

Original article

Association between sarcopenia and functional outcomes after bipolar hemiarthroplasty in elderly patients with displaced femoral neck fracture: Structural equation modeling

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Abstract

Background: Sarcopenia is an underrecognized condition that may impair recovery in older adults after hip fracture surgery.

Objectives: This study aimed to assess the effect of sarcopenia on the functional outcomes and hip muscle strength in elderly individuals with femoral neck fractures while accounting for other potential confounding factors using a structural equation model (SEM).

Methods: This prospective cohort study was conducted at a tertiary university hospital between January 2023 and October 2024, enrolling patients aged 60 years and older undergoing bipolar hemiarthroplasty for displaced femoral neck fractures. Functional recovery was evaluated at the 3-month follow-up using the Barthel Index (BI), Short Physical Performance Battery (SPPB), Harris Hip Score (HHS), and hip muscle strength. Sarcopenia was diagnosed per the 2019 Asian Working Group criteria, alongside assessments for osteoporosis and nutrition. SEM analyzed the effect of sarcopenia on recovery while adjusting for key factors.

Results: Sixty patients (mean age: 81.0 ± 8.4 years; 76.7% female) were included, of whom 15 (25.0%) were identified as sarcopenic. Sarcopenia and malnutrition had substantial negative effects on the BI, HHS, and SPPB scores. Longer hospital stays were independently associated with lower HHS. SEM revealed indirect pathways that linked age, body mass index, and baseline functional status to outcomes via sarcopenia and malnutrition. Sarcopenia was notably associated with reduced hip muscle strength, as measured by a latent variable.

Conclusion: Sarcopenia and malnutrition are major contributors to impaired short-term functional recovery after bipolar hemiarthroplasty in elderly patients with femoral neck fractures. Both factors affect the physical performance, hip-specific function, and independence in daily activities, independently and synergistically. The SEM highlighted the interrelationships between nutritional status, sarcopenia, and baseline function, emphasizing the importance of early detection and targeted interventions during postoperative care.

Keywords: Elderly patients, femoral neck fracture, functional outcomes, hip muscle strength, sarcopenia, structural equation modeling.

Hip fractures in older adults are a major public health concern worldwide that often result in long-term disability and increased mortality. Only 40.0% of elderly patients regain independent ambulation, and

more than half require ongoing care 1 year post-fracture.⁽¹⁾ Outcomes are strongly influenced by comorbidities such as osteoporosis, malnutrition, and sarcopenia.⁽²⁾

Sarcopenia is the progressive loss of muscle mass and function, and it is increasingly recognized as an important factor affecting recovery after hip fractures. Its prevalence in elderly Asian populations ranges from 11.0% to 76.0%,⁽²⁾ thus reflecting variation in diagnostic methods. In Thailand, the prevalence of sarcopenia among the general elderly population has

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been estimated at approximately 30.0%,⁽³⁾ and most individuals are community-dwelling and attend outpatient clinics.⁽⁴⁾ In contrast, a lower prevalence of 9.2% has been reported among elderly Thai patients with hip fractures.⁽⁵⁾ This discrepancy may partly be explained by methodological differences, particularly the use of bioelectrical impedance analysis, which can overestimate muscle mass, especially in patients with metal implants or fluid imbalance.⁽⁶⁾

Sarcopenia has been linked to impaired recovery following hip fractures,⁽⁷⁾ although findings on its effect remain inconsistent across studies. Some studies have reported that sarcopenia influences postoperative outcomes following hip replacement in individuals with femoral neck fractures,^(8,9) while others have reported no significant associations.^(10,11) These inconsistencies may reflect differences in populations, measurement tools, and study design.

This study aimed to assess the effect of sarcopenia on the functional outcomes and hip muscle strength in elderly individuals with femoral neck fractures while accounting for other potential confounding factors using the structural equation model (SEM).

Materials and methods

Study design

This prospective cohort study was reviewed and approved by the Institutional Review Board of the Faculty of Medicine, Chulalongkorn University (no. 0633/65; COA no. 0004/2023) and conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. Written informed consent was obtained from all participants. Preinjury activities of daily living data were collected through interviews with patients and caregivers upon hospital admission. The participants underwent screening for sarcopenia, which included assessments of muscle strength and body composition via dual-energy X-ray absorptiometry (DXA), alongside evaluations for osteoporosis and malnutrition. Clinical assessments were completed within 2 weeks of admission. The following functional outcomes were evaluated at the 3-month follow-up after bipolar hemiarthroplasty: the Barthel Index (BI), short physical performance battery (SPPB), Harris Hip Score (HHS), and hip muscle strength measurements.

Study population

The study population consisted of elderly patients with acute displaced femoral neck fractures who were scheduled for bipolar hemiarthroplasty. The inclusion criteria required that patients be over 60 years of age, able to communicate, and able to provide written informed consent. Patients were excluded if they had multiple traumatic injuries; pathological fractures due to cancer; previous proximal femur surgery or infection; language barriers; mental disorders, such as delirium, or neurological diseases that affected their coordination; or musculoskeletal disorders, such as rheumatoid arthritis.

Calculation of sample size

Based on a previous study, we assumed that after 3 months of follow-up, the BI would be 15 points lower in the sarcopenia group, with a standard deviation of 13.2 points.⁽⁹⁾ Given that sarcopenia affects approximately 50.0% of elderly patients with hip fractures, we assumed an equal distribution of patients between the groups.^(8,9) Based on these assumptions, a sample size of 26 patients per group (52 patients in total) was used to achieve 80% statistical power to detect a significant difference with a two-sided significance level of 5%. To account for an anticipated dropout rate of 15.0%, the sample size was increased to 60 participants.

