Observational Study

Medicine

OPEN

Gait changes after intramedullary nailing versus total hip arthroplasty for hip fractures in older adults

Lorenzo Fagotti, MD, MSc[a,b,*], Ruth Losada de Menezes, PT, PhD[a,c], Darlan Martins Ribeiro, PT, MSc[a], Maykon Lacerda de Santana, BEng[d], Daniel Augusto Maranho, MD, PhD[e], Silvana Schwerz Funghetto, RN, PhD[a]

Abstract

This study aimed to investigate potential differences in spatiotemporal gait parameters and clinical outcomes between older adults undergoing intramedullary nailing (IN) and those undergoing total hip arthroplasty (THA) for unilateral hip fractures. A secondary objective was to identify predictors of postoperative falls in older adults following surgical treatment for hip fractures. We conducted a prospective study involving 42 community-dwelling older adults, assessed 6 months post-surgery. Of these participants, 21 (14 females, 7 males; mean age 76.0 ± 8.6 years) underwent IN, while the remaining 21 (10 females, 11 males; mean age 75.3 ± 7.7 years) received THA. Primary outcomes included gait speed and step width for both treatment groups, while secondary outcomes included the incidence of postoperative falls and additional clinical and spatiotemporal gait parameters. The mean gait speed was 73.5 ± 26.8 cm/s for the IN group and 79.7 ± 27.5 cm/s for the THA group ($P = .46$). Step width was significantly lower in the IN group (15.7 ± 2.7 cm) compared to the THA group (17.9 ± 3.3 cm; $P < .05$, effect size = 0.7). Postoperative falls were reported by 13 patients (31%) overall, with no significant differences between the 2 treatment groups. Multivariate logistic regression analysis identified an increased step width (≥18 cm, OR = 5.24; 95% CI: 0.98–27.97; $\chi^2 = 1.66$, $P = .05$) as a potential independent risk factor for postoperative falls, while a higher modified Harris Hip score (≥80 points) was an independent protective factor (OR = 0.18; 95% CI: 0.03–0.97; $\chi^2 = -1.69$; $P = .04$). The area under the curve was 0.889 (95% CI: 0.809–0.989; $P < .001$). The optimal cutoff point for the highest sensitivity (100%) and specificity (65.5%) was 0.217. Model accuracy for predicting postoperative falls was 76.2%. In conclusion, both IN and THA resulted in favorable clinical outcomes and comparable gait speeds following hip fracture surgery in older adults, though step width was greater in the THA group. Despite the high overall incidence of postoperative falls, no significant differences in fall occurrence were observed between the 2 treatment groups.

Abbreviations: BMI = body mass index, GDS = geriatric depression scale, IN = intramedullary nailing, mHHS = modified Harris Hip score, MMSE = minimental state examination, THA = total hip arthroplasty.

Keywords: elderly, gait analysis, hip arthroplasty, hip fractures, intramedullary nailing, rehabilitation, spatiotemporal parameters

1. Introduction

Hip fractures in elderly people is a major public health issue because of its associated morbidity and mortality.[1,2] Falls are a major risk factor for hip fractures and the reduction in gait speed is highly associated with falls at the elderly.[3,4] Following the surgical management of a hip fracture, a large proportion of older adults will not fully recover the gait capacity, and almost 20% will not be able to walk independently.[5] Further, patients with older age who reach a minimal capability to walk after surgical treatment of a hip fracture, will be at increased risk of a subsequent fall.[6,7]

Several gait parameters change with aging, including a decrease in gait speed and an increase in step width.[8] A decreased gait speed is considered as a strong predictor of falls.[3,9] On the contrary, a wider step width improves the supporting base and balance control.[10] Factors that predict gait abnormalities following a hip fracture in this population include

The authors have no funding and conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

[a] *Post-Graduation Program of Sciences and Health Technology (Programa de Pós-Graduação em Ciências e Tecnologias em Saúde), Faculdade de Ceilândia, Universidade de Brasília (UnB), Brasília, DF, Brazil,* [b] *Instituto Vero Passo Saúde Integrada e Análise do Movimento, Brasília, DF, Brazil,* [c] *Universidade Federal de Goiás (UFG), Goiânia, GO, Brazil,* [d] *Centro de Reabilitação e Readaptação Dr. Henrique Santillo (CRER), Goiânia, GO, Brazil,* [e] *Verticali Ortopedia, Centro Médico do Ribeirão Shopping, Ribeirão Preto, SP, Brazil.*

[*] *Correspondence: Lorenzo Fagotti, Post-Graduation Program of Sciences and Health Technology (Programa de Pós-Graduação em Ciências e Tecnologias em Saúde), Faculdade de Ceilândia, Universidade de Brasília (UnB), Brasília, DF, Brazil (e-mail: lorenzo@veropasso.com.br).*

How to cite this article: Fagotti L, de Menezes RL, Ribeiro DM, de Santana ML, Maranho DA, Funghetto SS. Gait changes after intramedullary nailing versus total hip arthroplasty for hip fractures in older adults. Medicine 2025;104:16(e41792).

