg)	79,2 (13,34)	74,2 (10,00)	89,5 (13,69)	83,2 (13,71)	74 (7,92)	92,3 (12,21)
Height (m)	1,65 (8,63)	1,61 (5,08)	1,75 (6,74)	1,67 (9,53)	1,59 (3,99)	1,75 (6,77)
BMI (kg/m²)	28,87 ((3,59) Min:21,2; Max:36,3	28,65 (3,39) Min:22,3; Max:34,4	29,33 (4,05) Min:21,2; Max:36,3	29,7 (3,75) Min:21,5; Max:34,2	29,1 (3,48) Min:22,8; Max:34,2	30,3 (4,25) Min:21,9; Max:34,1

Abbreviations: n—number of patients X—mean SD—standard deviation Min—minimum Max—maximum.

Total knee arthroplasty was performed using a cemented Vanguard®® knee implant (Biomet, Inc., Warsaw, IN, USA). All procedures were conducted through a medial parapatellar approach by two experienced knee arthroplasty surgeons. Subarachnoid anesthesia was administered in all patients as described by Jurewicz et al. [15]. The average length of hospital stay was 3.9 days (range: 3–5 days).

Patients were examined twice: Group I underwent evaluation one day before surgery and six weeks after TKA (Table 2), while Group II was evaluated one day before surgery and 1.5 years postoperatively (Table 3). No surgical complications, including vascular or nerve injury, postoperative infection, venous thromboembolism, or prosthesis loosening or dislocation, were observed.

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Table 2. Comparison of selected gait parameters in patients before and after surgery in Group I.

Group I	Preoperative, n=34		Postoperative (6 weeks), n=34		The Wilcoxon Test	
	Min-Max	X (SD)	Min-Max	X (SD)	Z	p
Stride length (m)	0,175–0,6	0,4 (0,097)	0,21– 0,75	0,42 (0,102)	-1,158	0,247
Walking speed (m/s)	0,2– 0,88	0,41 (0,027)	0,23–1,2	0,47 (0,022)	-1,857	0,063
Cadence (step per min)	60–92	72,9 (7,75)	64–92	77,06 (8,59)	-3,215	0,044

Abbreviations: n—number of patients X—mean SD—standard deviation.

Table 3. Comparison of selected gait parameters in patients before and 1.5 years after surgery in Group II.

Group II	Preoperative, n = 12		Postoperative (1.5 years), n = 12		W Kendall Test	
	Min-Max	X (SD)	Min-Max	X (SD)	W	p
Stride length (m)	0,27–0,60	0,39 (0,099)	0,42–0,68	0,52 (0,090)	0,757	<0,001
Walking speed (m/s)	0,29 –0,82	0,44 (0,022)	0,44 –1,46	0,69 (0,014)	0,674	<0,001
Cadence (step per min)	60 –92	73,7 (8,75)	87 –121	103,6 (7,44)	0,776	<0,001

Abbreviations: n—number of patients X—mean SD—standard deviation.

The limited number of participants in Group II was partly due to logistical difficulties. Seventeen patients declined follow-up participation due to travel inconvenience, as the research site was located far from their residences. Nine patients underwent surgery on other joints, excluding them from further participation due to the potential impact on gait outcomes. Six patients developed unrelated diseases preventing follow-up assessment, and two patients died during the study period.

3.1. Measurement of Temporal-Spatial Gait Parameters

The study was conducted in three stages. In the first stage, patients were qualified for inclusion based on established criteria and assigned to two study groups. In the second stage, baseline measurements were collected one day before total knee replacement (TKR). In the third stage, the measurements were repeated: six weeks postoperatively in Group I and 1.5 years postoperatively in Group II.

All gait tests were performed on a flat, level surface free of obstacles. Before each test, patients were instructed to walk naturally, simulating their typical daily gait. If a patient's walking pattern during the test differed noticeably from their natural gait (e.g., due to hesitation or altered pace), the instructions were repeated and the trial was restarted.

The first test assessed stride length and walking speed. A 15-meter long corridor was marked with tape to indicate the start and walking path. Patients walked continuously for three minutes at a self-selected brisk pace, turning at the end of the 15-meter course and continuing in the opposite direction. This approach aimed to reflect their natural everyday gait.

Stride length was measured as the distance between two identical foot contacts (heel to heel) in meters. Walking speed was recorded in meters per second (m/s) using a stopwatch over the 15-meter path, excluding the turnaround phases. The trials were digitally recorded from sagittal and frontal views. The measurements were registered with the use of an electronic device. The trial that best reflected the patient's natural gait was selected for analysis.

