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Functional Mobility Assessment after Unilateral Knee Arthroplasty: A Comparative Study of Two Prosthesis Types

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Authors' contributions

This work was carried out in collaboration among all authors. Author LPR was responsible for writing and submitting the present work to the journal and the Brazilian ethics committee. Author AMVT was responsible for guiding the structure of the article. Author UAV assisted in patient data collection, and author RBP was responsible for statistical analysis. Author CSO provided guidance from the project's conception. All the authors have read the final manuscript and agreed with all the relevant information included in the work. Authors HRSA and MRT were responsible for reviewing the work before its submission by the corresponding author. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To evaluate and compare the functional mobility of patients undergoing unilateral knee arthroplasty using two prostheses: fixed tibial plateau and rotating platform. This study addresses a gap in the existing literature by providing detailed insights into functional mobility patterns and prosthesis-specific outcomes.
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: Conducted at a tertiary hospital for rehabilitation and readaptation, in partnership with a private university from March 2022 to December 2024.
Methodology: Thirty-six patients who had previously undergone unilateral knee arthroplasty were included, equally divided between fixed and rotating platform prostheses. The Timed Up and Go (TUG) test, performed with the G-WALK inertial sensor, captured 15 functional mobility variables across two time points. Statistical analyses included variance tests and correlations to identify changes between time points and groups.
Results: The mean TUG time increased from 14.47 ± 3.03 seconds to 15.24 ± 3.85 seconds without statistical significance (*P=.301*). However, the Sit-to-Stand phase significantly reduced duration (*P=.036*). The turning phase demonstrated significant improvements in both duration (*P<.001*) and speed (*P<.001*). No statistically significant differences were observed between prosthesis types in most variables. The comparison between fixed and rotating platform prostheses is clinically important as it provides insights for tailoring postoperative rehabilitation strategies.
Conclusion: Fixed and rotating platform prostheses demonstrated comparable functional performance, with specific improvements noted over time. The findings emphasize the value of inertial sensors in conducting detailed clinical assessments and suggest opportunities for further research to enhance prosthesis selection and rehabilitation protocols. This study contributes to clinical practice by offering evidence that supports personalized rehabilitation strategies.

Keywords: Gait analysis; physical functional performance; postoperative period; rehabilitation.

1. INTRODUCTION

Knee osteoarthritis is characterized by structural modifications of the articular cartilage subchondral bone and other anatomical structures, such as Hoffa's fat pad, synovium, ligaments, and muscles. It is the most common progressive musculoskeletal condition (Primorac et al. 2020). Etiology can be divided into primary and secondary causes. Primary causes are often poorly defined, involving genetic factors, chronological age-related changes, ethnicity, and biomechanical factors. Secondary causes include post-traumatic, dysplastic, infectious, inflammatory, or poorly understood biochemical etiologies or a combination of these (Rošin et al. 2024). Knee osteoarthritis leads approximately 10% of individuals around the age of 60 to physical disability, directly impacting their functionality and quality of life (Primorac et al. 2020).

This condition causes pain, functional limitations, and a consequent decrease in quality of life, being a significant cause of functional limitation worldwide (Wojcieszek et al. 2022). Moreover, patients with knee osteoarthritis (OA) represent one of the leading causes of disability, significantly impacting mobility and daily quality of life, highlighting the importance of conducting studies on this pathology, especially considering its significant impact on daily mobility and quality of life (Walankar, Panhale & Koli 2018). Treatment involves conservative therapies, including rehabilitation, physical therapy, medication, and surgical therapies such as osteotomy, arthroscopy, and knee arthroplasty (Wang & Ma. 2022). Knee arthroplasty is considered a safe, cost-effective, and efficient surgical treatment method for knee osteoarthritis (Wang & Ma 2022). Regarding projections for the number of arthroplasty procedures performed, in the United States, more than 500,000 total knee arthroplasties (TKAs) are performed annually to relieve pain associated with OA, with future projections indicating that by 2030, over 3.48 million TKAs will be performed annually (Kurtz S. 2007).

When opting for surgical treatment with knee arthroplasty, the surgeon must determine during the preoperative evaluation the type of knee prosthesis appropriate for the patient's case, considering factors such as the need for greater or lesser prosthesis constraint, tibial plateau mobility, preservation or sacrifice of the posterior cruciate ligament, and fixation with or without cement to ensure joint congruence and more excellent resistance to stress and weight (Lan S. 2024). However, objective gait assessments are not part of routine clinical evaluations, and numerical outcome measures do not sufficiently capture gait difficulties in osteoarthritis, complicating the objective medical analysis of the patient's condition (Boekesteijn et al. 2021).

