

Bidirectional Relationship Between Hypoalbuminemia and Postoperative Pneumonia in Elderly Hip Fracture Patients: A Retrospective Cohort Study

Junxiang Wang^{1,2,*}, Hui Yu^{1,2,*}, Xin Xu^{1,2}, Junfei Guo^{1,2}

¹Department of Joint Surgery, Honghui Hospital, Xi'an Jiaotong University, Xi'an, Shanxi, 710054, People's Republic of China; ²Xi'an Key Laboratory of Pathogenesis and Precision Treatment of Arthritis, Xi'an, Shanxi, 710054, People's Republic of China

*These authors contributed equally to this work

Correspondence: Junfei Guo, Department of Joint Surgery, Honghui Hospital, Xi'an Jiaotong University, No. 555, Youyi East Road, Beilin District, Xi'an, Shaanxi, People's Republic of China, Email drjfguo@163.com

Background: Postoperative pneumonia is a common and severe complication following hip fracture (HF) surgery in the elderly. Hypoalbuminemia, a marker of poor nutritional status and systemic inflammation, is widely recognized as a predictor of adverse outcomes. However, their bidirectional relationship in elderly HF patients remains underexplored.

Methods: This retrospective cohort study was conducted in China enrolling elderly patients (≥ 65 years) with HFs between Mar 2020 and Feb 2023. After predefined participants selection inclusion and exclusion criteria, 1661 surgically treated HF patients were included and analyzed utilizing multiple statistical models, including univariate logistic regression, Lasso regression, and Boruta algorithm for variable selection, while multivariate logistic regression and propensity score matching (PSM) for assess the bidirectional relationship between hypoalbuminemia and postoperative pneumonia. All participants' demographics, injury-related data, surgery-related data, perioperative complications, and two-year follow-up mortality rates were collected and compared.

Results: A total of 1,661 patients were included, of whom 144 developed postoperative pneumonia (8.67%). Preoperative hypoalbuminemia was identified as an independent risk factor for postoperative pneumonia (OR: 7.96, 95% CI: 4.08–15.53, $P < 0.001$), while postoperative pneumonia itself was associated with an increased risk of developing hypoalbuminemia (OR: 2.34, 95% CI: 1.62–3.38, $P < 0.001$). PSM, as sensitivity analyses, further confirmed that postoperative pneumonia itself exacerbates hypoalbuminemia, creating a detrimental cycle. In addition, postoperative pneumonia significantly prolonged hospital stays, increased complication, and elevated mortality rates at 3 months to 2 years (OR: 1.83–3.43, all $P < 0.05$) follow-up period.

Conclusion: Preoperative hypoalbuminemia is a significant predictor of postoperative pneumonia in elderly patients with HFs, and postoperative pneumonia, in turn, exacerbates hypoalbuminemia, creating a deleterious cycle. Early nutritional assessment and intervention are essential in breaking this cycle and improving outcomes. These findings support the incorporation of routine nutritional screening and optimization into the preoperative care of elderly HF patients to reduce complications and enhance recovery.

Keywords: hypoalbuminemia, pneumonia, hip fractures, aged, bidirectional relationship, cohort studies

Introduction

Due to high prevalence of comorbidities, hip fractures in the elderly are frequently termed as “the last fracture in life”, which can lead to a series of complications and poor outcomes during hospitalization.^{1,2} Among these complications, postoperative pneumonia stands out as one of the most common and life-threatening, affecting 5.1% to 14.9% of elderly hip fracture patients.^{3–5} It can rapidly progress to serious pulmonary sequelae, including pleural effusion and atelectasis, particularly in patients with underlying chronic conditions, thereby triggering multi-organ dysfunction and exacerbating clinical deterioration.^{6,7} It is estimated that approximately 10% of patients develop fatal postoperative pneumonia during

hospitalization, which contributes to extended mechanical ventilation, longer intensive care unit and length of hospital stays (LOS) by 1.6 times, increased rates of secondary infections and readmissions, and a significantly elevated risk of in-hospital and long-term mortality.^{8–10} Given the projected doubling of the elderly population by 2050, the burden of hip fractures is expected to rise substantially, posing serious challenges to healthcare systems worldwide.^{11,12} It is therefore crucial to identify modifiable risk factors for postoperative complications and to implement early, targeted interventions to improve perioperative management and patient outcomes in this vulnerable population.

In recent years, numerous researches have been focused on predicting the occurrence of postoperative pneumonia in elderly hip fracture patients, with a particular emphasis on identifying risk factors that may predispose these patients to such complications.^{13–15} Known risk factors for postoperative pneumonia include advanced age, male gender, and poor preoperative health status—such as obesity, smoking, cardiovascular and cerebrovascular diseases, and compromised pulmonary and cognitive function.^{7,8,16} Serum albumin, a reliable marker of nutritional status and systemic inflammation, has emerged as a significant predictor of postoperative outcomes, including immune dysfunction, delayed wound healing, and increased susceptibility to infection. Hypoalbuminemia, often resulting from malnutrition and inflammation, has been consistently associated with immune suppression, delayed wound healing, and increased susceptibility to infections, including pneumonia, where the prevalence can reach up to 45.9% in high-risk patients.^{17–24}

Despite this growing body of evidence, most studies have only evaluated the unidirectional effect of hypoalbuminemia on postoperative pneumonia. In contrast, the possibility of a bidirectional relationship has received limited attention. Postoperative pneumonia may, in turn, worsen nutritional depletion and systemic inflammation, further reducing albumin levels and creating a self-perpetuating cycle of malnutrition and infection.^{25–28} In elderly patients, this vicious cycle is often compounded by frailty, multimorbidity, and impaired physiological reserve. Nonetheless, this interaction remains underrecognized in current clinical guidelines, contributing to persistent morbidity and mortality in this population.^{28–30}

To address this knowledge gap, the present retrospective cohort study aims to comprehensively assess the bidirectional association between hypoalbuminemia and postoperative pneumonia in elderly patients with hip fractures. We also examine the broader implications of this relationship on clinical outcomes to support more effective perioperative risk stratification and personalized management strategies.