Cadence (stride rate) was assessed separately in a square-shaped corridor, allowing continuous walking. This test was not digitally recorded. Cadence was defined as the number of steps taken during a one-minute walk. Patients began walking from a marked point and continued uninterrupted for one minute. A researcher operated the stopwatch and counted the steps taken. Recordings of selected trials were saved for further analysis of stride length and walking speed. Testing conditions were standardized for all participants. Stride length was measured with a validated tool accurate to 1 cm. Each patient was allowed up to three trials, with the best result used for statistical analysis.

Additionally, patients walked along a 3-meter-long tape laid on the floor. After five brisk steps, video recording began to capture the trial for detailed analysis. Selected recordings were used to evaluate stride length, cadence, walking speed, and overall gait quality. In cases where individual trials differed substantially, the entire test was repeated. All patients received standardized verbal instructions before testing, with repetitions if necessary.

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3.2. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics. The Shapiro-Wilk test was used to assess the normality of gait parameter distributions. As most distributions deviated significantly from normality, non-parametric methods were employed.

The Wilcoxon signed-rank test was used to compare pre- and postoperative results. Sex differences were analyzed using the Mann-Whitney U test, and correlations between functional outcomes and other variables were assessed using Spearman's rank correlation. A p-value < 0.05 was considered statistically significant, and a p-value < 0.1 was considered indicative of a statistical trend. In the subgroup of 12 patients evaluated 1.5 years postoperatively, comparisons of three dependent samples were conducted using the non-parametric Kendall test.

The integrity and accuracy of the study were supervised by a certified physiotherapist experienced in treating patients with knee osteoarthritis. Qualification for TKA was conducted by a specialist in orthopedics and traumatology. Statistical analyses were performed by a professional statistical consulting firm.

4. Results

The results of Group I are presented in Table 2 and include data on stride length, cadence, and walking speed before and six weeks after total knee arthroplasty (TKA).

The mean stride length increased slightly from 0.40 m (Min 0.175; Max 0.60) before surgery to 0.42 m (Min 0.21; Max 0.75) after TKA. The increase of 0.02 m, was not statistically significant. The mean walking speed rose from 0.41 m/s (Min 0.20; Max 0.88) before surgery to 0.47 m/s (Min 0.23; Max 1.20) six weeks postoperatively. This change was also not statistically significant. The cadence increased slightly, from 72.9 steps per minute (Min 60; Max 92) before surgery to 77.06 steps per minute (Min 64; Max 92) postoperatively. This change was statistically significant ($p = 0.044$).

In Group II, measurements were taken before TKA and 1.5 years after the procedure, as presented in Table 3. Gradual improvements were observed in walking speed, stride length, and cadence. The mean stride length before TKA was 0.39 m (Min 0.27; Max 0.60), increasing significantly to 0.52 m (Min 0.42; Max 0.68) at the 1.5-year follow-up.

Walking speed also improved significantly, rising from a mean of 0.44 m/s (Min 0.29; Max 0.82) preoperatively to 0.69 m/s (Min 0.44; Max 1.46) postoperatively. Cadence showed a significant increase, with the average number of steps per minute rising from 73.7 (Min 60; Max 92) before surgery to 103.6 (Min 87; Max 121) at the 1.5-year follow-up.

Statistical analysis comparing measurements before TKA and at 1.5 years postoperatively revealed a highly significant difference ($p < 0.001$). The most pronounced improvements in all assessed parameters were observed at the 1.5-year follow-up.

5. Discussion

The results obtained in this study do not fully align with those reported by Ogrodzka and Niedźwiedzki, who analyzed a group of 20 patients six months after total knee arthroplasty (TKA). They observed a reduction in the number of steps, stride length, and walking speed after surgery, as well as an increase in the time required to perform a single step and a longer stance phase compared to a healthy control group. In our study, the average step length after TKA was 0.47 m, and the average walking speed was 0.47 m/s, whereas in Ogrodzka and Niedźwiedzki's study these values were 0.41 m and 2.09 m/s, respectively. Moreover, our patients demonstrated faster walking speeds after surgery. This discrepancy may relate to the follow-up duration, which was six months in Ogrodzka and Niedźwiedzki's study compared to six weeks in ours.

Gait parameters are likely to improve further over time following surgery, possibly due to better functioning of the soft tissues surrounding the operated knee joint [16].

Abdel et al. conducted a clinical trial in patients three months after TKA. The mean stride length and walking speed improved from 0.82 m and 0.64 m/s before surgery to 0.96 m and 0.76 m/s postoperatively. These outcomes represented better functional results than those observed in our study, despite Abdel's cohort having a higher average age of 71 years.

The authors suggested that extending the follow-up period to six months or one year might reveal further differences. However, Börjesson et al. demonstrated that outcomes at five years postoperatively were similar to those at three months, indicating that most improvements occur early

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after TKA. In our study, at 1.5 years postoperatively, we observed improvements in walking speed, stride length, and cadence.