The postoperative period of knee arthroplasty also influences performance improvement, whether in terms of patient perception or outcome evaluation tests, using quality-of-life indices, gait speed, and knee range of motion, particularly from one year postoperatively (Freijo, Navarro e Villalba, 2024). Some authors indicate that knee arthroplasty restores lower limb function, with significant improvements in gait and balance after three months postoperatively, without additional improvement or balance changes beyond this period, considering only the Timed Up and Go and single-leg support tests (Tsubosaka et al. 2020).

We hypothesize that patients undergoing knee arthroplasty will show changes in functional mobility, especially in the knee joint with the prosthesis, and that these changes will become progressively evident over time. Characterizing functional mobility in this population using inertial sensors has practical implications as a basis for proposing surgical approaches tailored to prostheses that have less impact on improving functional mobility. This approach is scarcely available in the current scientific literature despite the prevalence of articles using self-reported assessment tests to establish postoperative outcomes of knee arthroplasty, which have limitations as they are based on patient perception (Youn et al. 2020). An alternative approach involves measuring outcomes based on performance, such as the 6-minute walk test (6MW) and Timed-Up-and-Go (TUG) (Iwata et al. 2024).

This study compares functional mobility in patients undergoing unilateral knee arthroplasty with fixed and rotating prostheses using the Timed Up and Go (TUG) test. Statistical analysis will also characterize the functional mobility patterns of patients undergoing posterior-stabilized knee arthroplasty with a fixed tibial plateau base and posterior-congruent knee arthroplasty with a rotating tibial plateau. Finally, it offers the possibility to compare the functional mobility patterns of patients who underwent the two types of prostheses. This is particularly important given the limited number of publications evaluating and comparing functional mobility using a follow-up approach in patients undergoing unilateral knee arthroplasty with different prosthesis types.

2. METHODOLOGY

The patients were selected from a tertiary hospital in Goiás, Brazil. The sample for this preliminary study consisted of 36 patients who had previously undergone total knee arthroplasty. The sample size was determined based on the results of a repeated measures analysis of variance by Tsubosaka et al. (2020), with a minimal difference between treatment means of 0.2, a standard deviation of 0.3, a test power of 80%, and an alpha of 0.05. The total sample size estimated for definitive results was established at 54 patients.

The patient assessment was carried out following approval from the Ethics and Research Committee. It involved a screening and evaluation protocol in which patients were assessed using the Timed Up and Go (TUG) test. Participants were informed about any potential discomfort or risks associated with the study. Initially, the research posed minimal risks to participants; however, given its multidisciplinary nature—encompassing Orthopedics and Physical Therapy—subjects might experience some discomforts, such as muscle fatigue, falls, or cramps during the evaluation.

In the event that participants experience discomfort during the research, they will be referred to the outpatient clinic, where they will receive care in accordance with the institution's procedures and regulations, as established in agreement with the institution's director. Given that the evaluation procedures in the fields of orthopedics and physical therapy are non-invasive, protective measures have been implemented to minimize risks, including allowing patients adequate time to acclimate to the laboratory environment and the professionals involved.

If patients experienced muscle fatigue or cramps at any point during the evaluations, the assessments would be paused. To reduce the risk of falls, the tests were carried out in suitable locations, supervised by experienced professionals available to provide immediate medical assistance if necessary. The evaluations were conducted by specialists in orthopedics and physical therapy. During the motor assessments, participants were accompanied by at least one volunteer along with a professional, who remained by their side throughout the evaluation process.

2.1 Eligibility Criteria

For the inclusion criteria, individuals must be classified as having advanced knee osteoarthritis with a Kellgren and Lawrence classification of ≥4, aged between 50 and 80, and having undergone their first surgery for osteoarthritis. Regarding the exclusion criteria, individuals must not present neurodegenerative diseases, secondary osteoarthritis, previous knee surgery, a history of knee fracture within the last 12 months, hip arthroplasty, a history of pre- or post-operative infection, comorbidities that impair proper recovery and post-operative rehabilitation, or a history of knee revision arthroplasty.

2.2 Patient Assessment

The evaluation process was conducted with a maximum duration of 30 minutes daily. Subjects were assessed using an inertial sensor (G-Walk) during the TUG test. Throughout the test procedure, this sensor captured and stored all 15 variables related to functional mobility parameters. The average of three TUG measurements was taken. The assessment was performed at two-time points: an initial post-surgical evaluation (on average 12 months after surgery) and a second evaluation two years after the surgical intervention. An identification form was initially completed, and anthropometric data were measured (body mass, height, and body mass index).