Materials and Methods

Study Design, Data Source and Participants

This retrospective cohort study recruited elderly patients (≥ 65 years) with intertrochanteric hip fractures (ITHF) at Honghui Hospital, Xi'an Jiaotong University, a part of a major national orthopedic union, from March 2020 and February 2023. The inclusion criteria for the study were: (1) patients aged 65 years or older who underwent surgical intervention using proximal femoral nail anti-rotation; (2) confirmed diagnosis of low-energy ITHF; (3) availability of preoperative serum albumin measurements within 24 hours of admission; (4) admission within 48 hours of injury; (5) written informed consent obtained from the patient or their legal representative. Exclusion criteria included: (1) patients presenting with multiple fractures or injuries, not limited to the hip; (2) pathological fractures indicative of underlying disease processes such as malignancy; (3) open fractures with a high risk of complications; (4) patients with chronic liver or kidney disease that could impact albumin metabolism; (5) pre-existing severe pulmonary conditions such as chronic obstructive pulmonary disease (COPD), which could confound pneumonia diagnosis; (6) patients contraindicated for surgery due to severe comorbidities or who refused surgical treatment. All patients were followed up for at least two years post-fracture to assess long-term outcomes, including pneumonia recurrence and mortality.

The study period was chosen based on the availability of a complete and standardized clinical database, ensuring consistency in data collection protocols during the COVID-19 era. This period also reflects a contemporary and representative elderly patient population undergoing surgical treatment for hip fractures in a tertiary referral center. Finally, a total of 1,661 eligible patients were included after applying strict inclusion and exclusion criteria, ensuring sufficient statistical power for multivariate analyses and subgroup comparisons.

Data Collection, Outcomes, Definitions, and Follow-up

To minimize potential confounding bias, a broad range of covariates were considered based on existing literature and clinical expertise. Patient data were extracted from the electronic medical records of the participating institutions, including demographics, surgical characteristics, and perioperative clinical indicators. The primary outcome was the incidence of postoperative pneumonia, diagnosed according to the Centers for Disease Control and Prevention (CDC) criteria for hospital-acquired pneumonia. Diagnostic criteria included clinical symptoms (fever, cough, dyspnea), radiographic findings (new or progressive infiltrates on chest X-ray), and microbiological confirmation (positive sputum or blood cultures). The primary exposure of interest was preoperative serum albumin levels, measured using standardized clinical laboratory protocols, with hypoalbuminemia defined as a serum albumin level <3.5 g/dL in accordance with established clinical guidelines.³¹

Body mass index (BMI) was classified as normal ($\text{BMI} < 24$ kg/m²), overweight ($24 \leq \text{BMI} < 28$ kg/m²), and obese ($\text{BMI} \geq 28$ kg/m²). The modified Elixhauser comorbidity method (mECM) was employed to detect comorbidities in patients upon admission utilizing 30 unique medical conditions and screened and further stratified into groups 1–5 representing <0 , 0, 1–5, 6–13, ≥ 14 , respectively. Prior research has illustrated that this technique is significantly more effective at accounting for comorbidities than other approaches, resulting in a more accurate forecast of complications and mortality.^{11,32} Additionally, ASA grade is a common predictor of mortality in orthopedic surgery. Thus, to ensure transparency, the authors have included both variables as their previous studies.^{33,34} Fractures were categorized as stable or unstable based on the Orthopaedic Trauma Association classification. The 15-item geriatric depression scale (GDS) was used to determine the depression symptoms and functional independence measures (FIM) was employed to evaluate patients' capacity to perform activities of daily living.³⁵ Data on perioperative complications, including sudden death, acute heart failure, acute respiratory failure, myocardial infarction, cerebral infarction, delirium, stress ulcers, arrhythmias, electrolyte imbalances, stress hyperglycemia, and deep vein thrombosis (DVT), were also collected. Survival status and date of death were recorded during follow-up, which commenced from patient enrollment and continued until the endpoint event, defined as death from any cause or the last follow-up (October 31, 2024), whichever occurred first. Follow-up visits occurred at 1-, 3-, 6-, 12-, and 24-month post-surgery via outpatient reviews or telephone interviews.

This study was approved by the Institutional Review Boards (IRBs) of the participating center and conducted in accordance with the principles of the Declaration of Helsinki (2013 revision). Written informed consent was obtained from all participants and all collected data were anonymized to ensure patient confidentiality. The current study followed the principles of the Helsinki Declaration and the work has been reported in line with the Strengthening the Reporting of cohort, cross-sectional and case-control studies in Surgery (STROCCS) criteria.³⁶

Statistical Analysis

A power analysis confirmed the adequacy of the sample size, with a 5% significance level and 80% power, using NCSS-PASS V11.0.7 software (<https://www.ncss.com/software/pass/>). Continuous variables were tested for normality using the Kolmogorov–Smirnov test. Descriptive statistics for normally distributed variables are presented as mean \pm standard deviation, and categorical variables are expressed as frequencies and percentages. Differences between groups were assessed using Student's t-tests for continuous variables and χ^2 or Fisher's exact tests for categorical data.