Determination of sarcopenia

Participants were classified as either sarcopenic or nonsarcopenic based on the 2019 criteria established by the Asian Working Group for Sarcopenia (AWGS).⁽⁷⁾ Sarcopenia was diagnosed when there was a concurrent reduction in muscle mass and grip strength. Grip strength was measured using a handheld dynamometer with participants seated comfortably, their dominant arm positioned close to their body, and the elbow bent to 90°. Each participant performed the test twice, and the highest recorded value was used for analysis.⁽⁴⁾ The grip strength thresholds were <28.0 kg for men and <18.0 kg for women.⁽¹²⁾ Appendicular skeletal muscle mass (ASM) was assessed using DXA of the non-fractured limb. To adjust for variations in body size, skeletal muscle mass index (SMI) was calculated as ASM divided by height squared (kg/m²). A low SMI was defined as <7.0 kg/m² for men and <5.4 kg/m² for women.⁽¹³⁾ Grip strength assessments and DXA measurements were performed on the same day to maintain consistency in data collection.

Variables

Demographic characteristics included age, sex, body mass index (BMI), side of injury, type of prosthesis (cemented or cementless), length of hospital stay (LOS), defined as the period from hospital admission to discharge, and baseline activity of daily living (ADL). The ADL was assessed using the BI (0–100, with higher scores indicating greater independence) at baseline and 3 months postoperatively.⁽¹⁴⁾ SPPB (0–12, with higher scores indicating better function) was used to assess lower-limb performance at 3 months.⁽¹⁵⁾ A handheld dynamometer (microFET®2) was used to measure hip flexion and abduction strength, which are particularly affected by the posterior approach in bipolar hemiarthroplasty.⁽¹⁶⁾ This assessment was particularly relevant due to the posterior surgical approach in bipolar arthroplasty, where the short external rotators and piriformis muscle are cut and subsequently sutured. As the piriformis muscle assists in hip abduction, its function is essential for walking stability, as it helps prevent falls by shifting body weight during movement. Abductor muscle strength is a key predictor of functional outcomes in patients with hip fractures.⁽¹⁷⁾ The HHS assesses hip function and pain using a combined questionnaire and clinical evaluation. Scores range from 0 to 100 and are classified as poor (<70), fair (70–80), good (80–90), or excellent (90–100). HHS has been validated as a reliable tool for pre- and post-operative assessment.⁽¹⁸⁾

Study procedures

Participants were recruited by orthopedic surgeons or research team members working in the emergency and orthopedic departments involved in the project. The principal investigator, an orthopedic surgeon, or a research assistant screened participants attending the clinics for eligibility. A member of the research team provided potential participants with detailed information about the study, including its objectives, procedures, treatment methods, potential benefits and risks, and then obtained verbal consent to be contacted.

Once the on-call orthopedic surgeon diagnosed a femoral neck fracture and the patient was deemed eligible, the research assistant or principal investigator invited the patient to participate, and written informed consent was obtained. The participants were given sufficient time to consider their decision. For patients unable to provide consent, written or verbal consent was obtained from their next of kin, with retrospective

consent sought from the patient whenever possible. If the next-of-kin was unavailable, the Regional Committee on Ethics in Medical Research was consulted to approve the inclusion of such patients, as this observational study did not cause harm to the participant. Written consent was retrospectively obtained from these patients. All included patients underwent bipolar hemiarthroplasty using the posterior surgical approach.

Baseline data, including age, sex, height, weight, BMI, injured side (right or left), type of prosthesis (cemented or cementless), LOS, and comorbidities (Charlson Comorbidity Index; CCI), were collected after hospitalization. Osteoporosis was diagnosed based on bone mineral density assessed by DXA of the unfractured hip, with a focus on the femoral head and neck. A T-score < -2.5 was used to classify patients as osteoporotic.

Baseline ADLs were assessed via BI in the orthopedic surgery department before surgery. The Mini Nutritional Assessment Short Form (MNA-SF), which is a 14-point scoring system, was used to evaluate the participants' nutritional status.⁽¹⁹⁾ Individuals were classified into three categories: normal nutrition with scores ranging from 12 to 14, at risk of malnutrition with scores ranging from 8 to 11, and malnourished with scores ranging from 0 to 7.⁽²⁰⁾ Functional outcomes, including BI, SPPB, hip muscle strength, and HHS, were assessed during the 3-month post-surgery follow-up.

Statistical analysis

Descriptive statistics were used to summarize baseline characteristics as the mean $\pm$ standard deviation (SD) for continuous variables and frequencies (%) for categorical variables. The normality of continuous variables was assessed using the Kolmogorov–Smirnov test. Group comparisons between sarcopenic and non-sarcopenic patients were performed using unpaired Student *t*-tests for continuous variables and Fisher's exact tests for categorical variables. Statistical significance was set at $P < 0.05$.

Furthermore, Pearson's correlation coefficients (*r*) were calculated to examine associations among continuous variables, with $r < 0.5$ considered low. Multiple linear regression was performed to identify independent predictors of 3-month functional outcomes. Model performance was evaluated using R^2 , adjusted R^2 , standard error, and root mean square error. Multicollinearity was assessed using the

variance inflation factor (VIF), with values <2 indicating acceptable multicollinearity. The SEM was applied to evaluate the direct and indirect effects of key predictors on 3-month outcomes, and the SEM was estimated using the maximum likelihood method. A latent variable (L1) representing overall hip muscle strength was constructed from four observed indicators: hip flexion and abduction strength on the injured and non-injured sides.

