

Biomechanical Assessment of Patients with Unilateral Total Knee Arthroplasty: A Preliminary Comparative Study

ABSTRACT

Aims: To identify the biomechanical differences between two types of prostheses (posterior-stabilized prosthesis with a fixed tibial plateau base and congruent prosthesis with a rotating tibial plateau) through functional performance measured by the 2-Minute Walk Test using the G-Sensor® inertial sensor (BTS Bioengineering S.p.A., Italy).

Study design: A prospective, observational, and comparative study with assessments conducted at two time points: 12 to 24 months after surgery.

Place and Duration of Study: This study was carried out in a tertiary hospital in collaboration with a private university in the state of Goiás, Brazil, between March 2022 and December 2024.

Methodology: This study evaluates and compares the functional performance of a sample of 36 patients using the 2-Minute Walk Test (2MWT) with an inertial sensor at two distinct time points, 12 to 24 months postoperatively. Patients were characterized by age, sex, BMI, postoperative time, laterality of the operated knee, and type of prosthesis used (fixed plateau or mobile plateau).

Results: The study included 36 participants (21 women and 15 men; mean age 69.38 years, BMI 30.46), with 24 undergoing right knee arthroplasty. Half received fixed, and half rotated tibial plateau prostheses. Postoperative assessments at 17.31 and 42.80 months showed no significant differences in gait parameters between prosthesis types or sides. Pearson's correlation revealed a strong negative relationship between test duration, cadence, and speed for rotating prostheses ($r = -0.67/-0.66$, $P = .001$) and between duration and speed for fixed prostheses ($r = -0.8$, $P < .001$).

Conclusion: This study found no significant functional differences between fixed and rotating tibial plateau prostheses using the 2-Minute Walk Test. Both implants effectively restored knee mobility, emphasizing the utility of inertial sensors for clinical assessment. Further research with larger samples is needed to confirm these findings.

Keywords: Gait Analysis; Physical Functional Performance; Postoperative Period; Rehabilitation.

1. INTRODUCTION

Progressive musculoskeletal conditions are common, and many patients lack access to proper diagnosis and treatment (Primorac et al. 2020). It causes pain, limitations in functional capacity, and a consequent reduction in quality of life (Walankar, Panhale & Koli 2018). Its origin can be classified as primary or secondary. Primary causes, often unclear, are associated with genetic factors, age-related changes, ethnic variations, and biomechanical aspects (Schofield et al., 2018). Secondary causes include post-traumatic, dysplastic, infectious, inflammatory, or biochemical origins that are not yet fully understood, or even a combination of these factors (Rošin et al. 2024).

Osteoarthritis is characterized by a dynamic imbalance between tissue repair and destruction within the synovial tissues (Natalie Min-Yi et al. 2022). During compositional

changes, cartilage loses its integrity (Hu et al. 2021), increasing its susceptibility to physical stresses or loads that patients experience during simple activities, such as walking. In an attempt at repair, chondrocyte hypertrophy occurs, leading to increased synthetic activity. However, inflammatory content is generated, exacerbating the degradation process over years of pathogenesis (Ren et al. 2023).

Among treatment options, knee arthroplasty surgery is considered a resource for advanced clinical conditions, aiming to restore joint functionality and improve patients' quality of life (Bruyère et al. 2019). Regarding the evolution of prosthetic materials and design, the surgeon must determine the type of knee prosthesis during the preoperative evaluation based on the patient's case, considering factors such as the need for greater or lesser prosthesis constraint, mobility of the tibial plateau, preservation or removal of the posterior cruciate ligament, and cemented or uncemented fixation, to ensure joint congruence and more excellent resistance to stress and load (Song, Park e Bae 2019).

The postoperative period of knee arthroplasty influences the evolution of functional performance, both in the patient's subjective perception and in objective tests evaluated through indicators such as quality of life, walking speed, and knee range of motion, with the most significant progress observed after the first year (Freijo, Navarro e Villalba, 2024). The knee replacement surgery contributes to the functional recovery of the lower limbs, promoting significant improvements in gait and balance within the first three months post-surgery. However, beyond this period, no further progression in balance is observed when specifically evaluated through the Timed Up and Go and single-leg support tests (Tsubosaka et al., 2020).

The objective of the present study is to evaluate and compare the functional performance of patients undergoing primary knee arthroplasty with two types of knee prostheses (posterior-stabilized prosthesis with a fixed tibial plateau base and congruent prosthesis with a rotating tibial plateau) for the treatment of advanced knee osteoarthritis using the 2-Minute Walk Test with the G-Sensor® inertial sensor (BTS Bioengineering S.p.A., Italy) in two distinct evaluations, corresponding to 12 and 24 months postoperatively.