To evaluate the impact of continuous clinical variables on both bidirectional outcomes of postoperative pneumonia and hypoproteinemia, we performed piecewise regression to determine optimal threshold cut-off values. Missing data for continuous variables (BMI 7.4%, FIM 6.9%) were imputed using linear regression. Univariate logistic regression, Lasso regression, and Boruta algorithm were utilized for variable selection to identify potential risk factors for postoperative pneumonia and hypoalbuminemia. Multicollinearity diagnostics were used to examine multicollinearity among the independent variables. Collinearity diagnostics showed that the largest value of variance inflation factor (VIF) was 1.30 and 1.31 for postoperative pneumonia (Figure 1A) and hypoalbuminemia (Figure 1B), respectively, suggesting that there was no obvious collinearity between the variables. Multivariate logistic regression analysis was then performed to determine the independent factors significantly associated with outcomes of postoperative pneumonia or hypoproteinemia, adjusting for potential confounders. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated, with

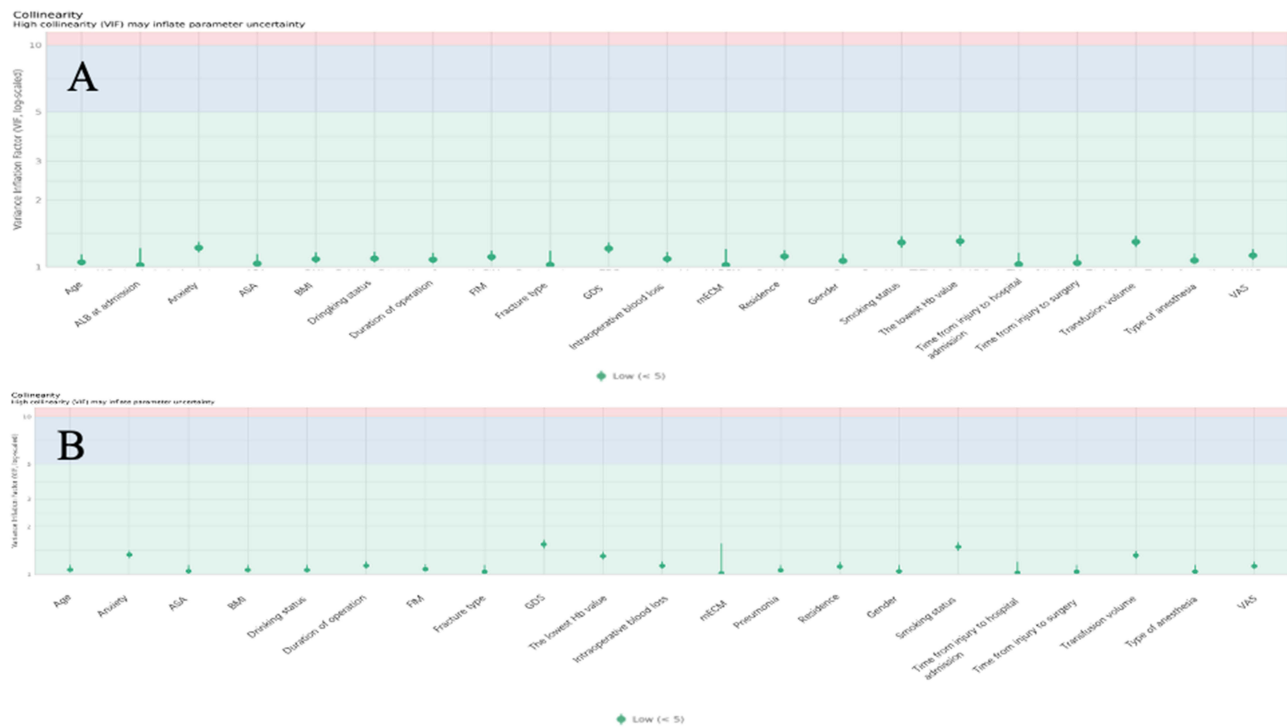


Figure 1 Collinearity diagnostics showed no obvious collinearity between the variables for postoperative pneumonia (**A**) and hypoalbuminemia (**B**).

statistical significance set at $P < 0.05$. Several variables such as age, gender, ASA, and mECM were also selected for inclusion in the multivariate analysis model, allowing for the consideration of biologically plausible or clinically relevant factors, even if they did not reach statistical significance in the covariates' selection processes. In order to enhance the reliability of our findings and ensure their relevance to real-life clinical practice, propensity score matching (PSM) with a 1:3 nearest neighbor method and a caliper of 0.2 was used to balance covariates between patients with and without pneumonia, reducing confounding bias. This statistical technique aimed to balance the covariates between the groups, ensuring that any observed differences in the outcomes were more likely to be attributed to the treatments themselves rather than the influence of confounding factors. Complications, LOS, survival probabilities at 1-month, 3-month, 6-month, 1-year, and 2-year for both groups were compared before and after matching. Since the sample size of the control group of $ALB \geq 35 \text{ g/L}$ ($n=531$) is smaller than that of the experimental group of $ALB < 35 \text{ g/L}$ ($n=1130$) and does not meet the requirements of 2–3 times, it is not suitable for PSM and then only multivariate logistic regression was performed to identify the risk factors for postoperative pneumonia.^{37–39}

All analyses were performed with R software (R Foundation for Statistical Computing, version 4.3.1) and methods functionally relied on the rms, the MatchIt, and the segmented package. A P -value of < 0.05 was considered statistically significant.

Results

Influence of Preoperative Hypoalbuminemia on Postoperative Pneumonia

After rigorous exclusion, 1,661 patients were included in the study, of whom 144 developed postoperative pneumonia, yielding an incidence rate of 8.67%. Using piecewise regression analysis, we identified the optimal cut-off points for key continuous variables in predicting postoperative pneumonia and hypoalbuminemia, including age, time from injury to hospital admission, time from injury to surgery, ASA, mECM, duration of operation, intraoperative blood loss, VAS, GDS, FIM, the lowest Hb level, and blood transfusion volume which were found to be 81 years, 9 hours, 6 days, 3, 2, 90 mins, 200mL, 5, 4, 83, 89 g/L, 4 units, respectively. These categorized variables were subsequently used in univariate and multivariate logistic regression analyses.