Model fit was assessed using established criteria: a non-significant chi-square test ($P > 0.05$), root mean square error of approximation (RMSEA) < 0.05 , comparative fit index (CFI) and Tucker-Lewis index (TLI) ≥ 0.95 , and standardized root mean square residual (SRMR) ≤ 0.10 .⁽²¹⁾ All statistical analyses were performed using Stata version 19.0 (StataCorp, College Station, TX, USA).

Results

Baseline characteristics

Between January 2023 and October 2024, 75 participants were screened for eligibility, resulting in the recruitment of 60 patients (**Figure 1**). No loss to follow-up was observed during the study period. The mean age of participants was 81.0 ± 8.4 years, with ages ranging from 60 to 95 years (**Table 1**). Most participants were female (76.7%), and the majority underwent cementless bipolar hemiarthroplasty (88.3%). Within the cohort, 15 patients had sarcopenia, whereas 45 did not. Those with sarcopenia exhibited significantly poorer baseline characteristics compared to their non-sarcopenic counterparts. They had markedly lower body weight (45.1 vs. 56.0 kg, $P < 0.001$) and BMI (18.5 vs. 22.2 kg/m², $P < 0.001$), longer LOS (13.2 vs. 7.5 days, $P < 0.001$), reduced baseline ADL as measured by the BI (80.0 vs. 89.6, $P = 0.009$), and poorer nutritional status (MNA-SF score: 8.4 vs. 11.1, $P < 0.001$).

Correlation analysis

Pairwise correlation analysis (**Table 2**) revealed several significant relationships ($P < 0.01$) among the study variables. Age was positively correlated with nutritional status (MNA-SF; $r = 0.441$, $P = 0.001$) and negatively correlated with baseline ADLs (BI; $r = -0.373$, $P = 0.003$), indicating that functional capacity declines with age. Furthermore, baseline ADLs were negatively associated with LOS ($r = -0.415$, $P = 0.001$). Sarcopenia exhibited a significant negative correlation with BMI ($r = -0.428$, $P = 0.001$) and a

positive correlation with LOS ($r = 0.452$, $P = 0.001$), thus highlighting its clinical impact on extended recovery. Notably, all correlations remained below the threshold for multicollinearity concerns ($r < 0.5$), indicating no risk of multicollinearity among the predictors.

Multivariate regression

The multiple linear regression analysis identified significant predictors of functional outcomes at 3 months post-surgery (**Table 3**). For the SPPB score, malnutrition (MNA-SF; $\beta = -2.08$, $P = 0.005$) and sarcopenia ($\beta = -2.76$, $P = 0.015$) were significant negative predictors. For the HHS score, malnutrition remained a strong negative predictor (MNA-SF; $\beta = -12.20$, $P < 0.001$), and LOS also demonstrated a significant negative association ($\beta = -0.57$, $P = 0.030$). Sarcopenia revealed a negative trend but was not significant ($P = 0.112$).

Regarding the BI score at 3 months post-surgery, malnutrition was the only significant predictor (MNA-SF; $\beta = -12.72$, $P = 0.001$), emphasizing the adverse impact of malnutrition on independence in daily activities. Sarcopenia showed a non-significant negative trend ($P = 0.192$). No other variables, including age, sex, BMI, CCI, baseline ADL, LOS, and osteoporosis, were significantly associated with any of the three functional outcomes. Moreover, no multicollinearity concerns were detected (all VIFs < 2).

Given the high correlations (**Table 4**) between hip muscle flexion strength on the injured and non-injured sides ($r = 0.942$) and hip abduction strength on the injured and non-injured sides ($r = 0.926$), these four measures were combined to construct a latent variable representing overall hip muscle strength (L1).

Structural equation modeling

The structural equation model (**Table 5; Figure 2**) showed significant direct and indirect effects of the key predictors on 3-month postoperative outcomes. LOS was directly associated with a lower HHS ($\beta = -0.41$, $P = 0.025$). Malnutrition (MNA-SF) negatively affected the HHS ($\beta = -11.76$, $P < 0.001$), SPPB ($\beta = -2.12$, $P < 0.001$), and BI ($\beta = -12.86$, $P < 0.001$). In addition, sarcopenia was linked to poorer outcomes: HHS ($\beta = -7.72$, $P = 0.008$), SPPB ($\beta = -3.29$, $P < 0.001$), and BI ($\beta = -13.69$, $P = 0.002$) and had a direct negative effect on hip strength (L1; $\beta = -2.76$, $P < 0.001$).