Received: 10 September 2024 / Received in final form: 18 February 2025 / Accepted: 19 February 2025

http://dx.doi.org/10.1097/MD.0000000000041792

cognitive decline, reduced grip strength, extracapsular fractures, and male sex.[11] Frailty significantly impacts mobility and physical status in older adults, often necessitating prolonged rehabilitation following surgical treatment for hip fractures.[12] In addition, older adults exhibiting signs of frailty have a higher likelihood of experiencing recurrent falls.[13]

Currently, the surgical decision making for the treatment of hip fractures in elderly patients involves more commonly the intramedullary nailing (IN) and total hip arthroplasty (THA). Gait asymmetry has been described following fracture fixation with IN.[14] However, it remains unclear whether the proportion and magnitude of gait abnormalities are greater in the IN or THA. There is a lack of evidence comparing the 2 most common procedures for the surgical treatment of hip fractures. Therefore, we aimed to evaluate the association of IN and THA with potential differences in spatiotemporal gait parameters and clinical outcomes in older patients who sustained a hip fracture. A secondary objective was to identify predictors of postoperative falls.

2. Methods

This prospective cohort study involved community-dwelling older adults aged 60 years and above who underwent surgery for hip fractures at our institution between January 2022 and December 2023. The minimum follow-up period from the date of surgery to gait analysis was 6 months. The study received approval from the Institutional Review Board Leide das Neves in Goiânia, Brazil, and all participants provided informed consent.

We included 42 patients who had sustained a unilateral hip fracture, with a mean age of 75 ± 7 years (range: 61–92 years). The cohort comprised 24 women (57%) and 18 men (43%). The mean ± SD body mass index (BMI) was 23 ± 8 kg/m² (range: 16–30 kg/m²). Of the 42 patients, 21 underwent IN (14 women and 7 men; mean ± SD age, 76 ± 9 years; mean ± SD BMI, 23 ± 3 kg/m²). The remaining 21 patients (50%) underwent THA (10 women and 11 men; mean ± SD age, 75 ± 7 years; mean ± SD BMI, 24 ± 3 kg/m²) (Table 1). Participants were recruited through convenience sampling from those who underwent unilateral hip surgery for hip fractures at our institution. Postoperatively, all participants were advised to bear weight as tolerated and were referred to external physical therapy programs.

Data for the study were collected at 6 months postoperatively. The demographic and clinical characteristics assessed included age, sex, BMI, cardiovascular status (such as high blood pressure or cardiopathy), diabetes melitus, smoking history, readmission rates, and the interval between fracture and surgical treatment. A fall was defined as any unexpected event that caused the individual to descend to a lower level.[15] Additionally, postoperative falls were monitored during the 6-month follow-up period.

Other variables included the modified Harris Hip score (mHHS),[16] grip strength measured with a manual dynamometer, the geriatric depression scale (GDS),[17] and the minimental state examination (MMSE)[18] (Table 2).

Plain pelvis radiographs obtained at hospital admission were used to categorize patients into different treatment groups. Intertrochanteric (extracapsular) fractures were treated with unilateral IN using a locked antegrade nail (Síntese Comercial Hospitalar, Goiânia, Brazil) (Fig. 1A). In contrast, femoral neck (intracapsular) fractures were managed with unilateral noncemented THA (Prisma Medical Materiais Cirúrgicos, Goiânia, Brazil) (Fig. 1B). Within this cohort, 14 patients underwent surgery via a posterior approach, and 7 were treated using a direct lateral approach. All procedures were conducted by a board-certified orthopedic surgeon under the supervision of the senior hip surgeon on duty at our institution on the day of the surgery. At the 6-month follow-up appointment, all participants underwent gait analysis. A three-dimensional motion analysis system with the Vicon® System, 10 Vicon® MX-T40 cameras with a sampling rate of 120 Hz was used. The Conventional Gait Model was used for biomechanical modeling of the lower limb and pelvis segments, in the Vicon implementation (Gait PlugIn). A fourth-order Butterworth filter with a cutoff frequency of 6 Hz was used to process the marker trajectories. All data were normalized by the gait cycle using 51 sampling points from each stride.[19] Participants wore shorts, a sleeveless shirt and walked barefoot, looking straight ahead at a marker fixed on the wall, and completed 5 walks across an 8-m walkway wall with comfortable speed. Spatiotemporal gait parameters were: average cadence (steps/minute), gait speed (cm/s), stride length (m), step length (m), step width (cm), walk ratio (step length/cadence), and step time (s). Because of potential influence on gait analysis, we did not include patients with: (1) BMI above 30 kg/m², (2) lumbar spine surgery or leg pain when walking (radiculopathy), (3) poor vision or hearing, (4) Parkinson disease, (5) high-energy trauma, (6) history of other fracture of the lower limbs surgically treated, and (7) cardiac pacemaker and metallic implant.