The characteristics of patients who developed postoperative pneumonia and those who did not are presented in Table 1. In univariate analysis, age \geq 81 years, male, live in urban, unstable fracture type, time from injury to surgery \geq 6 days, ASA \geq 3, regional anesthesia, intraoperative blood loss \geq 200 mL, the lowest Hb level \geq 89 g/L, and blood transfusion volume $<$ 4 units, and ALB at admission $<$ 35 g/L were significantly associated with post-operative pneumonia ($P<0.10$).

Table 1 The Univariate and Multivariate Analyses of All Involved Factors Associated with Postoperative Pneumonia

Variables	Univariate				Multivariate	
	Total (n=1661)	Pneumonia (n=144)	No Pneumonia (n=1517)	P Value	OR (95% CI)	P Value
Demographics						
Gender					Reference	
Male	487 (29.3%)	55 (38.2%)	432 (28.5%)			
Female	1174 (70.7%)	89 (61.8%)	1085 (71.5%)	0.014*	0.57 (0.39, 0.84)	0.004**
Age, years					Reference	
$<$ 81	912 (54.9%)	60 (41.7%)	852 (56.2%)			
\geq 81	749 (45.1%)	84 (58.3%)	665 (43.8%)	$<0.001^*$	1.60 (1.10, 2.32)	0.015**
BMI, kg/m ²						
Normal (BMI $<$ 24)	1103 (66.4%)	99 (68.7%)	1004 (66.2%)			
Overweight (24 \leq BMI $<$ 28)	437 (26.3%)	37 (25.7%)	400 (26.4%)	0.751		
Obesity (BMI \geq 28)	121 (7.3%)	8 (5.6%)	113 (7.4%)	0.384		
Residence					Reference	
Rural	567 (34.1%)	40 (27.8%)	527 (34.7%)			
Urban	1094 (65.9%)	104 (72.2%)	990 (65.3%)	0.092*	1.52 (1.01, 2.27)	0.044**
Smoking status						
Current	351 (21.1%)	34 (23.6%)	317 (20.9%)			
Past	95 (5.7%)	8 (5.6%)	87 (5.7%)	0.708		
Never	1215 (73.2%)	102 (70.8%)	1113 (73.4%)	0.450		
Drinking status						
Current	1597 (96.2%)	138 (95.8%)	1459 (96.2%)			
Never	64 (3.8%)	6 (4.2%)	58 (3.8%)	0.838		
Surgery-related indicators						
Fracture type					Reference	
Stable (A1.1–A2.1)	867 (52.2%)	63 (43.8%)	804 (53.0%)			
Unstable (A2.2–A3.3)	794 (47.8%)	81 (56.2%)	713 (47.0%)	0.034*	1.31 (0.91, 1.90)	0.146
Time from injury to hospital admission, hours						
$<$ 9	786 (47.3%)	72 (50.00%)	714 (47.1%)			
\geq 9	875 (52.7%)	72 (50.00%)	803 (52.9%)	0.500		
Time from injury to surgery, days					Reference	
$<$ 6	1029 (62.0%)	72 (50.0%)	957 (63.1%)			
\geq 6	632 (38.0%)	72 (50.0%)	560 (36.9%)	0.002*	1.65 (1.13, 2.40)	0.009**
ASA					Reference	
$<$ 3	764 (46.0%)	122 (84.7%)	1493 (98.4%)			
\geq 3	897 (54.0%)	22 (15.3%)	24 (1.6%)	$<0.001^*$	4.57 (3.12, 6.70)	$<0.001^{**}$
mECM					Reference	
$<$ 2	857 (51.6%)	75 (52.1%)	782 (51.5%)			
\geq 2	804 (48.4%)	69 (47.9%)	735 (48.5%)	0.902	1.20 (0.33, 4.42)	0.782
Type of anesthesia					Reference	
General	642 (38.7%)	45 (31.2%)	597 (39.4%)			
Regional	1019 (61.3%)	99 (68.8%)	920 (60.6%)	0.056	1.54 (1.03, 2.29)	0.034**
Duration of operation, mins						
$<$ 90	879 (52.9%)	79 (54.9%)	800 (52.7%)			
\geq 90	782 (47.1%)	65 (45.1%)	717 (47.3%)	0.625		
Intraoperative blood loss, mL					Reference	
\geq 200	965 (58.1%)	90 (62.5%)	875 (57.7%)			
$<$ 200	696 (41.9%)	54 (37.5%)	642 (42.3%)	0.002*	0.58 (0.40, 0.85)	0.005**

(Continued)

Table 1 (Continued).