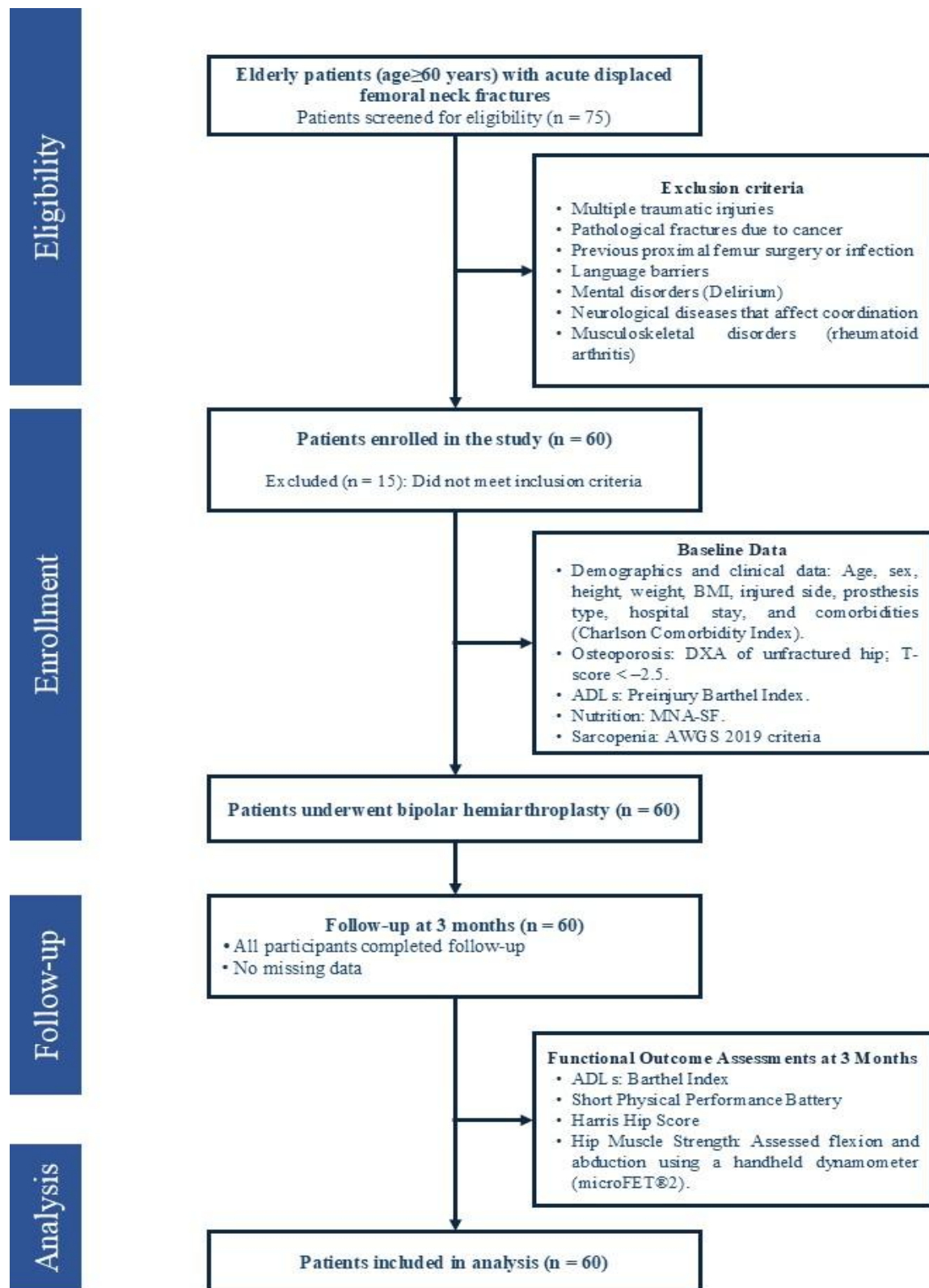


Figure 1. Flowchart of participant enrollment and follow-up. ADLs, activities of daily living; AWGS 2019, Asian Working Group for Sarcopenia 2019; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; MNA-SF, mini nutritional assessment short form.

Table 1. General characteristics of participants stratified by sarcopenia status.

General characteristics	Mean (SD)		Range		
Age (years)	81.0 (8.4)		60.0–95.0		
Height (cm)	157.7 (8.7)		145.1–191.3		
Weight (kg)	53.3 (10.0)		38.0–76.4		
BMI (kg/m²)	21.3 (3.8)		13.7–31.2		
	(n)		(%)		
Gender					
Male	14		23.3%		
Female	46		76.7%		
Type of prosthesis					
Cemented	7		11.7%		
Cementless	53		88.3%		
Baseline characteristics by group					
	Sarcopenia (n = 15)		Non-sarcopenia (n = 45)		
Characteristics	Mean	SD	Mean	SD	P-value
Age (years)	84.2	8.0	80.0	8.3	0.07
Height (cm)	156.2	8.8	158.2	8.8	0.44
Weight (kg)	45.1	7.0	56.0	9.3	<0.001*
BMI (kg/m²)	18.5	2.7	22.2	3.6	<0.001*
CCI	4.4	2.7	3.8	2.7	0.44
	(n)	(%)	(n)	(%)	
Gender					
Male	4	28.6%	10	71.4%	0.734
Female	11	23.9%	35	76.1%	
Side of injury					
Left	8	25.8%	23	74.2%	0.881
Right	7	24.1%	22	75.9%	
Type of prosthesis					
Cemented	4	26.7%	3	6.7%	0.06
Cementless	11	73.3%	42	93.3%	
Osteoporosis (T-score ≤ -2.5)					
Yes	11	34.4%	21	65.6%	0.084
No	4	14.3%	24	85.7%	
	Mean	SD	Mean	SD	
Length of hospital stay (days)	13.2	8.1	7.5	3.3	<0.001*
Baseline ADL BI (points)	80.0	12.3	89.6	11.8	<0.01*
MNA-SF (points)	8.4	1.6	11.1	2.0	<0.001*

ADL, activities of daily living; BI, Barthel Index; BMI, body mass index; CCI, Charlson Comorbidity Index; cm, centimeters; kg, kilograms; kg/m², kilograms per square meter; MNA-SF, mini nutritional assessment–short form; SD, standard deviation.

