ISSN: 2690-9189

Research Article

International Journal of Orthopaedics Research

Analysis of Postural Adaptation in Elderly Individuals with Unilateral Knee Osteoarthritis: Implications for Postural Control and Gait Initiation

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Submitted: 2025, Jan 03; **Accepted:** 2025, Feb 13; **Published:** 2025, Feb 19

Citation: Silva, L. G., Marques, L. F. P., Fukao, L. M., Júnior, J. A. V., Nora, F. G. D. S. A., (2025). Analysis of Postural Adaptation in Elderly Individuals with Unilateral Knee Osteoarthritis: Implications for Postural Control and Gait Initiation. *Int J Ortho Res, 8*(1), 01-06.

Abstract

Objective: *To investigate the impact of unilateral knee osteoarthritis on static and dynamic postural control during gait initiation in elderly individuals, comparing them to active, healthy older adults.*

Methodology: *Forty elderly individuals were divided into two groups: G1, composed of 20 individuals with unilateral knee osteoarthritis awaiting total knee arthroplasty (TKA), and G2, composed of 20 active elderly individuals without osteoarthritis. Biomechanical assessments were conducted using a plantar pressure platform to measure variables related to the Center of Pressure (COP) during bipedal postural control with eyes open and closed, and gait initiation. The variables analyzed included COP displacement amplitude in the anteroposterior (COPAP) and mediolateral (COPML) directions, and mean COP displacement velocity in the anteroposterior (VELAP) and mediolateral (VELML) directions.*

Results: *Individuals with knee osteoarthritis (G1) exhibited greater COP displacement amplitude in the anteroposterior direction (COPAP) during bipedal postural control with both eyes open and closed compared to the control group (G2). During gait initiation, G1 displayed greater COPAP and COPML values in the anticipatory phase compared to G2. No significant differences were observed between groups in the execution phases of the first and second steps.*

Conclusion: *Unilateral knee osteoarthritis negatively affects postural control, especially static and dynamic balance, in elderly individuals. The results suggest the need for targeted intervention programs to improve postural control and dynamic stability in older adults with knee osteoarthritis, aiming to reduce fall risk and enhance mobility.*

Keywords: Knee Osteoarthritis, Postural Control, Gait Initiation, Balance, Elderly

1. Introduction

Maintaining postural stability while standing upright is a fundamental challenge, requiring continuous and subtle adjustments to counteract the constant force of gravity. This complex process, though not yet fully understood, depends on the seamless integration of sensory and motor systems [1]. These systems work in concert to ensure balance control and spatial orientation, both of which are critical in orthopedics and fall prevention.

In orthopedic research and clinical practice, postural stability is particularly relevant due to its direct association with musculoskeletal function and injury risk. Impairments in postural control can significantly impact mobility, increasing susceptibility to falls, especially among older adults and individuals with joint pathologies such as osteoarthritis. Understanding the biomechanical mechanisms that regulate stability is essential for developing effective rehabilitation and preventive interventions.

Walking, a dynamic and coordinated action, begins with an anticipatory postural adjustment (APA) phase. During this phase, the body prepares itself for movement by activating neuromuscular mechanisms that stabilize posture before initiating displacement. This is followed by the execution phase, where the actual movement occurs (Hommen et al., 2024). In orthopedic studies, analyzing these phases helps identify gait alterations that may increase fall risk in individuals with musculoskeletal conditions.

The center of gravity (CG) has been extensively used as an indicator of postural stability and fall risk, particularly in populations with orthopedic impairments. Alterations in CG displacement patterns can reflect deficits in neuromuscular control, balance maintenance, and overall functional mobility. Consequently, assessing these variables is crucial for evaluating fall risk and designing targeted interventions in orthopedic rehabilitation.

Falls, commonly defined as an unexpected change in body position, are a major health concern, especially among older adults with musculoskeletal disorders (Chen et al., 2024). They can lead to severe complications, including fractures, hospitalizations, and long-term functional limitations. Furthermore, falls often contribute to a decline in quality of life, increasing the likelihood of physical inactivity and social isolation. Addressing postural stability through biomechanical assessments is essential for mitigating these risks.