The Timed Up and Go (TUG) test analyzed functional mobility parameters. This test quantifies, in seconds, the time it takes for an individual to perform a task consisting of standing up from a standardized chair without armrests, walking three meters, turning around, walking back toward the chair, and sitting down again (Maiora et al. 2024). Subjects were instructed to perform the test at a self-selected, safe pace to avoid the risk of falling. The test was performed twice, with the first serving as familiarization. Data was collected using a portable G-sensor positioned at the L5 vertebra level. This is a wireless inertial sensor system designed for human motion analysis.

The sensors are controlled by a data recording unit (up to 16 elements) via ZigBee radio communication. Each sensor has dimensions of 62mm × 36mm × 16mm, a weight of 60g, and is composed of a three-axis accelerometer (maximum scale of ±6g), a three-axis gyroscope (full scale of ±300°/s), and a three-axis magnetometer (full scale of ±6 Gauss). This device is calibrated with gravitational acceleration immediately after manufacturing. For this study, only one device was used, collecting 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

Descriptive statistics were provided using the mean, standard deviation, median, and interquartile range. A two-factor analysis of variance (ANOVA) was performed to compare differences between prosthesis types (dependent variable) and the TUG test (independent variable). In cases of sphericity violation, values were adjusted using a base-10 logarithm, and if violations persisted, the Kruskal-Wallis test was applied. A t-test or Mann-Whitney test, in the case of non-parametric data, was used to compare independent variables between prosthesis types. The relationship between functional mobility, postoperative time, and prosthesis type was analyzed using Pearson's correlation test or Spearman's correlation test or its non-parametric counterpart. Analyses were conducted using the SPSS statistical software version 19 (IBM), considering a p-value ($P<.05$) as the threshold for statistical significance.

3. RESULTS AND DISCUSSION

Data collection was conducted with research participants, and the sample was characterized according to the data presented in Table 1. The analysis of the results revealed that the average time for the Timed Up and Go (TUG) test increased from 14.47 ± 3.03 seconds to 15.24 ± 3.85 seconds. However, this change was not statistically significant according to Wilk's Lambda test for the collection time factor ($P=.301$) and the type of prosthesis used ($P=.456$). This suggests that although there was an increase in the time required to perform the TUG, the observed differences over time or between prosthesis types (fixed and rotating) were not sufficiently large to be considered statistically significant.

In the Sit-to-Stand phase, which assesses the movement of standing up from a seated position, a decrease in the duration of this movement was observed, from 1.83 ± 0.40 seconds to 1.66 ± 0.42 seconds. This reduction was statistically significant over time (*P=.036*), indicating an improvement in the efficiency of this movement over time. However, no significance was found regarding the type of prosthesis used (*P=.134*) or between the groups with fixed and rotating prostheses (*P=.665*). Additionally, the anterior-posterior acceleration in this phase decreased from 4.08 ± 1.79 m/s² to 3.69 ± 2.24 m/s², with no significant difference for the collection time (*P=.348*), the type of prosthesis (*P=.278*), or between the groups (*P=.263*).

The mediolateral velocity in the Sit-to-Stand phase also decreased from 2.03 ± 0.82 m/s² to 1.82 ± 0.88 m/s². Although this reduction was noteworthy, no significant difference was observed for time (*P=.287*), the type of implant (*P=.095*), or between the groups (*P=.984*). The vertical velocity in this phase decreased from 4.55 ± 1.91 m/s² to 3.95 ± 1.96 m/s², with no statistical significance for time (*P=.090*), the type of prosthesis (*P=.604*) or between the groups (*P=.286*).

In the Stand-to-Sit phase, which assesses the movement of sitting down, the duration increased from 2.09 ± 0.39 seconds to 2.15 ± 0.93 seconds, again without significant differences for time (*P=.682*), the type of prosthesis (*P=.086*), or between the groups (*P=.513*). The anterior-posterior acceleration in this phase decreased from 3.51 ± 1.30 m/s² to 3.25 ± 0.94 m/s², with no significance for time (*P=.368*), the type of implant (*P=.700*), or between the groups (*P=.648*). The mediolateral velocity decreased from 3.65 ± 1.36 m/s² to 3.03 ± 1.31 m/s², with a significant difference for time (*P=.026*) but no significance for the type of implant (*P=.292*) or between the groups (*P=.820*). Additionally, vertical acceleration increased from 4.60 ± 2.03 m/s² to 5.42 ± 2.43 m/s², with a trend toward significance for time (*P=.065*) but no significant difference for the type of implant (*P=.371*) or between the groups (*P=.762*).