Table 2. Correlation matrix of predicted variables.

	Age	Sex	BMI	CCI	LOS	MNA-SF category	Osteoporosis	Baseline ADL BI	Sarcopenia
Age	1.000								
Sex	0.047 (0.718)	1.000							
BMI	-0.022 (0.862)	0.080 (0.540)	1.000						
CCI	0.255 (0.049)	0.039 (0.763)	-0.037 (0.779)	1.000					
LOS	0.323 (0.011)	-0.102 (0.435)	-0.165 (0.207)	0.288 (0.025)	1.000				
MNA-SF category	0.441* (0.001)	0.204 (0.116)	-0.179 (0.169)	0.315 (0.014)	0.2749 (0.033)	1.0000			
Osteoporosis	0.256 (0.025)	0.115 (0.378)	-0.140 (0.286)	0.164 (0.210)	0.156 (0.234)	0.187 (0.151)	1.000		
Baseline ADL BI	-0.373* (0.003)	-0.152 (0.244)	-0.065 (0.621)	-0.361 (0.004)	-0.415* (0.001)	-0.177 (0.174)	-0.285 (0.027)	1.000	
Sarcopenia	0.230 (0.076)	-0.045 (0.729)	-0.428* (0.001)	0.101 (0.441)	0.452* (0.001)	0.3672* (0.003)	0.231 (0.075)	-0.334* (0.009)	1.000

P-value < 0.01. ADL, activities of daily living; BI, Barthel Index; BMI, body mass index; CCI, Charlson Comorbidity Index; LOS, length of hospital stay; MNA-SF, mini nutritional assessment–short form.

Table 3. Multivariate multiple regression results for predictors of functional outcomes at 3-month follow-up.

SPPB: $R^2 = 0.48$, adjusted $R^2 = 0.39$, RMSE = 2.75, $P < 0.001$

Variable	Coefficient	SE	<i>P</i> -value	95% (Lower)	CI (Upper)	VIF
Age	-0.06	0.053	0.229	-0.171	0.041	1.54
Sex	0.007	0.906	0.994	-1.812	1.827	1.16
BMI	-0.02	0.109	0.845	-0.240	0.197	1.33
CCI	0.08	0.147	0.588	-0.216	0.377	1.31
LOS	-0.05	0.09	0.490	-0.217	0.105	1.52
Baseline ADL BI	0.02	0.036	0.602	-0.054	0.093	1.67
MNA-SF category	-2.08	0.716	0.005	-3.524	-0.645	1.60
Sarcopenia	-2.76	1.102	0.015	-4.982	-0.552	1.80
Osteoporosis	0.44	0.8	0.580	-1.15	2.03	1.24

HHS: $R^2 = 0.65$, adjusted $R^2 = 0.59$, RMSE = 8.76, P -value < 0.001

Age	-0.101	0.168	0.551	-0.439–	0.237	1.54
Sex	-1.228	2.879	0.671	7.013	4.555	1.16
BMI	-0.067	0.346	0.846	-0.763	0.628	1.33
CCI	0.626	0.470	0.189	-0.317	1.570	1.31
LOS	-0.569	0.255	0.030	-1.082	-0.056	1.52
Baseline ADL BI	0.139	0.116	0.236	-0.094	0.374	1.67
MNA-SF category	-12.202	2.277	<0.001	-16.776	-7.627	1.60
Sarcopenia	-5.66	3.504	0.112	-12.708	1.369	1.80
Osteoporosis	0.54	2.52	0.83	-4.52	5.60	1.24

BI: $R^2 = 0.51$, adjusted $R^2 = 0.42$, RMSE = 14.27, P -value < 0.001

Age	-0.195	0.274	0.481	-0.746	0.356	1.54
Sex	-0.415	4.692	0.930	-9.840	9.008	1.16
BMI	-0.018	0.564	0.974	-1.152	1.116	1.33
CCI	0.141	0.766	0.854	-1.396	1.68	1.31
LOS	-0.425	0.416	0.312	-1.261	0.41	1.52
Baseline ADL BI	0.27	0.19	0.161	-0.111	0.652	1.67
MNA-SF category	-12.717	3.71	0.001	-20.17	-5.264	1.60
Sarcopenia	-7.551	5.709	0.192	-19.019	3.917	1.80
Osteoporosis	-1.82	4.10	0.660	-10.07	6.43	1.24

ADL, activities of daily living; BI, Barthel Index; BMI, body mass index; CCI, Charlson Comorbidity Index; LOS, length of hospital stay; MNA-SF, mini nutritional assessment–short form; R^2 , coefficient of determination; RMSE, root mean square error; SE, standard error; VIF, variance inflation factor.

Table 4. Correlation matrix of hip muscle strength parameters.

	Hip flexion (injured)	Hip flexion (non-injured)	Hip abduction (injured)	Hip abduction (non-injured)
Hip flexion (injured)	1.000			
Hip flexion (non-injured)	0.942 <i>P</i> <0.001	1.000		
Hip abduction (injured)	0.846 <i>P</i> <0.001	0.736 <i>P</i> <0.001	1.000	
Hip abduction (non-injured)	0.868 <i>P</i> <0.001	0.797 <i>P</i> <0.001	0.926 <i>P</i> <0.001	1.000

Table 5. Direct and indirect effects of predictors on functional outcomes based on structural equation modeling.