2. METHODOLOGY

The study participants were recruited from a tertiary hospital in Goiás, in Goiânia, Brazil. The initial sample of this study consisted of 36 patients who had already undergone total knee arthroplasty. The sample size calculation was based on the findings of Tsubosaka et al. (2020) in a repeated-measures analysis of variance, using a minimum treatment mean difference of 0.2, a standard deviation of 0.3, a statistical power of 80%, and a significance level of .05. Based on these parameters, the total sample size was estimated to be 54 patients.

Data collection was conducted following approval from the Research Ethics Committee. Patients underwent a screening and evaluation protocol, including the Timed Up and Go (TUG), Walk, and 2-Minute Walk tests. All participants were informed beforehand about potential risks and discomforts associated with participation. Although the study presented a low level of risk, as it involved non-invasive procedures in Orthopedics and Physiotherapy, some discomforts could occur, such as muscle fatigue, cramps, or falls during testing.

If any discomfort arose during the study, participants were referred to a hospital outpatient clinic, where they were attended to according to internal protocols and regulations previously agreed upon with the institution's management. To minimize potential risks, patients were

given sufficient time to adapt to the laboratory environment and familiarize themselves with the research team.

2.1 Eligibility criteria

For the inclusion criteria, participants were required to have a diagnosis of advanced knee osteoarthritis classified as grade ≥ 4 on the Kellgren and Lawrence scale, be between 50 and 80 years of age, and be undergoing their first surgery to treat osteoarthritis. Exclusion criteria included the presence of neurodegenerative diseases, secondary osteoarthritis, prior knee surgeries, a history of knee fractures in the last 12 months, hip arthroplasty, pre- or postoperative infection, comorbidities that could hinder adequate rehabilitation and recovery after surgery, and having undergone knee revision arthroplasties.

All patients adhered to a standardized rehabilitation protocol conducted at a single institution, receiving treatment from the same team of professionals to ensure uniformity across all groups. To reduce potential bias, physical therapists and educational professionals were not directly involved in the treatment procedures.

2.2 Patient assessment

Functional performance assessment was conducted using the 2-Minute Walk Test with the inertial sensor (G-Sensor®, BTS Bioengineering S.p.A., Italy), validated according to the protocol described (Wang et al. 2024). Participants were instructed to walk at their normal speed along a 10-meter path marked by two red cones, as shown in Image 1. This test assesses the patient's walking ability, utilizing the G-sensor to gather detailed data on distance, steps, symmetry, speed, cadence, stride, pelvic angles, propulsion, gait cycle, and phases. The entire time was timed by the researchers, with no stops, using the inertial sensor (G-Sensor®, BTS Bioengineering S.p.A., Italy) positioned on the lumbar region (specifically at the L2 level) with an elastic strap (Pîrșcoveanu et al. 2024).



Fig. 1. Patient undergoing the collection of the 2 MWT with the respective demarcation on the floor to guide the test

The portable G-sensor is a wireless inertial sensor system for analyzing human movement (Sankarpandi et al. 2017). The sensors are controlled by a data recording unit (up to 16 elements) through ZigBee-type radio communication. Each sensor has dimensions of 62mm x 36mm x 16mm, weighs 60g, and consists of a three-axis accelerometer (maximum range

of $\pm 6g$), a three-axis gyroscope (full-scale $\pm 300^\circ/s$), and a three-axis magnetometer (full scale ± 6 Gauss). This device is calibrated with gravitational acceleration immediately after manufacturing. For this study, only one device was used to collect data at a sampling frequency of 50 Hz. The inertial sensor data were transmitted via Bluetooth to a computer and processed using proprietary software (BTS G-STUDIO, version 2.6.12.0), automatically providing the parameters (Studio Idee Material 2024).

2.3 Statistical analysis

The normality of the data was assessed using the Kolmogorov-Smirnov test. The walk test parameter data were presented as mean and standard deviation (SD). To explore the impact of prosthesis type (fixed or rotating) and laterality (operated knee vs. non-operated knee) on the walk test variables, a two-factor analysis of variance (ANOVA) was performed. An intra-group Pearson correlation test was also conducted to analyze the relationship between temporal parameters (analysis duration, speed, and cadence) and pelvic symmetry (rotation, tilt, and obliquity). All analyses were performed using the statistical software SPSS 19 (IBM, USA), and statistical significance was set at $P < .05$.