The primary outcomes were gait speed and step width. Step width was defined as the lateral distance from the center of 1 heel print to the line of progression formed by 2 consecutive prints of the opposite foot.[8]

Secondary outcomes included the mHHS, with scores classified as follows: 70 to 79 is considered fair, 80 to 89 is considered good, and 90 or above is considered excellent.[16] Additionally, cardiovascular status, grip strength, MMSE, GDS, occurrence of postoperative falls, and other spatiotemporal gait parameters.

Finally, multivariate logistic regression analysis was conducted to determine whether patient characteristics and treatment groups were associated with the occurrence of postoperative falls.

Table 1

Demographic and clinical characteristics of patients undergoing intramedullary nailing versus total hip arthroplasty.

Variables	IN n = 21	THA n = 21	*P*-value
Females (n)	14 (67%)	10 (48%)	.21
Males (n)	7 (33%)	11 (52%)	–
Age (yr)	76 ± 8	75 ± 8	.80
Weight (kg)	60 ± 12	64 ± 13	.30
Height (m)	1.59 ± 0	1.60 ± 0	.69
BMI (kg/m²)	23 ± 3	24 ± 4	.29
Cardiovascular	16 (76%)	14 (67%)	.49
Diabetes	6 (29%)	4 (19%)	.46
Smoking	1 (4%)	6 (29%)	.03
Readmission	2 (10%)	2 (10%)	1.0
Time fracture surgery (d)	7 ± 4.4	7 ± 5.7	.79

BMI = body mass index, IN = intramedullary nailing, THA = total hip arthroplasty.

Table 2

Clinical outcomes and fall incidence in intramedullary nailing versus total hip arthroplasty groups.

Variables	IN n = 21	THA n = 21	*P*-value
Postoperative faller	6 (28.6%)	7 (33.3%)	.73
mHHS (points)	81 ± 10	85 ± 9	.22
Grip strength (kg)	24 ± 8	27 ± 9	.27
GDS (points)	4 ± 3	4 ± 3	.83
MMSE (points)	21 ± 4	19 ± 5	.06

GDS = geriatric depression scale, IN = intramedullary nailing, mHHS = modified Harris Hip score, MMSE = minimental state examination, THA = total hip arthroplasty.