The rotation phase, which assesses the turning movement, showed a decrease in average duration from 3.45 ± 0.90 seconds to 2.57 ± 0.77 seconds, with a significant difference for time (*P<.001*) and for the type of implant (*P=.017*). However, no significant difference was observed between the types of implants (*P=.409*). The rotation speed increased from 54.62 ± 12.12°/s to 68.74 ± 17.71°/s, with clear statistical significance for time (*P<.001*) but no significant difference for the type of implant (*P=.327*) or between the groups (*P=.743*).

In the final rotation phase, the duration decreased from 2.48 ± 0.79 seconds to 2.23 ± 0.49 seconds, with a trend toward significance for time (*P=0.056*) and the type of implant (*P=.053*), but no significant difference between the groups (*P=.155*). Finally, the average rotation speed in the final phase increased from 68.03 ± 15.38°/s to 75.13 ± 13.81°/s, with a significant difference for time (*P=.008*) and a trend toward significance for the type of implant (*P=.057*). However, no significant difference was observed between the groups (*P=.316*).

Table 1. Characterization of the sample of patients participating in the study

Participants	**Total**	**36**
Sex	Female	21
	Male	15
Average Age	69,38 years	
Average Weight	77,8 kg	
Average Height	1,60m	
Average BMI	30,46	
Laterality	Right	24
	Left	12
Implant	Fixed Plateau	18
	Rotating Plateu	18
Average Postoperative Period (1°st Evaluation)	17,31 meses	
Average Postoperative Period (2°st Evaluation)	42,80 meses	

The results demonstrate that, while some significant changes were observed over time in specific phases and variables, differences between fixed and rotating prostheses were generally not statistically significant, indicating similar functional performance. Notably, the significant improvement in the Sit-to-Stand phase suggests enhanced ability in daily activities like transitioning from sitting to standing, directly benefiting independence and quality of life. Similarly, improved rotation speed reflects better dynamic stability, potentially reducing fall risks. The comparable outcomes between prosthesis types emphasize optimizing rehabilitation strategies over prioritizing specific prostheses. These findings support the development of targeted interventions to address functional deficits, such as mediolateral velocity or vertical acceleration, for improved mobility and patient outcomes.

The results demonstrate the complexity of functional adaptations following total knee arthroplasty (TKA). While the improvement in the efficiency of movements such as Sit-to-Stand was significant over time, other parameters, such as the total time for the Timed Up and Go (TUG) test, did not show statistically significant differences. This lack of significance, coupled with reported functional difficulties in daily activities such as climbing stairs or getting in and out of vehicles (Berghmans et al. 2018), suggests that postoperative gains may not fully meet these patients' daily demands.

The data reinforce the importance of precise and comprehensive measurements to evaluate the impact of TKA. The analysis of spatiotemporal and kinematic parameters, such as the duration of specific phases and accelerations in different directions, is essential for a detailed understanding of gait in patients undergoing this surgical intervention. Previous studies show that inertial sensors provide measurements comparable to optoelectronic and electro-electronic systems, widely regarded as the gold standard (Kobsar et al., 2020). This opens new possibilities for large-scale clinical assessments at lower costs, especially in settings that lack sophisticated equipment (Boekesteijn et al. 2022).

However, gait analysis in laboratory settings may be influenced by factors such as the Hawthorne effect, which describes changes in behavior due to direct observation by researchers (Akgülle et al.,2022). This interference can be particularly relevant for gait studies, where direct observation may lead to unnatural movement patterns. Thus, the difference between daily and laboratory gait is a limitation that must be considered when interpreting results. Future studies could benefit from data collection in more natural environments, such as using inertial sensors under real-life conditions, to assess functional performance more representatively.

The findings also align with systematic reviews that have identified slower gait speed, shorter step length, and shorter stride duration in individuals with knee or hip osteoarthritis (OA) compared to healthy controls (Ritsuno et al. (2023). These gait alterations are consistent with the functional limitations observed in post-TKA patients, even when some parameters show improvements over time, such as in the Sit-to-Stand or rotation phases. However, the absolute values of these changes in many cases remain below the minimum detectable thresholds reported in the literature, such as those established by TUG, 6MW, and SCT (King et al. 2022). This reinforces that while some changes are statistically significant, their clinical relevance may be questionable.