Quantifying biomechanical variables such as the center of pressure (COP) and the center of mass (COM) plays a fundamental role in understanding postural stability. These parameters provide insight into how individuals maintain equilibrium and respond to external perturbations. In orthopedic populations, deviations in COP and COM trajectories can indicate compensatory strategies or deficits in postural control, emphasizing the need for tailored rehabilitation programs.

This study aims to explore the dynamics of postural stability during gait initiation in elderly individuals with unilateral knee osteoarthritis, comparing them to active older adults. By investigating these mechanisms, the study seeks to contribute to the existing body of knowledge and support the development of effective strategies for fall prevention in orthopedic patients.

2. Methodology

This study followed an experimental design and involved the analysis of bipedal postural control and gait initiation in elderly individuals with and without knee osteoarthritis. Detailed biomechanical assessments were conducted using a plantar pressure platform to measure variables related to the Center of Pressure (COP). The methodology was structured to ensure scientific rigor and reproducibility of the results.

2.1. Participants

The study included forty elderly individuals of both sexes, divided into two distinct groups. Group 1 (G1) consisted of 20 elderly individuals with a unilateral knee osteoarthritis diagnosis who did not respond to conservative treatments and were referred for primary Total Knee Arthroplasty (TKA), with an average age of 72.10 years. Group 2 (G2) included 20 active elderly individuals, with an average age of 66.85 years, without a diagnosis of knee osteoarthritis. The anthropometric characteristics of the participants are detailed in Table 1.

Variable	Group G1	Group G2
Age (years)	72.10 (± 1.75)	66.85 (± 0.60)
Body Mass (kg)	78.35 (± 3.20)	68.90 (± 4.12)
Height (cm)	162.45 (± 2.25)	159.60 (± 2.10)
Legend: G1: elderly individuals diagnosed with unilateral knee osteoarthritis; G2: active elderly individuals without injury. Data are expressed as mean (± standard deviation).		

Table 1: Anthropometric Data of Study Participants

2.2. Inclusion and Exclusion Criteria

The following inclusion criteria were adopted for sample selection: elderly individuals of both sexes with knee osteoarthritis referred for total knee arthroplasty. Exclusion criteria included the presence of neurological disorders that could compromise the motor performance of the lower limbs, a history of lower limb prostheses, and the presence of deformities or calluses on plantar surfaces.

2.3. Ethical Aspects

The study was approved by the Research Ethics Committee and registered under opinion number 24845019.2.0000.5083. All participants signed the Informed Consent Form (ICF), ensuring their right to voluntarily participate and withdraw from the study at any time. Additionally, the study strictly followed the guidelines of Resolution No. 466/2012 of the National Health Council, which establishes standards for research involving human beings. The research was also conducted in compliance with the General Data Protection Law (LGPD - Law No. 13.709/2018), ensuring the confidentiality and privacy of participants' collected information.

2.4. Bipedal Postural Control and Gait Initiation

The bipedal postural control study involved three trials conducted with eyes open. Participants stood on a plantar pressure platform, with feet hip-width apart, focusing their gaze on a red light point at eye level. After an auditory signal, they remained static for 60 seconds.

In the gait initiation phase, three trials were also performed. Participants stood on the plantar pressure platform, with feet comfortably positioned, one on each side of the platform. After an auditory signal, they took a step off the pressure platform using the limb affected by osteoarthritis, alternating sides in each trial.
Plantar pressure was recorded using the Baroscan, Podotech platform (50x50cm), equipped with 4,096 capacitive sensors and a sampling rate of 50 Hz, allowing precise capture of plantar pressure distribution.

2.5. Analyzed Variables

Variables related to the Center of Pressure (COP) behavior were analyzed:
1. COP Displacement Amplitude in the anteroposterior (COPAP) and mediolateral (COPML) directions, expressed in centimeters, representing the difference between the extreme positions of the COP.
2. COP Mean Displacement Velocity in the anteroposterior (VELAP) and mediolateral (VELML) directions, expressed in centimeters per second, reflecting the COP displacement rate.

The evaluation followed the procedures proposed by Nora et al. (2020). The COP trajectory during gait initiation was segmented into:

- **Phase 1 - Anticipatory:** from the beginning of movement to the lateral position of the COP towards the swing foot.
- **Phase 2 - Execution of the First Step:** from the end of the anticipatory phase to the lateral position of the COP towards the support foot.
- **Phase 3 - Execution of the Second Step:** from the end of the first step execution to the end of the movement, as the COP moved forward.