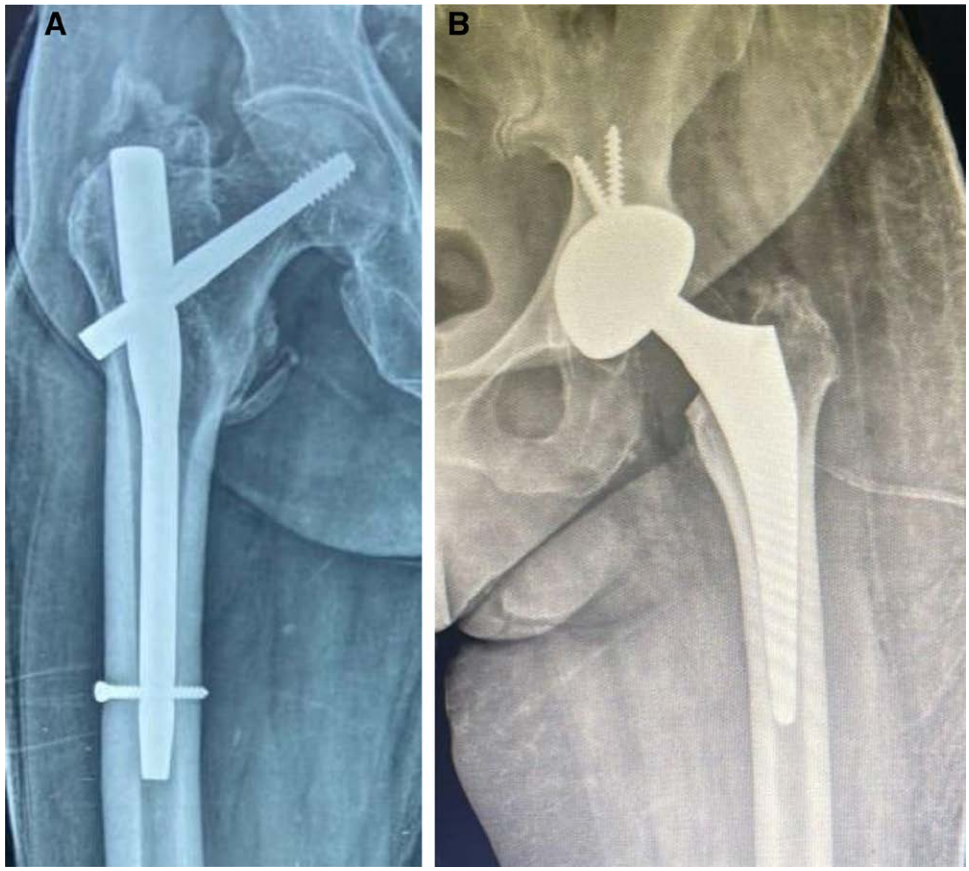

Figure 1. (A) Intramedullary nailing for an extracapsular right hip fracture. (B) Total hip arthroplasty for an intracapsular left hip fracture.

2.1. Statistical analysis

The sample size was calculated using G*Power Version 3.1.9.6. The effect size was derived from mean cadence differences observed in a pilot study involving a small cohort of older adults who underwent IN for extracapsular hip fractures, compared with a larger cohort of older adults who also received IN.[14] A minimum of 19 patients per group was necessary to achieve a significance level of 5% and a power of 80%. Accounting for a 10% loss to follow-up, a total of 21 subjects were assigned to each group (IN and THA).

Descriptive analysis was conducted using frequency and proportion, mean ± SD, median and range (minimum–maximum). The normality of numeric outcomes was assessed using the Shapiro–Wilk test. For age, BMI and spatiotemporal gait parameters including gait speed, step length, walk ratio, step width and stride length, an independent Student *t* test was used to compare IN and THA groups. The Mann–Whitney *U* test was used for time between fracture and surgery, mHHS, cadence, and step time. Differences in categorical data, including sex, clinical history, and fall status, were analyzed using the chi-square test. Stepwise multivariate logistic regression was performed to screen out statistically significant factors associated with postoperative falls. The following variables were included: age, sex, cardiovascular status, grip strength, MMSE, treatment group, GDS, gait speed and step width. *P*-values less than .05 were considered significant. Statistical analyses were performed using SPSS® Version 26.0 (SPSS Inc., Chicago, IL).

3. Results

We observed no differences in the mean gait speed between the IN group and THA (74 ± 27 cm/s for IN cohort in comparison to 80 ± 28 cm/s for THA cohort, $P = .47$ (Table 3). The step width was lower in the IN group compared to the THA group (16 ± 3 cm in comparison with 18 ± 3 cm; $P = .02$, effect size = 0.7).

Postoperative clinical outcomes, as assessed by the mHHS, were generally good, with a mean ± SD score of 81 ± 10 for the IN group compared to 85 ± 9 ($P = .23$) for the THA group. Grip strength for the IN group was 24 ± 8 kg compared to 27 ± 9 kg ($P = .27$) for the THA group, while for MMSE, IN group showed a value of 21 ± 4 compared to 19 ± 5 ($P = .06$) for the THA group. Four patients were readmitted for clinical complications. One case of upper gastrointestinal bleeding and 1 case of mild head injury occurred in the IN group, while 1 case of upper gastrointestinal bleeding and 1 case of urinary retention occurred in the THA group. No additional orthopedic procedures were required, and all patients were discharged from the hospital without further issues.

Regarding postoperative fall status, 13 (31%) of the 42 patients reported experiencing a fall within 6 months after surgery. No significant differences were found in clinical outcomes, treatment groups, or spatiotemporal parameters between postoperative fallers and non-fallers. Stepwise multivariate logistic regression identified increased step width as a potential independent risk factor (≥18 cm, OR = 5.24; 95% CI: 0.98–27.97; $\chi^2 = 1.66$; $P = .05$), while a higher mHHS was an independent protective factor (≥80 points, OR = 0.18; 95% CI: 0.03–0.97; $\chi^2 = -1.69$; $P = .04$) for falls following surgical treatment of hip fractures in older adults (Table 4). The Hosmer–Lemeshow test was found not significant ($P = .54$). The Nagelkerke R Square value was 32.6%. The area under the curve for calculating the probability of a postoperative fall was 0.889 (95% CI: 0.809–0.989; $P < .001$) (Fig. 2). The optimal cutoff point for the highest sensitivity (100%) and

Table 3

Spatiotemporal gait parameters of participants.