3. RESULTS AND DISCUSSION

The study included 36 participants, comprising 21 women and 15 men. The participants had a mean age of 69.38 years, a mean weight of 77.8 kg, and a mean height of 1.60 meters, resulting in an average body mass index (BMI) of 30.46. Regarding laterality, most participants (24 individuals) underwent procedures on the right knee, while 12 underwent procedures on the left knee. As for the type of implant used, 18 patients received a fixed tibial plateau prosthesis, and the other 18 were treated with a rotating tibial plateau prosthesis.

Postoperative follow-up assessments were conducted at two distinct time points. The average postoperative period for the first evaluation was 17.31 months, while the second evaluation occurred, on average, 42.80 months after surgery. These data provide a comprehensive overview of the participants' characteristics and the timeline of the assessments, allowing for a detailed analysis of the results based on the type of implant and postoperative progression.

The means and standard deviations (SD) of the walk test variables between the groups are shown in Table 1. ANOVA revealed no differences between the groups or laterality for the stance phase variables ($F_{(1,70)} = 1,589$, $p = .21$; $F_{(1,70)} = .738$, $p = .39$ respectively), Left Double Support ($F_{(1,70)} = 2,718$, $p = .1$; $F_{(1,70)} = .425$, $p = .5$ respectively), Left Single Support ($F_{(1,70)} = .966$, $p = .32$; $F_{(1,70)} = .336$, $p = .56$ respectively); left Swing ($F_{(1,70)} = 2,369$, $p = .12$; $F_{(1,70)} = .395$, $p = .53$ respectively); Gait Cycle ($F_{(1,70)} = .907$, $p = .34$; $F_{(1,70)} = .357$, $p = .9$ respectively), Step Length ($F_{(1,70)} = .150$, $p = .7$; $F_{(1,70)} = .110$, $p = .9$ respectively). These results indicate that the type of prosthesis, whether fixed or rotating plateau, combined with the laterality of the operated knee, shows no significant differences among the variables.

Regarding Pearson's correlation, we observed that the test analysis duration is strongly related to cadence and speed in the rotating prosthesis group ($r = -0.67$, $P = .001$, and $r = -0.66$, $P = .001$, respectively). This means that the longer the test takes to complete, the lower the speed and cadence. However, in the fixed prosthesis group, only speed strongly correlated with test execution time ($r = -0.8$, $P < .001$).

Another interesting point is that there was a negative correlation between cadence and pelvic rotation only in patients with fixed prostheses. In other words, the greater the pelvic

rotation of patients with a fixed knee prosthesis, the lower the cadence. In contrast, no correlation was found between temporal parameters (analysis duration, cadence, and speed) and pelvic movements (tilt, rotation, and obliquity) in the rotating prosthesis group.

Table 1. Walk test parameters between groups

	Prosthesis	Mean	Standard Deviation (SD)
Left Support Phase	Fixed	59,6647	4,10443
	Rotatory	61,2705	3,74463
Left Double Support	Fixed	10,0182	2,72458
	Rotatory	10,537	2,54496
Left Single Support	Fixed	41,0371	6,69893
	Rotatory	39,862	3,41849
Left Swing	Fixed	40,7465	3,59969
	Rotatory	38,8	3,54356
Right Support Phase	Fixed	59,4971	2,66816
	Rotatory	60,0005	3,62996
Right Double Support	Fixed	9,07	2,38795
	Rotatory	10,654	3,16307
Right Single Support	Fixed	40,3088	3,6152
	Rotatory	39,308	4,73844
Right Swing	Fixed	40,5088	2,68201
	Rotatory	40,0285	3,54284
Stopping Phase	Fixed	32,7824	7,53195
	Rotatory	31,56	9,36878
Cadence	Fixed	96,1447	10,4493
	Rotatory	98,7745	13,27879
Speed	Fixed	0,9482	0,20559
	Rotatory	0,969	0,20131
Inclination Symmetry	Fixed	54,9647	24,51374
	Rotatory	46,6275	23,43925
Obliquity Symmetry	Fixed	92,2647	5,98832
	Rotatory	87,555	16,57492
Rotation Symmetry	Fixed	93,9824	6,67177
	Rotatory	94,465	6,96361

The results demonstrated no significant difference between the fixed and rotating plateau bases in terms of functional performance, as measured by the 2MWT. This test is a modification of the 12-Minute Walk Test, validated for patients who may face difficulties performing the original test after surgical interventions (Marjanski et al., 2021). The statistical analysis revealed no significant differences regarding the studied variables between the groups. Both data sets suggest that the bases, regardless of the plateau type, are effective in restoring knee function and improving patient mobility, with neither being significantly superior.