2.6. Statistical Analysis

Statistical analysis was performed using Minitab 21 (Minitab) software. Initially, data normality and homogeneity were verified using the Kolmogorov-Smirnov test. Subsequently, the non-parametric Tukey test was applied to verify intragroup differences in the analyzed variables. The significance level adopted was $p \leq 0.05$. Results are presented as mean (± standard deviation).

3. Results

This study analyzed the variables of static and dynamic balance, focusing on the investigation of postural control in elderly individuals diagnosed with unilateral knee osteoarthritis compared to active and healthy elderly individuals. The results clearly revealed the impact of knee osteoarthritis on postural control, demonstrating a greater reliance on proprioception for maintaining static balance compared to healthy elderly individuals. Table 2 details the results regarding the medio-lateral displacement amplitude (COPML), as well as the displacement velocity of the COP in the anteroposterior (VELAP) and medio-lateral (VELML) directions during bipedal postural control under two distinct conditions: with open eyes (OE) and closed eyes (CE). These data provide a deeper understanding of how knee osteoarthritis affects static balance, with important implications for interventions and programs aimed at improving the quality of life of these elderly individuals.

BIPEDAL POSTURAL CONTROL - OPEN EYES			
Variable	**Group G1**	**Group G2**	**p-value**
COPAP (cm)	5.78 (±2.65)	1.42 (±0.20)	0.03*
COPML (cm)	4.02 (±2.30)	1.30 (±0.60)	0.40
VELAP (cm/s)	3.01 (±0.80)	1.70 (±0.38)	0.55
VELML (cm/s)	2.40 (±0.45)	1.85 (±0.40)	0.42
BIPEDAL POSTURAL CONTROL - CLOSED EYES			
Variable	**Group G1**	**Group G2**	**p-value**
COPAP (cm)	9.21 (±3.50)	1.85 (±0.25)	0.01*
COPML (cm)	8.70 (±3.60)	1.50 (±0.30)	0.01*
VELAP (cm/s)	3.50 (±0.50)	2.20 (±0.20)	0.40
VELML (cm/s)	3.65 (±0.42)	2.00 (±0.50)	0.38
Legend: G1 = elderly individuals diagnosed with unilateral knee osteoarthritis; G2 = active elderly individuals without a knee osteoarthritis diagnosis. *Tukey test significant ($p < 0.05$). Data are presented as mean values ± standard error.			

Table 2: Center of Pressure Behavior during Bipedal Postural Control with Open and Closed Eyes

The results of the bipedal postural control with open eyes revealed that Group G1, composed of elderly individuals diagnosed with unilateral knee osteoarthritis, exhibited significantly higher values (p=0.03) in the displacement amplitude of the Center of Pressure (COP) in the anteroposterior direction (COPAP) compared to Group G2, composed of active elderly individuals without a knee osteoarthritis diagnosis. Regarding the displacement amplitude of the COP in the medio-lateral direction (COPML) and displacement velocities of the COP in the anteroposterior (VELAP) and medio-lateral (VELML) directions, Group G1 also showed higher values compared to Group G2, although these differences did not reach statistical significance, as shown in Table 2.

During bipedal postural control with closed eyes, Group G1, composed of elderly individuals diagnosed with unilateral knee osteoarthritis, exhibited significantly higher values in both the displacement amplitude of the Center of Pressure (COP) in the anteroposterior direction (COPAP_CE - p = 0.01) and in the medio-lateral direction (COPML_CE - p = 0.01) compared to Group G2, composed of active elderly individuals without a knee osteoarthritis diagnosis. However, for the remaining variables under this condition, no statistically significant differences were observed between the two groups.

Table 3 presents information on the results related to the displacement amplitude of the Center of Pressure (COP) in the anteroposterior (COPAP) and medio-lateral (COPML) directions, as well as the displacement velocity of the COP in the anteroposterior (VELAP) and medio-lateral (VELML) directions during gait initiation.