Variables	IN n = 21	THA n = 21	*P*-value
Cadence (steps/min)	98.1 ± 18.7	100.6 ± 11.8	.82
Gait speed (cm/s)	73.5 ± 26.8	79.7 ± 27.5	.46
Step length (m)	0.4 ± 0.1	0.4 ± 0.1	.45
Stride length (m)	0.8 ± 0.2	0.9 ± 0.2	.45
Step width (cm)	15.7 ± 2.7	17.9 ± 3.3	.02
Walk ratio	0.45 ± 0.1	0.46 ± 0.0	.88
Step time (s)	0.9 ± 0.4	0.8 ± 0.1	.91

IN = intramedullary nailing, THA = total hip arthroplasty.

specificity (65.5%) was 0.217, with model accuracy for detecting postoperative falls at 76.2%.

4. Discussion

Hip fracture among elderly populations represents a significant public health challenge, with post-incident mortality rates reaching 30% within the first year postfracture.[2] Postoperative management requires early mobilization protocols combined with comprehensive rehabilitation strategies to optimize functional recovery outcomes. The most common surgical treatments for hip fractures in elderly individuals are the IN and THA.[20] This study compares the spatiotemporal gait parameters of older adults who underwent either IN or THA for the treatment of hip fractures. We observed that both surgical procedures may provide comparable outcomes, except for the step width parameter in gait analysis.

Step width is a critical parameter of motor control that correlates with mediolateral stability during walking.[8,10] Indeed, the step width tends to increase progressively with aging.[10,21] It is well known that an increase in step width reduces the hip abductor moment, leading to more stability with less exigency of the gluteus medius.[22] Values that are considered normal for older men and women are 9 ± 5 and 8 ± 4 cm, respectively.[8] Conversely, we observed values that could be considered high for step width, and patients treated with THA showed even greater width values (16 ± 3 cm in IN vs 18 ± 3 cm in THA; $P = .02$). Patients who underwent osteosynthesis with IN depend on callus formation at the fracture site to become more stable and safer for full and reliable weight bearing.[23] We may acknowledge that our follow up period is not sufficient for complete functional recovering after the fracture consolidation, naturally leading to larger step width to aid in the gait stability. Nevertheless, patients undergoing THA may evolve to even greater step width. We may hypothesize that the joint preservation in the IN cohort could at least preserve part of the proprioception and balance control, while the joint replacement could affect the abductor muscles during the surgical approach, although more patients in the THA group had the abductor muscles preserved with a posterior approach. Moreover, there is the potential effect on biomechanical status of the THA, in which the femoral offset could be more altered. Nevertheless, all these hypotheses are controversial and subject to debate,[13,24–26] warranting further research to clarify the importance of the step width for the gait stability in older patients who sustained proximal femur fractures.

Gait speed is a spatiotemporal gait parameter frequently employed to assess fall risk in the elderly. For young adults, the average gait speeds are 139 ± 0.47 cm/s for men and 135 ± 0.43 cm/s for women. In contrast, older adults aged 75 to 79 years exhibit average gait speeds of 122 ± 15 cm/s for males and 112 ± 17 cm/s for females.[8,27] A significant reduction in gait speed can indicate a decline in balance, physical function, and strength, thereby increasing the risk of falls.[3,4]

Table 4

Summary of results from stepwise multivariate analysis of postoperative falls.

	Beta	Wald test	Odds ratio			*P*-value
			OR	Inferior	Superior	
MMSE (≥18)	2.28	3.58	9.75	0.92	103.3	.059
mHHS (≥80)	-1.69	3.97	0.18	0.03	0.97	.046
Step width (≥18)	1.66	3.75	5.24	0.98	27.97	.053

These findings are also observed in older adults following surgical treatment for hip fractures.[9,11] Although our study did not reveal significant differences in mean gait speed between treatment groups, the overall mean gait speed for our sample was 71 ± 0.3 cm/s, indicating a substantial decrease compared to normative values. In a study involving an older population with a mean age of 82 ± 6 years, Thingstad et al reported a mean gait speed of 62 ± 0.2 cm/s, measured 4 months after hip fracture surgery.[11] The differences between this study and our cohort may be attributed to variations in age ranges, as older ages are associated with more severe levels of frailty and sarcopenia. In healthy older adults, a comparison of age groups shows a 10% decrease in mean gait speed when comparing those aged 75 to 79 years with those aged 80 to 84 years.[8]