Advanced knee osteoarthritis significantly disrupts movement patterns, and although TKA corrects pathological gait patterns, maintaining functional improvements requires proper rehabilitation and convalescence.

Braito et al. examined 17 patients before and eight weeks after TKA. The mean walking speed increased slightly from 0.91 m/s to 0.93 m/s, and stride length increased from 1.05 m to 1.09 m, though these changes were not statistically significant [18].

These findings support the view that significant improvement in abnormal movement patterns requires longer postoperative periods. Similar observations were made by Ogrodzka and Niedźwiedzki, where pathological gait persisted six months after TKA [19].

Callies et al. assessed six patients 12 months after TKA, a younger and leaner group compared to ours. They reported walking speeds of 1.29 m/s and 1.5 m/s and stride lengths of 0.67 m and 0.75 m before and after surgery, respectively, indicating improvement consistent with our findings [20].

Patterson et al. investigated whether sex, obesity, or time after surgery influenced gait quality in 43 patients (58% women). Their results indicated that men had worse gait outcomes compared to women, with men experiencing a decrease in walking speed after TKA, while women showed improvement. Patterson's findings differ from ours, as we observed overall improvements in both sexes [21].

Urlich et al. focused exclusively on women up to 10 years post-TKA. Temporal-spatial gait parameters remained impaired even after this period, with patients walking 1.2 m/s slower than healthy controls and exhibiting shorter steps and prolonged double support times [22].

Thus, TKA does not fully restore all aspects of knee function, even long-term.

Naili et al. reported that although walking speed improved slightly one year after TKA, abnormal gait patterns persisted compared to healthy controls.

Moreover, 9 out of 28 patients reported a decline in quality of life one year after surgery, mainly those with poorer baseline outcomes [23]. This contrasts with our findings, where walking speed improved significantly 1.5 years postoperatively.

Metcalfe et al. showed that despite improved walking speed after TKA, abnormal limb loading patterns often persisted, increasing the risk of contralateral knee degeneration [24].

These findings highlight the need for preoperative rehabilitation to optimize postoperative gait outcomes. In our study, stride length improved from 0.39 m preoperatively to 0.52 m 1.5 years postoperatively.

Gait characteristics after TKA are crucial surgical outcomes. Okita et al. demonstrated that even years after TKA, asymmetrical gait biomechanics persisted, reflecting adaptive strategies to protect the reconstructed knee [25]. These findings align with our observation of residual gait deviations despite improvements.

Fenner et al. reported that only 20% of TKA patients restored normal gait patterns postoperatively, despite similar walking speeds between patients and controls [26].

Patients with better knee function achieved better gait parameters, consistent with our findings.

Bonnefoy-Mazure et al. found that three months after TKA, patients exhibited worse gait parameters compared to preoperative status. However, one year postoperatively, physiological gait patterns were largely restored, closely aligning with our 1.5-year results [27].

In a further study, Bonnefoy-Mazure et al. demonstrated that patients with higher BMI had slower walking speeds and reduced knee range of motion both before and after TKA [28].

Similarly, our study found an association between BMI and gait parameters.

Maier et al. used 3D gait analysis in patients with persistent postoperative pain and identified reduced walking speed and stride length [29]. Our cohort did not experience persistent pain, which may explain the better functional outcomes.

Singhi et al. found that although stride length was reduced in the operated limb, TKA improved overall gait efficiency [30]. Our results support this finding, with improvements in walking speed and stride length already evident six weeks after surgery and more pronounced at 1.5 years.

The main limitation of our study was the small sample size in the long-term follow-up group. While all patients participated in the short-term assessment (six weeks after surgery), the long-term evaluation at 1.5 years included only six individuals, who represented a separate study group rather than a continuation of the initial cohort. The primary reasons for the limited participation were

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logistical barriers and the emergence of new health problems, as detailed in the Materials and Methods section. Moreover, the progressive nature of osteoarthritis complicated long-term assessment, as degenerative changes in the contralateral knee, already evident in the preoperative phase, could have influenced later gait outcomes.This research received no external funding. Informed consent was obtained from all participants.

6. Conclusions

1. Total knee arthroplasty (TKA) contributes to significant improvements in temporal-spatial gait parameters, particularly stride length, walking speed, and cadence. These improvements become more pronounced over time, with the most substantial gains observed 1.5 years after surgery.
2. In the early postoperative period (six weeks), changes in gait parameters are present but not always statistically significant. This may be attributed to the limited convalescence period and the early phase of rehabilitation. However, a statistically significant improvement in cadence was already evident at this stage.
3. Long-term follow-up (1.5 years after TKA) reveals statistically significant increases in all analyzed gait parameters, confirming that time plays a crucial role in achieving full functional recovery.

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