ANTICIPATORY PHASE			
Variable	**Group G1**	**Group G2**	**p-value**
COPAP (cm)	11.25 (±2.40)	8.10 (±4.50)	0.03*
COPML (cm)	17.00 (±2.50)	10.00 (±5.90)	0.03*
VELAP (cm/s)	8.50 (±2.00)	5.80 (±2.00)	0.04*
VELML (cm/s)	11.00 (±3.60)	7.40 (±2.70)	0.03*
EXECUTION OF 1ST STEP			
Variable	**Group G1**	**Group G2**	**p-value**
COPAP (cm)	6.80 (±2.50)	8.60 (±2.40)	0.06
COPML (cm)	8.40 (±1.80)	9.60 (±4.80)	0.08
VELAP (cm/s)	7.50 (±2.90)	8.40 (±3.70)	0.07
VELML (cm/s)	6.90 (±2.60)	5.90 (±2.10)	0.06
EXECUTION OF 2ND STEP			
Variable	**Group G1**	**Group G2**	**p-value**
COPAP (cm)	6.50 (±1.50)	6.60 (±2.30)	0.07
COPML (cm)	7.80 (±1.70)	8.90 (±3.00)	0.06
VELAP (cm/s)	8.90 (±2.90)	9.50 (±6.40)	0.06
VELML (cm/s)	7.90 (±2.30)	8.60 (±3.90)	0.07
Legend: G1 = elderly individuals diagnosed with unilateral knee osteoarthritis; G2 = active elderly individuals without a knee osteoarthritis diagnosis. *Tukey test significant ($p < 0.05$). Data are presented as mean values ± standard error.			

Table 3: COP Behavior during Gait Initiation Phases

During the anticipatory phase, Group G1, composed of elderly individuals diagnosed with unilateral knee osteoarthritis, exhibited higher displacement values of the Center of Pressure (COP) in the anteroposterior (COPAP - p = 0.03) and medio-lateral (COPML - p = 0.03) directions compared to Group G2, composed of active elderly individuals without a knee osteoarthritis diagnosis. This difference was also reflected in the displacement velocities of the COP in the anteroposterior (VELAP - p = 0.04) and medio-lateral (VELML - p = 0.03) directions. However, during the execution phases of the first and second steps, both groups exhibited similar behavior, with no statistically significant differences observed. These findings suggest that the most significant differences in dynamic balance occur during the anticipatory phase but tend to level out during step execution.

4. Discussion

The present study highlights the impact of unilateral knee osteoarthritis on postural control, particularly in both static and dynamic balance. Our findings indicate that individuals with osteoarthritis rely more on proprioceptive input to maintain balance, which aligns with previous studies demonstrating altered sensory dependence in populations with musculoskeletal impairments [1-3]. These postural control adaptations suggest modifications in sensory-motor integration, a crucial component for balance regulation and gait initiation [4,5]. Understanding these changes is essential in orthopedics, particularly for developing rehabilitation strategies aimed at preventing falls in individuals with osteoarthritis [6,7].

Our analysis of bipedal postural control with open and closed eyes revealed significant differences in COP behavior between elderly individuals with knee osteoarthritis (G1) and active elderly individuals without osteoarthritis (G2). The COPAP displacement in G1 was significantly greater than in G2 under both visual conditions, with particularly pronounced instability when visual feedback was removed. These findings suggest a greater reliance on vision to maintain postural stability in osteoarthritic individuals, a phenomenon that has been previously documented in aging populations with proprioceptive deficits [8,9].

The increased medio-lateral COP displacement (COPML) observed in G1 under closed-eye conditions further highlights the challenges faced by individuals with knee osteoarthritis in maintaining lateral stability. Medio-lateral instability has been strongly associated with increased fall risk in elderly populations [10]. This finding supports previous studies emphasizing the role of proprioceptive dysfunction in postural control impairments among individuals with musculoskeletal disorders (Gibson, 1987).

Additionally, velocity parameters (VELAP and VELML) were generally higher in G1, particularly under closed-eye conditions. This suggests that osteoarthritic individuals exhibit increased postural sway, which is consistent with prior studies demonstrating that individuals with knee osteoarthritis tend to display greater instability due to neuromuscular deficits [11]. These results highlight the need for rehabilitation programs focusing on proprioceptive training to enhance stability and reduce fall risk.

The anticipatory phase of gait initiation revealed significantly higher COPAP and COPML displacements in G1 compared to G2. This suggests that individuals with osteoarthritis exhibit larger preparatory shifts in COP to compensate for joint instability and muscular weaknesses [12, 13]. These exaggerated anticipatory postural adjustments may reflect a compensatory mechanism aimed at increasing base support and maintaining stability, albeit at the cost of biomechanical efficiency [14, 15].