Although no significant differences in gait parameters were observed between postoperative fallers and non-fallers, our study found that over 30% (13 out of 42) of patients reported experiencing a fall within 6 months after surgery. This high incidence underscores a significant risk of subsequent falls and increased morbidity within this population. Regarding obesity, which has been linked to gait abnormalities such as reduced gait speed and increased step width, all 42 patients in the study exhibited normal BMI values. This reduces the likelihood of gait adjustments related to increased body weight and ground reaction forces.[4,28] All spatiotemporal gait parameters, except step width, did not differ between treatment groups. This suggests that both treatment options are comparable and viable for the surgical management of hip fractures in this population. Increased step width is commonly associated with recurrent fallers.[29,30] This association can be viewed as a double-edged sword: while an increased step width may serve as a protective mechanism, enhancing stability and balance in response to diminished postural control, an excessive increase in step width might disrupt the natural gait pattern and potentially elevate the risk of falls due to altered biomechanics and gait dynamics.

The present study has several limitations. First, we were unable to enroll a control group of older individuals, matched by sex, age, and BMI, who underwent gait analysis to provide fair comparison with the normality for age. Second, we also could not match our cohorts by sex and BMI, as inclusion was sequential and based on the occurrence of a fall. Third, we acknowledge the presence of selection bias, as patients were allocated into both groups with different fracture types. Potentially, more severe and displaced fractures were treated with THA, consequently leading to an imbalance in our allocation. Fourth, many patients in this study experienced a prolonged interval between hip fracture and surgical intervention, which may have led to decreased mobility. Patients underwent surgical procedures at a tertiary-care public hospital and were subsequently referred to rehabilitation services in their respective municipalities of residence. Consequently, a standardized postoperative protocol was not available for all patients, leading to a suboptimal rehabilitation program, which could contribute to an overall increased step width as a compensatory mechanism to enhance lateral stability. Fifth, the follow-up period was relatively short, limiting the scope of our findings to the short-term. Future studies

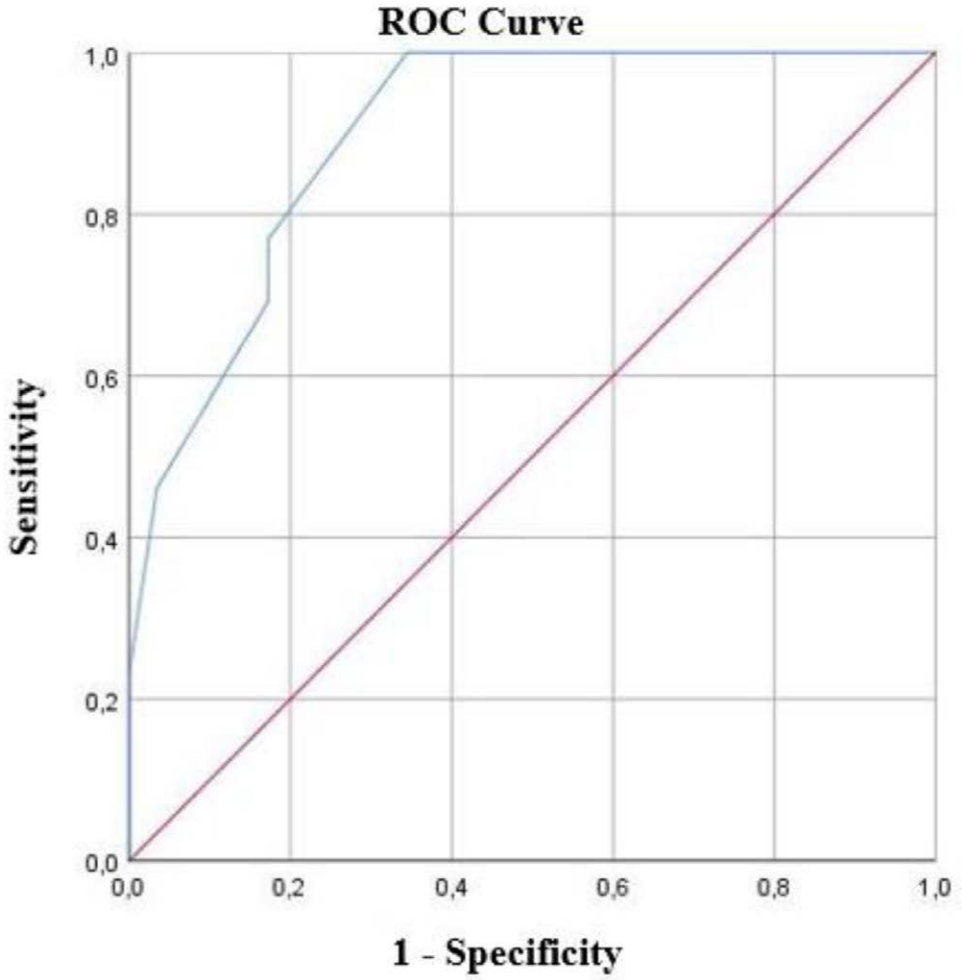

Figure 2. ROC curve for postoperative fall risk prediction model.