Variables	Coefficient	SE	<i>P</i> -value	95% CI
HHS				
Direct effects:				
LOS	-0.41	0.19	0.025	-0.8 to -0.03
MNA-SF category	-11.76	1.79	<0.001	-15.3 to -8.2
Sarcopenia	-7.72	2.86	0.008	-13.3 to -2.1
Indirect effects:				
Age	-0.38	0.11	0.001	-0.60 to -0.15
BMI	0.32	0.15	0.032	0.02 to 0.62
Baseline ADL BI	0.17	0.05	0.003	0.05 to 0.28
MNA-SF category				
Direct effects:				
Age	0.03	0.008	<0.001	0.01 to 0.04
SPPB				
Direct effects:				
MNA-SF category	-2.12	0.54	<0.001	-3.18 to -1.06
Sarcopenia	-3.29	0.83	<0.001	-4.91 to -1.66
Indirect effects:				
Age	0.06	0.02	0.006	0.11 to 0.01
BMI	0.13	0.05	0.008	0.03 to 0.24
Baseline ADL BI	0.04	0.01	0.01	0.009 to 0.07
BI				
Direct effects:				
MNA-SF category	-12.86	2.71	<0.001	-18.19 to -7.54
Sarcopenia	-13.69	4.43	0.002	-22.38 to -4.99
Indirect effects:				
Age	-0.41	0.14	0.003	-0.69 to -0.14
BMI	0.57	0.24	0.02	0.09 to 1.05
Baseline ADL BI	0.16	0.07	0.022	0.02 to 0.31
Sarcopenia				
Direct effects:				
BMI	-0.04	0.01	<0.001	-0.06 to -0.01
Baseline ADL BI	-0.01	0.003	0.001	-0.02 to -0.005
L1				
Direct effects:				
Sarcopenia	-2.76	0.68	<0.001	-4.11 to -1.41
Indirect effects:				
BMI	0.11	0.04	0.008	0.03 to 0.20
Baseline BI	0.03	0.01	0.01	0.008 to 0.06

ADL, activities of daily living; BI, Barthel Index; BMI, body mass index; CI, confidence interval; HHS, Harris Hip Score; L1, latent variable 1 (hip muscle strength); LOS, length of hospital stay; MNA-SF, mini nutritional assessment-short form; SE, standard error; SPPB, short physical performance battery.

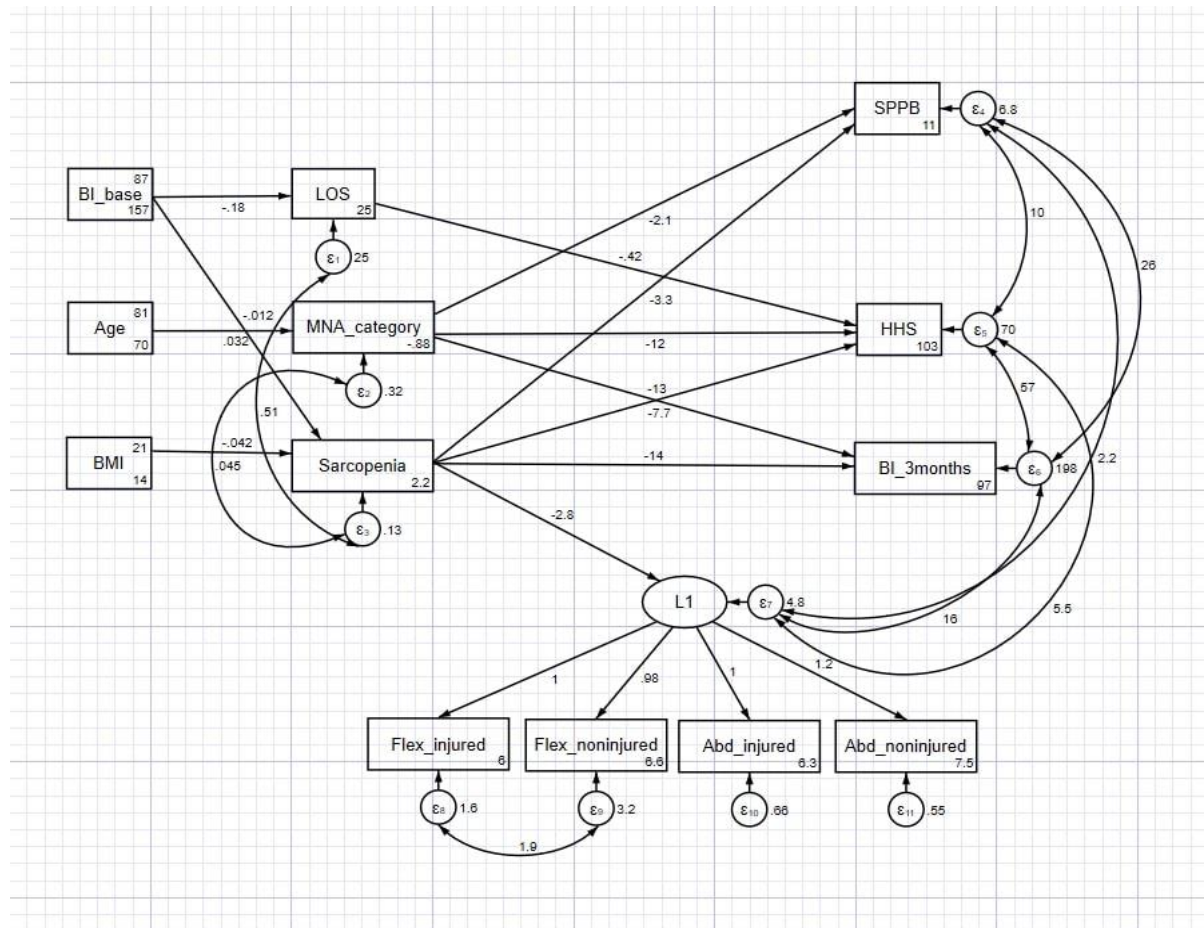


Figure 2. Structural equation modeling. BMI, body mass index; HHS, Harris hip score; LOS, length of hospital stay; SPPB, short physical performance battery.