Variables	Univariate				Multivariate	
	Total (n=1661)	Pneumonia (n=144)	No Pneumonia (n=1517)	P Value	OR (95% CI)	P Value
Perioperative clinical indicators						
VAS						
<5	871 (52.4%)	77 (53.5%)	794 (52.3%)			
≥5	790 (47.6%)	67 (46.5%)	723 (47.7%)	0.795		
GDS						
<4	667 (40.2%)	62 (43.1%)	605 (39.9%)			
≥4	994 (59.8%)	82 (56.9%)	912 (60.1%)	0.458		
FIM						
<83	860 (51.8%)	71 (49.3%)	789 (52.0%)			
≥83	801 (48.2%)	73 (50.7%)	728 (48.0%)	0.535		
Anxiety						
No	1345 (81.0%)	122 (84.7%)	1223 (80.6%)			
Yes	316 (19.0%)	22 (15.3%)	294 (19.4%)	0.231		
The lowest Hb level, g/L						
<89	829 (49.9%)	59 (41.0%)	770 (50.8%)		Reference	
≥89	832 (50.1%)	85 (59.0%)	747 (49.2%)	0.025*	0.82 (0.54, 1.24)	0.347
Blood transfusion, units						
<4	605 (36.4%)	71 (49.3%)	534 (35.2%)		Reference	
≥4	1056 (63.6%)	73 (50.7%)	983 (64.8%)	<0.001*	1.35 (0.86, 2.11)	0.194
ALB at admission, g/L						
≥35	531 (32.0%)	10 (6.9%)	521 (34.3%)		Reference	
<35	1130 (68.0%)	134 (93.1%)	996 (65.7%)	<0.001*	7.96 (4.08, 15.53)	<0.001**

Notes: Values are presented as the number (%). * $P < 0.10$: statistical significance. ** $P < 0.05$: statistical significance.

Abbreviations: OR, odds ratio; BMI, body mass index; ASA, American society of Anesthesiologists physical status classification system; mECM, modified Elixhauser's Comorbidity Measure; VAS, visual analogue scale; GDS, Geriatric Depression Scale; FIM, functional independence measure; ALB, Albumin.

Lasso regression (Figure 2A and B) and Boruta algorithm (Figure 2C and D) identified ALB at admission < 35 g/L, ASA ≥ 3 , intraoperative blood loss ≥ 200 mL, and ALB at admission < 35 g/L, the lowest Hb level ≥ 89 g/L, ASA ≥ 3 , intraoperative blood loss ≥ 200 mL as significant risk factors for postoperative pneumonia. Multivariate analysis confirmed that preoperative hypoalbuminemia remained a strong predictor of postoperative pneumonia, with an OR of 7.96 (95% CI: 4.08–15.53, $P < 0.001$). The ASA grade ≥ 3 also emerged as a key risk factor (OR: 4.57, 95% CI: 3.12–6.70, $P < 0.001$).

Influence of Postoperative Pneumonia on Postoperative Hypoalbuminemia

Of the 1,661 patients, 512 developed postoperative hypoalbuminemia, with an incidence of 30.82%. After transforming the covariates into categorical variables by piecewise regressions, the characteristics of patients who developed postoperative hypoalbuminemia and those who did not are presented in Table 2. In univariate analysis, age ≥ 81 years, obesity, unstable fracture type, time from injury to surgery ≥ 6 days, ASA ≥ 3 , regional anesthesia, duration of operation ≥ 90 mins, VAS ≥ 5 , FIM ≥ 83 , the lowest Hb level < 89 g/L, and blood transfusion volume ≥ 4 units, and with postoperative pneumonia were significantly associated with the development of postoperative hypoalbuminemia ($P < 0.10$).

Lasso regression (Figure 3A and B) and Boruta algorithm (Figure 3C and D) identified postoperative pneumonia, age ≥ 81 years, ASA ≥ 3 , regional anesthesia, FIM ≥ 83 , blood transfusion volume ≥ 4 units, and postoperative pneumonia, age ≥ 81 years, ASA ≥ 3 as key risk factors for postoperative hypoalbuminemia. Finally, in the multivariate analysis of the association between postoperative pneumonia and postoperative hypoalbuminemia, a total of 10 influencing factors were identified (all $P < 0.05$). After adjusting for the effects of other covariates, the association between postoperative pneumonia and postoperative hypoalbuminemia remained strong (OR: 2.34, 95% CI: 1.62–3.38, $P < 0.001$). Besides, age ≥ 81 years had the greatest impact on the development of postoperative hypoalbuminemia (OR: 2.02, 95% CI: 1.62–2.53, $P < 0.001$).