Furthermore, gait initiation velocity measures (VELAP and VELML) were also significantly elevated in G1 during the anticipatory phase. This increased movement velocity suggests a more abrupt transition between static posture and dynamic motion, potentially leading to impaired control of the body's center of mass. Studies indicate that rapid postural transitions in older adults with osteoarthritis can lead to inefficient weight shifting, further increasing fall risk [4].

During the execution of the first and second steps, the differences between G1 and G2 became less pronounced, although individuals with osteoarthritis exhibited trends toward reduced COP displacement and step length. These findings align with prior research showing that osteoarthritic individuals adopt more cautious gait strategies, likely as a protective measure against instability (Conaghan, Vanharanta & Dieppe, 2005; Guermazi et al., 2012).

Interestingly, while COP displacement was slightly lower in G1 compared to G2 during the execution phase, velocity parameters remained elevated. This suggests that osteoarthritic individuals may compensate for reduced stability by increasing movement velocity, potentially as an attempt to quickly re-establish balance (Findlay & Kuliwaba, 2016). This behavior, however, can be problematic, as rapid step transitions have been linked to increased fall risk due to inadequate postural control [16].

Given the significant postural control impairments observed in individuals with knee osteoarthritis, rehabilitation efforts should prioritize interventions aimed at improving proprioception and neuromuscular coordination. Studies have demonstrated the efficacy of targeted balance training programs in reducing postural instability and fall risk [17].

Furthermore, proprioceptive training, including exercises designed to enhance somatosensory feedback, may be particularly beneficial for individuals with osteoarthritis-related instability. The integration of multisensory training programs that combine visual, vestibular, and proprioceptive inputs has been shown to enhance postural control and gait stability (Collins, 1949; Jamshidi, Pelletier & Martel-Pelletier, 2018) [17].

Given the progressive nature of osteoarthritis, early intervention strategies are essential to preventing further declines in postural control and functional mobility. Emerging technologies, such as virtual reality-based balance training and wearable biofeedback systems, offer promising approaches for improving dynamic stability in osteoarthritic populations (Caliva et al., 2022; Luyten, Dell'Accio & De Bari, 2012).

Additionally, regenerative medicine approaches, including the use of mesenchymal stem cells for cartilage repair, may play a role in preserving joint function and reducing biomechanical compensations associated with osteoarthritis (McGonagle, Baboolal & Jones, 2017) [3,18]. These advancements, combined with traditional orthopedic rehabilitation, could provide a comprehensive framework for managing postural instability and mitigating fall risk in individuals with knee osteoarthritis.

5. Conclusion

The present study reinforces the critical role of postural control impairments in elderly individuals with unilateral knee osteoarthritis, particularly in both static and dynamic balance. The results emphasize the necessity for tailored intervention programs that address proprioceptive deficits and compensatory strategies affecting gait initiation. These findings highlight the importance of implementing targeted rehabilitation strategies to enhance stability, reduce fall risks, and improve functional mobility in osteoarthritic populations.

By integrating findings from previous studies, this research contributes to a broader understanding of postural adaptations in older adults and their implications for clinical rehabilitation [8,12,15]. Future studies should further investigate the neurobiomechanical aspects of gait control, particularly how altered sensory feedback and motor planning influence dynamic stability. Understanding these mechanisms will be instrumental in developing more effective and evidence-based rehabilitation protocols.

Additionally, this study underscores the urgency of early intervention strategies in mitigating functional decline associated with osteoarthritis. Multimodal approaches combining strength training, proprioceptive exercises, and assistive technologies should be prioritized in rehabilitation programs. The integration of innovative solutions, such as virtual reality-based balance training and wearable biofeedback systems, holds promise in optimizing postural stability and promoting mobility in older adults with musculoskeletal impairments.

As the global aging population continues to expand, addressing mobility limitations and fall risks in osteoarthritic individuals becomes increasingly important. Future research should explore individualized and technology-assisted strategies to enhance movement efficiency, preserve functional independence, and improve quality of life. A comprehensive approach that combines biomechanical, neuromuscular, and rehabilitative perspectives will be key to advancing clinical management and optimizing outcomes for aging individuals with knee osteoarthritis [19-23].

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