with longer follow-up and larger sample sizes would be valuable to support surgical decision-making among surgeons, patients, and their families, as well as to further investigate increased step width as an independent risk factor for falls in older adults. Despite our short follow up, we believe that the first 6 months following a hip fracture are crucial in determining whether a patient becomes a routine faller. Finally, our findings may not be generalizable to patients treated with other surgical interventions, such as cannulated screw fixation or dynamic hip screw, which are also commonly used for treating certain types of hip fractures.

5. Conclusion

Following hip fracture surgery in elderly patients, both IN and THA resulted in favorable clinical outcomes, as indicated by the mHHS. Gait analysis showed comparable gait speeds between the 2 treatment groups, although the overall step width for the entire sample is higher than the normative values for older adults. Patients undergoing IN exhibited a decreased step width compared to those undergoing THA. However, there were no significant differences in the occurrence of postoperative falls between the treatment groups.

Acknowledgments

We wish to express our sincere gratitude tophysical therapists Luis Fernando Martins de Souza Filho and Andréia Pascoal Trevenzol Barros for their invaluable assistance with patient care. We also extend our thanks to Engr. Marcelo Klafke for his technical support. Additionally, we are grateful to João Alírio Teixeira da Silva Junior MD and Luciano Lucindo da Silva MD for their expert support in patient management. Finally, we acknowledge the *Programa de Pós-Graduação em Ciências e Tecnologias em Saúde* at the *Faculdade de Ceilândia, Universidade de Brasília (UnB)* for their support throughout this project.

Author contributions

Conceptualization: Lorenzo Fagotti, Ruth Losada de Menezes, Silvana Schwerz Funghetto.
Data curation: Darlan Martins Ribeiro.
Formal analysis: Maykon Lacerda de Santana.
Investigation: Lorenzo Fagotti.
Methodology: Ruth Losada de Menezes, Darlan Martins Ribeiro, Silvana Schwerz Funghetto.
Supervision: Ruth Losada de Menezes, Daniel Augusto Maranho.
Software: Maykon Lacerda de Santana.
Validation: Maykon Lacerda de Santana, Silvana Schwerz Funghetto.
Visualization: Daniel Augusto Maranho.
Writing – original draft: Lorenzo Fagotti.
Writing – review & editing: Lorenzo Fagotti, Darlan Martins Ribeiro, Daniel Augusto Maranho, Silvana Schwerz Funghetto.

References

[1] Nikkel LE, Fox EJ, Black KP, Davis C, Andersen L, Hollenbeak CS. Impact of comorbidities on hospitalization costs following hip fracture. J Bone Joint Surg Am. 2012;94:9–17.

[2] Lin JC-F, Liang W-M. Mortality, readmission, and reoperation after hip fracture in nonagenarians. BMC Musculoskelet Disord. 2017;18:144.

[3] Adam CE, Fitzpatrick AL, Leary CS, et al. Change in gait speed and fall risk among community-dwelling older adults with and without mild cognitive impairment: a retrospective cohort analysis. BMC Geriatr. 2023;23:328.

[4] Silva J, Atalaia T, Abrantes J, Aleixo P. Gait biomechanical parameters related to falls in the elderly: a systematic review. Biomechanics. 2024;4:165–218.

[5] Iosifidis M, Iliopoulos E, Panagiotou A, Apostolidis K, Traios S, Giantsis G. Walking ability before and after a hip fracture in the elderly predicts greater long-term survivorship. J Orthop Sci. 2016;21:48–52.

[6] Crandall CJ, Larson JC, LaCroix AZ, et al. Risk of subsequent fractures in postmenopausal women after nontraumatic vs traumatic fractures. JAMA Intern Med. 2021;181:1055–63.

[7] Bradley D, Lloyd DA, Williamson NA, et al. Recurrent and injurious falls in the year following hip fracture: a prospective study of incidence and risk factors from the Sarcopenia and Hip Fracture Study. J Gerontol A Biol Sci Med Sci. 2009;64:599–609.

[8] Hollman JH, McDade EM, Petersen RC. Normative spatiotemporal gait parameters in older adults. Gait Posture. 2011;34:111–8.