Indirectly, older age predicted a lower HHS ($\beta = -0.38, P = 0.001$), SPPB ($\beta = -0.06, P = 0.006$), and BI ($\beta = -0.41, P = 0.003$) via the MNA-SF. Lower BMI was also associated with a reduced HHS ($\beta = 0.32, P = 0.032$), SPPB ($\beta = 0.13, P = 0.008$), BI ($\beta = 0.57, P = 0.020$), and hip muscle strength (L1) ($\beta = 0.11, P = 0.008$) via sarcopenia. Baseline ADL positively contributed to HHS ($\beta = 0.17, P = 0.003$), SPPB ($\beta = 0.04, P = 0.010$), BI ($\beta = 0.16, P = 0.022$), and L1 ($\beta = 0.03, P = 0.010$) through its effect on sarcopenia. Sarcopenia was influenced by BMI ($\beta = -0.04, P < 0.001$) and baseline ADL ($\beta = -0.01, P = 0.001$). The CCI and osteoporosis were excluded from the SEM because they demonstrated non-significant associations with functional outcomes in multiple regression analyses and exhibited no meaningful correlations with the primary prediction variables.

Residual covariances among the model variables are shown in **Table 6**. Significant positive residual covariances were found between key outcome

variables, indicating unexplained shared variance beyond the structural paths in the model. The SPPB and BI scores at 3 months post-surgery showed a strong residual covariance ($\beta = 25.79, P < 0.001$). HHS exhibited significant positive residual covariances with SPPB ($\beta = 10.35, P = 0.001$) and BI at 3 months post-surgery ($\beta = 57.19, P = 0.001$), as well as with the L1 latent hip strength variable ($\beta = 5.45, P = 0.036$). SPPB and L1 were positively associated ($\beta = 2.18, P = 0.008$), as were BI at 3 months post-surgery and L1 ($\beta = 15.81, P = 0.001$), highlighting the contribution of hip strength to functional recovery. Sarcopenia and LOS showed a modest but significant residual covariance ($\beta = 0.51, P = 0.032$). A strong residual covariance was found between muscle strength measurements of the injured and non-injured sides ($\beta = 1.86, P < 0.001$), thus confirming consistency across limb strength. These findings support the interrelationships among physical function, nutritional status, and sarcopenia in this clinical population, beyond the direct structural paths specified in the model.

Table 6. Residual covariances between latent and observed variables in the structural equation model.

Covariance pair	Coefficient	P-value
LOS – sarcopenia	0.51	0.032
HHS – SPPB	10.35	0.001
HHS – BI at 3 months	57.19	0.001
HHS – L1 (hip muscle strength)	5.45	0.036
MNA-SF category – Sarcopenia	0.045	0.084
SPPB – BI at 3 months	25.79	<0.001
SPPB – L1 (hip muscle strength)	2.18	0.008
BI at 3 months – L1 (hip muscle strength)	15.81	0.001
Hip flexion (injured) – Hip flexion (non-injured)	1.86	<0.001

BI, Barthel Index; HHS, Harris hip score; LOS, length of hospital stay; MNA-SF, mini nutritional assessment–short form; SPPB, short physical performance battery.

Model fit

The model demonstrated excellent fit, as indicated by the non-significant chi-square test ($P = 0.615$), an RMSEA < 0.001 (P -close = 0.831), and high CFI (CFI = 1.000, TLI = 1.009). Although the SRMR was 0.094, indicating a marginally acceptable fit, the model's overall fit was adequate.

Discussion

This prospective cohort study examined the effects of sarcopenia on the functional outcomes and hip muscle strength in elderly individuals with femoral neck fractures using SEM to control for potential confounding factors.

The findings revealed that sarcopenia and low MNA-SF scores were significant predictors of recovery, as measured by SPPB, HHS, BI, and hip muscle strength at 3 months post-surgery. Patients with sarcopenia had lower weight, BMI, MNA-SF scores, and baseline ADL, along with longer LOS. In the multivariate regression analysis, sarcopenia was correlated with lower SPPB scores and showed a negative trend with HHS and BI. Furthermore, sarcopenia directly affected SPPB, HHS, BI, and hip muscle strength, whereas age, BMI, and baseline ADL indirectly influenced the outcomes via MNA-SF and sarcopenia. This impact may result from decreased muscle mass and impaired muscle quality, neuromuscular coordination, and strength capacity.⁽²²⁾ Our results align with previous research indicating that sarcopenia leads to impaired mobility, prolonged rehabilitation, and poor functional outcomes in orthopedic populations.^(23, 24) In addition, sarcopenia is associated with a higher risk of perioperative complications, such as infections, dislocations, and poor wound healing, which can impede postoperative recovery.⁽²⁵⁾ In hip arthroplasty, patients with sarcopenia often experience slower mobility gains and

are more likely to require extended rehabilitation services.⁽²⁶⁾ The combination of sarcopenia and osteoporosis exacerbates these issues, which highlights the need for early intervention via prerehabilitation programs focused on resistance training and nutrition optimization.^(27, 28)