This statistical aspect is particularly relevant to the scientific literature, as gait analysis after knee joint arthroplasty is essential for understanding recovery progress. Gait is directly linked to maintaining an active and autonomous lifestyle (Boekesteijn et al., 2021). The practical importance of this study lies in its potential to guide surgeons and healthcare teams

in the doctor-patient relationship, justifying the procedure and the possible post-surgical outcomes for different plateau types. This allows for a tailored approach based on the patient's individual characteristics and specific needs, and it is possible to apply this test in clinical settings to create more precise medical protocols and interventions (Yuksel et al., 2017).

Evaluating functional mobility in patients has become a prominent focus in clinical research. Evidence, including results from the initial sample of the present study, indicates no significant differences in the range of motion (ROM) between the two types of prostheses. An extensive review of 70 relevant studies found no notable disparities between mobile-bearing and fixed-bearing total knee arthroplasty (TKA) across short-term, mid-term, and long-term follow-up periods for any measured outcomes (Hantouly et al., 2022).

Another original study evaluated the Walk Test variables in patients with mobile and fixed plateau implants and found no significant differences between the groups (Wang et al., 2020). The Pearson correlation analysis revealed that the test duration was strongly related to cadence and speed in the rotating prosthesis group. Additionally, there was a negative correlation between cadence and pelvic rotation only in patients with fixed prostheses. However, a significant limitation of that study for current analyses is that it is over 20 years old, during which significant advances in measuring these variables have been made.

One limitation of the present study was the absence of numerical scales to assess pain scores. Patients undergoing this type of surgical intervention may experience chronic or acute pain during daily activities or even while performing controlled tests. Such scales provide a simple representation ranging from no pain (score of 0) to maximum pain (score of 10), which could help contextualize post-surgical sensitivity (Boggs et al., 2024). Another limitation identified is that the sample of patients was incomplete, which affected statistical significance, although no systematic bias was observed. Future evaluations should adopt a multifaceted approach that integrates objective and subjective measures.

4. CONCLUSION

This preliminary study's results demonstrate no significant difference in functional performance between fixed and rotating tibial plateau prostheses, as measured by the 2-Minute Walk Test (2MWT). Both types of implants proved effective in restoring knee mobility and functionality in patients undergoing total knee arthroplasty. Furthermore, the findings highlight the importance of using objective tools, such as inertial sensors, for functional evaluation and identifying variables correlated with performance, such as cadence, speed, and pelvic parameters.

Although the type of prosthesis did not significantly influence the gait parameters analyzed, a strong negative correlation was observed between test execution time and cadence/speed in the rotating prosthesis group. In contrast, this relationship extended to pelvic rotation in the fixed prosthesis group. These results align with the current literature and emphasize the viability of both prostheses in functional recovery, with neither being superior to the other.

This study contributes to clinical practice by providing relevant information to guide implant selection, considering patients' characteristics. Moreover, it highlights the potential of the 2MWT combined with inertial sensors as a practical tool for clinical monitoring and decision-making in outpatient clinics and rehabilitation centers. Future studies with larger samples and extended follow-up periods are needed to confirm these findings and further explore the

relationships between biomechanical parameters and functional outcomes in different populations.

ETHICAL APPROVAL

The present study complies with the guidelines and regulatory standards for research involving human beings, formulated by the National Health Council of the Ministry of Health, established in October 1996, and updated in Resolution 466 in 2012 in Brazil. The study was conducted after approval by the ethics committee under protocol number 6.775.127 and CAAE certification number 52052421.9.0000.5076. This is a prospective, observational, and comparative study in which all participants agreed to participate by signing an informed consent form, acknowledging that their procedure was voluntary, free of charge, and experimental.

All participants had access to all relevant information and were permitted to withdraw from the research or revoke their consent without prejudice or harm. Additionally, the absolute confidentiality of participants' identities was ensured based on ethical principles of confidentiality and privacy. The study was carried out at a tertiary referral hospital specializing in rehabilitation, in partnership with a private university in the interior of Goiás, which possesses the technical and infrastructural capacity and sufficient institutional support to ensure the successful completion of the project. This included a fully equipped motion analysis laboratory with a portable, wireless g-walk inertial sensor (sensor, BTS bioengineering s.p.a., Italy).

DISCLAIMER (USE OF ARTIFICIAL INTELLIGENCE)

The authors confirm that GPT-4 was utilized to rewrite and edit this manuscript, with the sole purpose of improving the English grammar of the translated text, originally written in Brazilian Portuguese. The AI's function was strictly to enhance grammatical accuracy and ensure compliance with academic writing standards, without introducing any additional content. Details of the AI's involvement are as follows:

1. The original manuscript, drafted in Brazilian Portuguese, was translated into English, and AI was used to refine the grammar and ensure the final text met academic English standards.
2. Specific prompts were created to direct the AI in correcting grammatical errors and ensuring the translation adhered to academic norms.

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