Another important point is the similarity between the performances of fixed and rotating prostheses. The results show that, despite statistically significant differences in some variables, such as the duration of the rotation phase, the prostheses tend to exhibit comparable functional performances. This equivalence between different prostheses reflects technological advances in the field, indicating that both can be effective in functional rehabilitation, depending on other factors such as surgical preferences or patient adaptations (Boekesteijn et al. 2022).

Finally, a recognized limitation of this study was the lack of complete data for all participants, which may reduce the statistical power of the analyses. However, as mentioned, the analysis of the subset with complete data did not reveal systematic bias. Moreover, functional recovery should not be evaluated solely based on objective parameters. Perceptions of pain, function, motivation, and psychological state are essential factors that influence recovery and vary significantly between individuals. A comprehensive understanding of functional recovery after TKA requires a multifaceted approach that combines objective measures with subjective assessments to capture the nuances of each patient's experience (Boekesteijn et al. 2022).

The small sample size of this study, comprising 36 participants equally divided between the two prosthesis types, presents limitations in the reliability and generalizability of the findings. A smaller sample reduces statistical power, increasing the likelihood of Type II errors, where meaningful differences may not be statistically significant. Furthermore, it limits the ability to detect nuanced differences between subgroups, particularly when analyzing variables with higher variability. This constraint may also hinder the extrapolation of results to a broader population, as the observed outcomes may not fully represent the diversity of patient responses to unilateral knee arthroplasty. Despite this limitation, using advanced measurement tools, such as inertial sensors, ensures that the data collected is precise and detailed, providing valuable insights. Future studies with larger sample sizes would enhance the robustness of these findings and allow for more definitive conclusions regarding functional performance and the comparative efficacy of fixed and rotating prostheses.

4. CONCLUSION

The results of this study highlight the complexity of functional adaptations following total knee arthroplasty (TKA). While a significant improvement in movement efficiency during the Sit-to-Stand phase was observed over time, other parameters, such as the total time for the Timed Up and Go (TUG) test, did not show statistically significant differences. Additionally, fixed and rotating prostheses demonstrated comparable functional performances, with no significant differences in most analyzed variables.

The analysis also indicated significant changes during the rotation phase, with a reduction in duration and increased rotation speed, suggesting specific improvements over time. However, other variables, such as accelerations and velocities in different directions during the Sit-to-Stand and Stand-to-Sit phases, showed trends toward significance or did not exhibit statistically relevant changes.

The study's limitations include incomplete data for all participants, potentially reducing statistical power, though no systematic bias was identified. A multifaceted evaluation integrating objective and subjective measures, such as pain perception, motivation, and psychological state, is recommended. Future research could increase the sample size to detect minor differences, include more diverse populations for broader applicability, and integrate patient-reported outcomes for a holistic view of recovery. More extended follow-up periods provide insights into long-term adaptations, while real-world activity monitoring with wearable sensors could enhance ecological validity and address laboratory limitations. These modifications would strengthen the study's robustness and clinical relevance.

The study ultimately underscores the promise of inertial sensor-based technologies for conducting extensive clinical measurements in real-world settings, providing benefits in terms of cost and accessibility. These findings enhance our understanding of the limitations and possibilities for functional recovery following total knee arthroplasty (TKA), highlighting the need for personalized and holistic approaches to rehabilitation. Future research should incorporate both subjective and objective assessments to gain a more comprehensive insight into functional recovery after knee arthroplasty.

ETHICAL APPROVAL AND CONSENT

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 Platform Brazil, Anápolis, Goiás, 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 their participation by signing an informed consent form, acknowledging that the procedure they underwent 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 at any time without any 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 tertiary hospital in partnership with a private university possesses the technical and infrastructural capacity, as well as sufficient institutional support, to ensure the successful completion of the project. This included a fully equipped motion analysis laboratory with the portable and wireless g-walk inertial sensor (gsensor, bts bioengineering s.p.a., italy).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors acknowledge the use of GPT-4 for rewriting and editing this manuscript, specifically for refining the English grammar of the translated text, which was originally written in Brazilian Portuguese. The AI's role was strictly limited to improving the grammatical accuracy and ensuring alignment with academic language standards, without adding any new information to the text. The details of AI usage are as follows:

1. The original manuscript, written in Brazilian Portuguese, was translated into English, and AI was employed to enhance the grammatical quality of the final version, adhering to academic English conventions.
2. Carefully designed prompts were used to guide the AI in making grammatical corrections and verifying the translation’s consistency with academic norms.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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