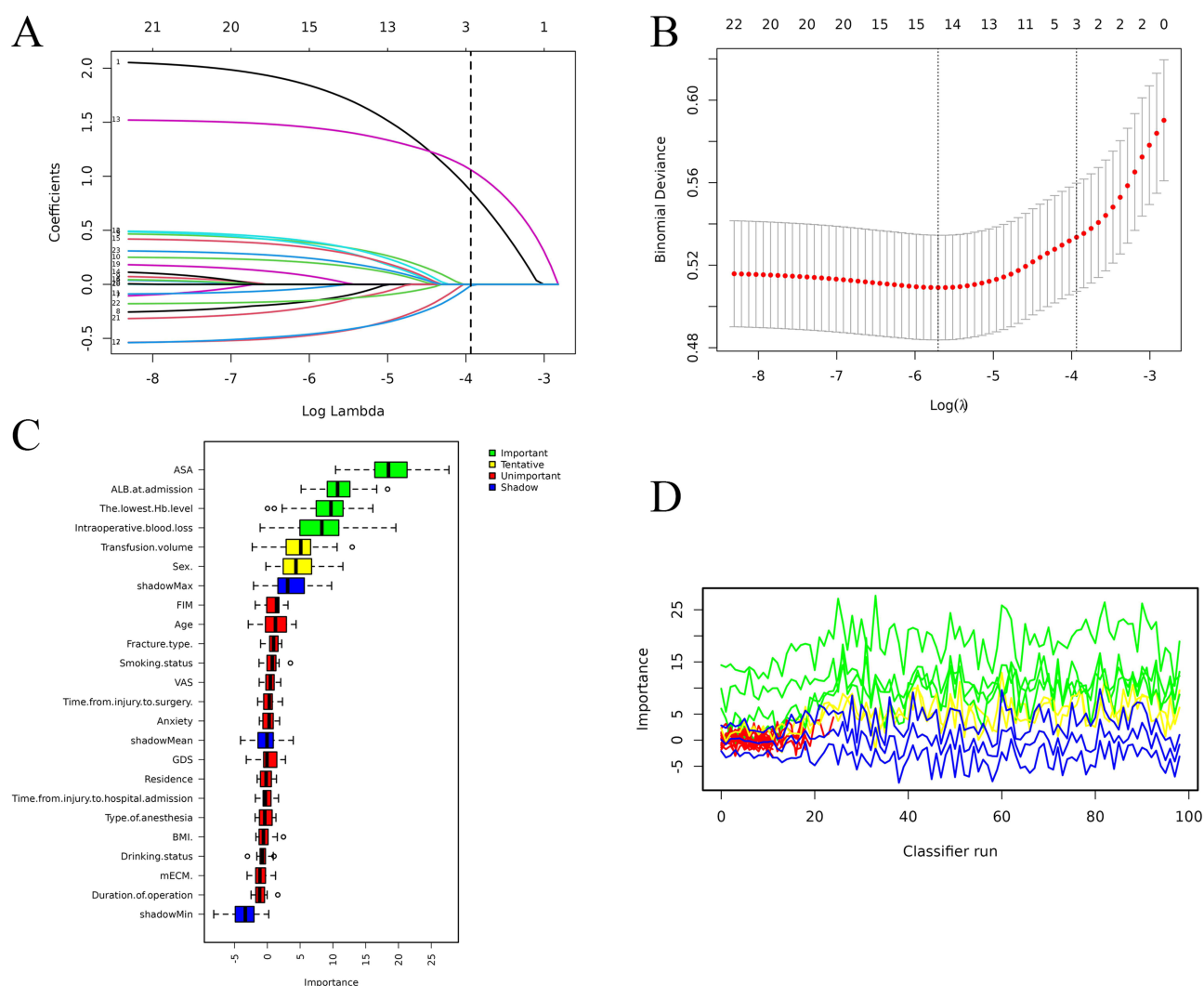


Figure 2 Selection of covariates for analysis between preoperative hypoproteinemia and postoperative pneumonia using Lasso regression and Boruta algorithm. **(A)** Lasso regression path plot; **(B)** Binomial deviance plot; **(C)** Variable importance bar plot; **(D)** Variable importance over classifier runs.

Impact of Postoperative Pneumonia on Patient Outcomes

Before propensity score matching, patients in the pneumonia group had a higher proportion of males, individuals aged ≥ 81 years, unstable fractures, and ASA ≥ 3 , and a lower proportion of patients with hemoglobin levels < 89 g/L and transfusion volumes < 4 units (all $P < 0.05$). After performing 1:3 greedy nearest-neighbor propensity score matching, all baseline differences were balanced ($P > 0.05$, Table 3). After propensity score weighting, a notable reduction in standardized mean differences (SMDs) can be observed with the SMDs of all involved covariates are smaller than 0.1, which indicates that the potential influence of confounding factors is eliminated, enabling a more reliable comparison of treatment effectiveness (Figure 4). Post-matching analysis revealed that postoperative pneumonia was associated with significantly increased risks of hypoproteinemia (OR, 2.32; 95% CI: 1.56–3.46; $P < 0.001$), acute heart failure (OR, 2.02; 95% CI: 1.15–3.52; $P = 0.013$), acute respiratory failure (OR, 7.86; 95% CI: 3.63–18.40; $P < 0.001$), stress ulcer (OR, 2.88; 95% CI: 1.04–7.97; $P = 0.038$), electrolyte disbalance (OR, 1.57; 95% CI: 1.06–2.33; $P = 0.025$), longer LOS (18.3 vs 15.3 days; $P < 0.001$), and increased mortality at 3 months to 2 years (OR: 1.83–3.43, all $P < 0.05$) (Table 4).

Discussion

This retrospective, bidirectional, cohort study provides compelling evidence that preoperative hypoalbuminemia significantly elevates the likelihood of developing pneumonia following surgery, while postoperative pneumonia itself

Table 2 The Univariate and Multivariate Analyses of All Involved Factors Associated with Hypoproteinemia