Nutritional status also emerged as an independent predictor of postoperative functional recovery. Malnutrition or the risk of malnutrition, as assessed by the MNA-SF, was associated with poorer outcomes for ADL, SPPB, and HHS. This finding aligns with previous research showing that patients with malnutrition face higher mortality and complication rates following hip fracture surgery, with in-hospital mortality rates as high as 27.0% compared to 7.0% for well-nourished patients and one-year mortality rates reaching 46.0% vs. 17.0%.⁽²⁹⁾ Similarly, Yagi T, *et al.*⁽³⁰⁾ demonstrated that poor nutritional status is an independent risk factor for postoperative complications. Furthermore, Han TS, *et al.*⁽³¹⁾ reported that malnourished patients experienced longer hospital stays, delayed mobilization, a higher risk of pressure ulcers, and a greater likelihood of being discharged to institutional care. These findings are consistent with our results, which showed that malnutrition significantly predicted longer hospitalization and poorer functional recovery.

LOS was found to be an independent negative predictor of HHS, which suggests that prolonged hospitalization may hamper hip-specific functional recovery. These findings emphasize the importance of optimizing perioperative care to reduce LOS and thus enhance rehabilitation outcomes. In addition, better baseline functional status, as measured by the pre-injury BI, was associated with improved recovery across all outcomes. This study emphasizes the role of early mobilization and pre-injury physical conditioning in promoting postoperative independence.

Moreover, the strong correlations observed between hip flexion and abduction strength on the injured and non-injured sides supported the construction of an L1 to represent the overall hip muscle strength. Notably, sarcopenia exerted a direct, significant negative effect on this latent construct, thereby underscoring how muscle loss compromises functional capacity. These results reinforce the central role of muscle health in recovery following hip fracture surgery. The identification of sarcopenia and malnutrition as independent, modifiable risk factors provides critical opportunities for early intervention. Therefore, geriatric patients with hip fractures should undergo systematic screening for sarcopenia and nutritional status upon admission.

A major strength of this study is its prospective design, conducted in accordance with the STROBE guidelines. It comprehensively assessed short-term outcomes following bipolar hemiarthroplasty for femoral neck fractures using validated measures, including BI for ADL, SPPB, HHS, and hip muscle strength. The application of the AWGS-2019 criteria ensured consistent and reliable sarcopenia diagnosis, thereby enabling comparability with other studies. The use of an SEM provided a robust analytical framework that allowed for the simultaneous evaluation of direct and indirect relationships among interrelated variables, which is an advantage over conventional regression approaches. Internal validity was strengthened by a clearly defined population and strict inclusion/exclusion criteria. Moreover, the SEM was demonstrated to be an excellent model fit, supported by strong indices, thereby reinforcing the reliability of our findings.

This study has several limitations. First, the relatively small sample size may have reduced statistical power and limited generalizability. In addition, the imbalance in group sizes (15 vs. 45) may further decrease the statistical power and increase the risk of Type II errors, particularly for the non-significant secondary outcomes. Moreover, although an SEM was used to account for complex relationships and potential confounders, its application to a small sample size should be interpreted with caution, and the findings should be considered as exploratory. Although the model demonstrated excellent fit, notable residual covariances were observed among the key outcome variables, including SPPB, HHS, BI, and the L1 latent construct, which suggests the presence of unmeasured or omitted factors contributing to the shared variance. While such residual associations are

not uncommon in SEM, they highlight the multifactorial nature of postoperative recovery and may limit the model's ability to fully delineate causal pathways. In addition, important variables such as socioeconomic status, cognitive function, and baseline frailty were not included and may have provided further insight into patient outcomes. Furthermore, the single-center design may have introduced selection bias and limited external validity across different institutions or healthcare systems. Lastly, the three-month follow-up only provides a short-term assessment of functional recovery; thus, future studies should incorporate longer follow-up periods to evaluate the sustained outcomes and late complications.

These findings have important implications for clinical practice and future research. Early identification and targeted management of sarcopenia should be integrated into the perioperative care pathways for elderly patients with hip fractures to optimize their recovery and reduce long-term functional decline. Multimodal interventions, including nutritional support, progressive resistance training, and efforts to minimize hospitalization duration, may provide tangible benefits. Future studies should aim to validate these results in larger, multicenter cohorts and explore additional determinants of recovery, including frailty, cognitive health, and social support. Moreover, expanding the SEM framework to incorporate time-dependent variables could further elucidate the dynamic processes underlying the postoperative functional trajectories in this vulnerable population.

Conclusion

This study highlights sarcopenia as the strongest negative predictor of functional outcomes in elderly patients undergoing bipolar hemiarthroplasty, thus emphasizing its crucial impact on postoperative recovery. The structural equation model demonstrated that the patients' baseline functional status significantly improved outcomes by reducing comorbidities and hospital stays, whereas prolonged stays exacerbated muscle loss and functional decline. These findings underscore the need for the early evaluation of sarcopenia and targeted interventions to improve recovery in this vulnerable population.

Author contributions

SA contributed substantially to the study's concept and design, methodology, investigation, and writing—original draft. SJK contributed substantially to supervision, statistical analysis, and writing—review and editing. ST contributed to project administration, validation, and writing—review and editing.

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Not applicable

Conflict of interest statement

The authors have no relevant financial or non-financial interests to disclose.

Data sharing statement

The datasets generated and analyzed during the current study are available for non-commercial purposes from the corresponding author upon reasonable request.

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