[9] Middleton A, Fritz SL, Lusardi M. Walking speed: the functional vital sign. J Aging Phys Act. 2015;23:314–22.

[10] Wang Y, Mei Q, Jiang H, et al. The biomechanical influence of step width on typical locomotor activities: a systematic review. Sports Med Open. 2024;10:83.

[11] Thingstad P, Egerton T, Ihlen EF, Taraldsen K, Moe-Nilssen R, Helbostad JL. Identification of gait domains and key gait variables following hip fracture. BMC Geriatr. 2015;15:150.

[12] Mangione KK, Craik RL, Kenny A, et al. The effect of frailty on walking recovery after hip fracture: a secondary analysis of the Community Ambulation Project. J Gerontol A Biol Sci Med Sci. 2021;76:e335–9.

[13] Jehu DA, Davis JC, Falck RS, et al. Risk factors for recurrent falls in older adults: a systematic review with meta-analysis. Maturitas. 2021;144:23–8.

[14] Gausden EB, Sin D, Levack AE, et al. Gait analysis after intertrochanteric hip fracture: does shortening result in gait impairment? J Orthop Trauma. 2018;32:554–8.

[15] Beghi E, Gervasoni E, Pupillo E, et al. Prediction of falls in subjects suffering from Parkinson disease, multiple sclerosis, and stroke. Arch Phys Med Rehabil. 2018;99:641–51.

[16] Vishwanathan K, Akbari K, Patel AJ. Is the modified Harris hip score a valid and responsive instrument for outcome assessment in the Indian population with pertrochanteric fractures? J Orthop. 2018;15:40–6.

[17] Almeida OP, Almeida SA. Short versions of the geriatric depression scale: a study of their validity for the diagnosis of a major depressive episode according to ICD-10 and DSM-IV. Int J Geriatr Psychiatry. 1999;14:858–65.

[18] Lenardt MH, Michel T, Wachholz PA, Borghi AS, Seima MD. O desempenho de idosas institucionalizadas no mini exame do estado mental. Acta Paul Enferm. 2009;22:638–44.

[19] Santos Bueno GA, Ribeiro DM, Gervásio FM, Correia AM, de Menezes RL. Gait profile score identifies changes in gait kinematics in non-faller, faller, and recurrent faller older adult women. Gait Posture. 2019;72:76–81.

[20] Fischer H, Maleitzke T, Eder C, Ahmad S, Stöckle U, Braun KF. Management of proximal femur fractures in the elderly: current concepts and treatment options. Eur J Med Res. 2021;26:86.

[21] Owings TM, Grabiner MD. Variability of step kinematics in young and older adults. Gait Posture. 2004;20:26–9.

[22] Stief F, Holder J, Feja Z, Lotfolahpour A, Meurer A, Wilke J. Impact of subject-specific step width modification on the knee and hip adduction moments during gait. Gait Posture. 2021;89:161–8.

[23] Ju JB, Zhang PX, Jiang BG. Hip replacement as an alternative to intramedullary nail in elderly patients with unstable intertrochanteric fracture: a systematic review and meta-analysis. Orthop Surg. 2019;11:745–54.

[24] Sivakumar A, Rickman M, Thewlis D. Gait biomechanics after proximal femoral nailing of intertrochanteric fractures. J Orthop Res. 2023;41:862–74.

[25] Reindl R, Harvey EJ, Berry GK, Rahme E. Intramedullary versus extramedullary fixation for unstable intertrochanteric fractures: a prospective randomized controlled trial. J Bone Joint Surg Am. 2015;97:1905–12.

[26] Fang C, Gudushauri P, Wong TM, Lau TW, Pun T, Leung F. Increased fracture collapse after intertrochanteric fractures treated by the dynamic hip screw adversely affects walking ability but not survival. Biomed Res Int. 2016;2016:4175092.

[27] Zhai M, Huang Y, Zhou S, et al. Effects of age-related changes in trunk and lower limb range of motion on gait. BMC Musculoskelet Disord. 2023;24:234.

[28] Spyropoulos P, Pisciotta JC, Pavlou KN, Cairns MA, Simon SR. Biomechanical gait analysis in obese men. Arch Phys Med Rehabil. 1991;72:1065–70.

[29] Scott D, McLaughlin P, Nicholson GC, et al. Changes in gait performance over several years are associated with recurrent falls status in community-dwelling older women at high risk of fracture. Age Ageing. 2015;44:287–93.

[30] Nordin E, Moe-Nilssen R, Ramnemark A, Lundin-Olsson L. Changes in step width during dual-task walking predict falls. Gait Posture. 2010;32:92–7.