Variables	Univariate				Multivariate	
	Total (n=1661)	Hypoproteinemia (n=512)	No Hypoproteinemia (n=1149)	P Value	OR (95% CI)	P Value
Demographics						
Gender					Reference	
Male	487 (29.3%)	141 (27.5%)	346 (30.1%)			
Female	1174 (70.7%)	371 (72.5%)	803 (69.9%)	0.287	1.19 (0.93, 1.52)	0.164
Age, years					Reference	
<81	912 (54.9%)	216 (42.2%)	696 (60.6%)			
≥81	749 (45.1%)	296 (57.8%)	453 (39.4%)	<0.001*	2.02 (1.62, 2.53)	<0.001**
BMI, kg/m ²					Reference	
Normal (BMI<24)	1103 (66.4%)	355 (69.3%)	748 (65.1%)			
Overweight (24≤BMI<28)	437 (26.3%)	132 (25.8%)	305 (26.5%)	0.452	0.99 (0.77, 1.27)	0.914
Obesity (BMI≥28)	121 (7.3%)	25 (4.9%)	96 (8.4%)	0.010*	0.59 (0.36, 0.95)	0.030**
Residence						
Rural	567 (34.1%)	165 (32.2%)	402 (35.0%)			
Urban	1094 (65.2%)	347 (67.8%)	747 (65.0%)	0.273		
Smoking status						
Current	351 (21.1%)	104 (20.3%)	247 (21.5%)			
Past	95 (5.7%)	28 (5.5%)	67 (5.8%)	0.976		
Never	1215 (73.2%)	380 (74.2%)	835 (72.7%)	0.557		
Drinking status						
Current	1597 (96.2%)	498 (97.3%)	1099 (95.6%)			
Never	64 (3.8%)	14 (2.7%)	50 (4.4%)	0.117		
Surgery-related indicators						
Fracture type						
Stable (A1.1–A2.1)	867 (52.2%)	281 (54.9%)	586 (51.0%)			
Unstable (A2.2–A3.3)	794 (47.8%)	231 (45.1%)	563 (49.0%)	0.144		
Time from injury to hospital admission, hours						
<9	786 (47.3%)	241 (47.1%)	545 (47.4%)			
≥9	875 (52.7%)	271 (52.9%)	604 (52.6%)	0.891		
Time from injury to surgery, days						
<6	1029 (62.0%)	302 (59.0%)	727 (63.3%)		Reference	
≥6	632 (38.0%)	210 (41.0%)	422 (36.7%)	0.097*	1.20 (0.95, 1.50)	0.122
ASA					Reference	
<3	764 (46.0%)	189 (36.9%)	575 (50.0%)			
≥3	897 (54.0%)	323 (63.1%)	574 (50.0%)	<0.001*	1.56 (1.25, 1.96)	<0.001**
mECM					Reference	
<2	857 (51.6%)	258 (50.4%)	599 (52.1%)			
≥2	804 (48.4%)	254 (49.6%)	550 (47.9%)	0.512	1.16 (0.69, 3.83)	0.671
Type of anesthesia					Reference	
General	642 (38.7%)	164 (32.0%)	478 (41.6%)			
Regional	1019 (61.3%)	348 (68.0%)	671 (58.4%)	<0.001*	1.54 (1.22, 1.93)	<0.001**
Duration of operation, min					Reference	
<90	879 (52.9%)	258 (50.4%)	621 (54.0%)			
≥90	782 (47.1%)	254 (49.6%)	528 (46.0%)	0.068*	1.34 (1.07, 1.67)	0.010**
Intraoperative blood loss, mL						
<200	696 (41.9%)	215 (42.0%)	481 (41.9%)			
≥200	965 (58.1%)	297 (58.0%)	668 (58.1%)	0.961		
Perioperative clinical indicators						
VAS					Reference	
<5	871 (52.4%)	250 (48.8%)	621 (54.0%)			
≥5	790 (47.6%)	262 (51.2%)	528 (46.0%)	0.049*	1.30 (1.05, 1.62)	0.018**
GDS						
<4	667 (40.2%)	207 (40.4%)	460 (40.0%)			
≥4	994 (59.8%)	305 (59.6%)	689 (60.0%)	0.880		

(Continued)

Table 2 (Continued).

Variables	Univariate				Multivariate	
	Total (n=1661)	Hypoproteinemia (n=512)	No Hypoproteinemia (n=1149)	P Value	OR (95% CI)	P Value
FIM						
<83	860 (51.8%)	245 (47.9%)	615 (53.5%)	0.033*	Reference	0.012**
≥83	801 (48.2%)	267 (52.1%)	534 (46.5%)			
Anxiety						
No	1345 (81.0%)	414 (80.9%)	931 (81.0%)	0.936	Reference	0.002**
Yes	316 (19.0%)	98 (19.1%)	218 (19.0%)			
The lowest Hb level, g/dL						
≥89	832 (50.1%)	247 (48.2%)	585 (50.9%)	0.075*	Reference	0.002**
<89	829 (49.9%)	265 (51.8%)	564 (49.1%)			
Blood transfusion						
<4	605 (36.4%)	218 (42.6%)	387 (33.7%)	<0.001*	Reference	0.001**
≥4	1056 (63.6%)	294 (57.4%)	762 (66.3%)			
Postoperative pneumonia						
No	1517 (91.3%)	435 (85.0%)	1082 (94.2%)	<0.001*	Reference	<0.001**
Yes	144 (8.7%)	77 (15.0%)	67 (5.8%)			

Notes: Values are presented as the number (%). *P<0.10: statistical significance. **P<0.05: statistical significance.

Abbreviations: OR, odds ratio; BMI, body mass index; ASA, American society of Anesthesiologists physical status classification system; mECM, modified Elixhauser's Comorbidity Measure; VAS, visual analogue scale; GDS, Geriatric Depression Scale; FIM, functional independence measure; ALB, Albumin.

exacerbates hypoalbuminemia, creating a detrimental cycle that impacts patient outcomes. Specifically, postoperative pneumonia is associated with prolonged LOS, increased complications, and a heightened risk of mortality, further underscoring the critical nature of early identification and intervention.

Previous studies^{4,22,24,40} have provided evidence that preoperative hypoalbuminemia is a risk factor for postoperative pneumonia in elderly patients with hip fractures. A PSM study by Tian et al, involving 1,318 patients, showed that preoperative hypoalbuminemia increases the risk of postoperative pneumonia by 6.18 times.²² A retrospective study including 720 patients identified preoperative hypoalbuminemia as an independent risk factor for postoperative pneumonia following femoral neck fractures, further supporting our findings.²⁴ A large meta-analysis encompassing 35 studies and 337,818 patients demonstrated that hypoalbuminemia (<3.5 g/dL) significantly elevates the risk of postoperative pneumonia by 2.68 times.¹⁵ These consistent results across various studies reinforce the robustness of hypoalbuminemia as a key predictor of postoperative complications in this patient population.

Serum albumin levels serve as a vital indicator of both nutritional status and the body's inflammatory and immune responses, with a strong negative correlation to C-reactive protein (CRP) levels.⁴¹⁻⁴³ In elderly patients, surgery-induced trauma and catabolic stress exacerbate existing malnutrition, impairing immune function and making them more susceptible to postoperative infections, including pneumonia.⁴⁴ The recovery process, particularly after hip fracture surgery, necessitates significant protein resources for bone and muscle repair, and hypoalbuminemia directly hampers this process by slowing recovery and prolonging bed rest.⁴⁵ Furthermore, the lack of adequate serum albumin leads to a decrease in blood colloid osmotic pressure, promoting interstitial fluid accumulation that may result in pleural effusion and elevate the risk of hospital-acquired pneumonia.²⁰ Beyond immune function, hypoalbuminemia compromises the alveolar-capillary barrier in the lungs, enhancing permeability and facilitating pathogen invasion. Studies have shown that low albumin levels can compromise the epithelial and endothelial layers of the lungs, increasing permeability and allowing pathogens to infiltrate lung tissues more easily.^{46,47} This combined effect of weakened immune responses and impaired pulmonary defenses likely explains the heightened vulnerability of hypoalbuminemic patients to postoperative pneumonia.

Our analysis revealed that more than 60% of elderly patients presented with hypoalbuminemia at admission, highlighting the frequent occurrence of this condition within this population. The added burden of pulmonary infection, exacerbated by trauma and surgery, further intensifies the inflammatory response and nutritional depletion, contributing to the development of postoperative hypoalbuminemia.⁴⁸ This, in turn, perpetuates the cycle of hypoalbuminemia and

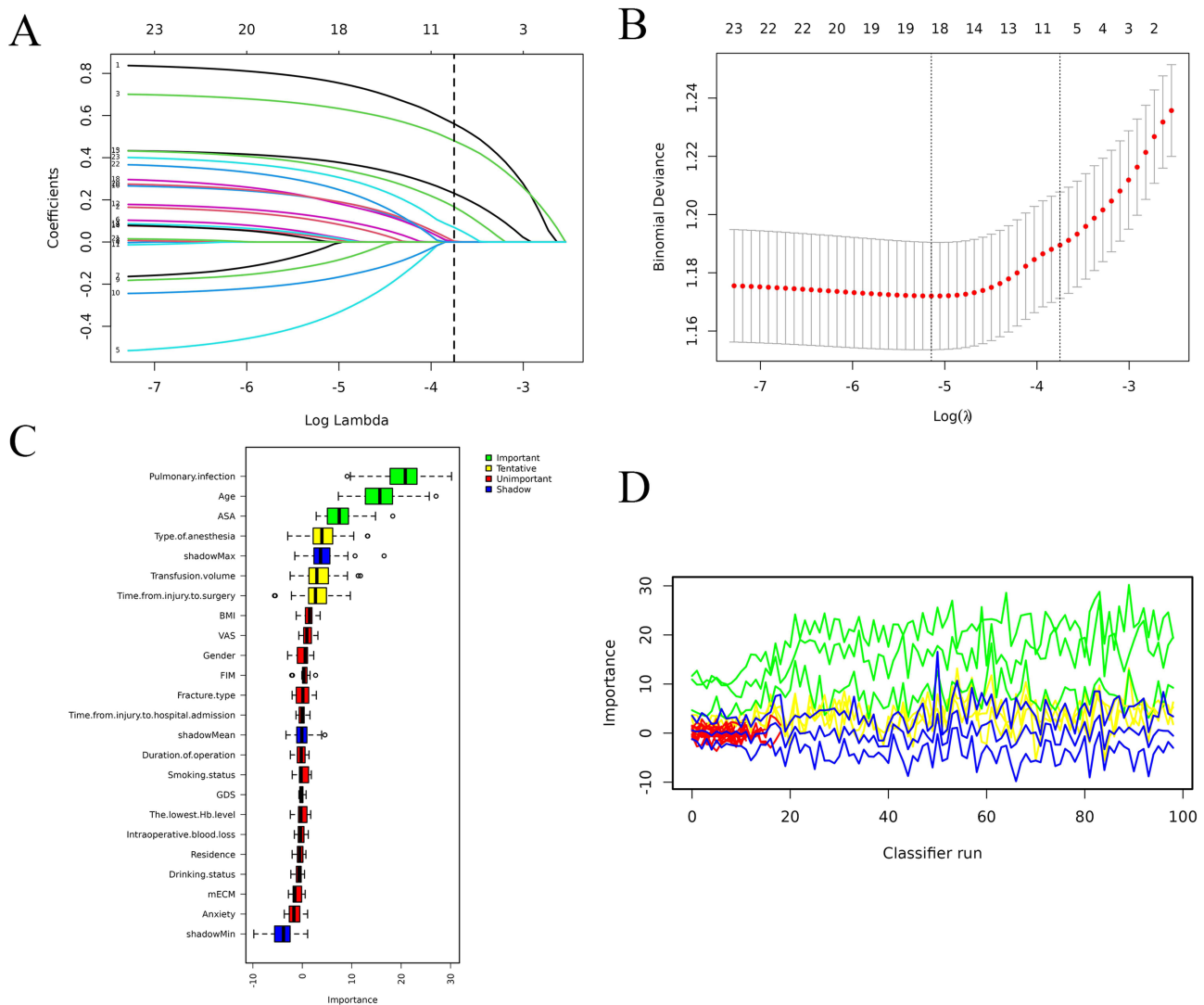


Figure 3 Selection of covariates for analysis between postoperative pneumonia and postoperative hypoproteinemia using Lasso regression and Boruta algorithm. **(A)** Lasso regression path plot; **(B)** Binomial deviance plot; **(C)** Variable importance bar plot; **(D)** Variable importance over classifier runs.

pneumonia.⁴ Postoperative pneumonia is a particularly severe complication in elderly patients undergoing hip fracture surgery, with significant implications for prognosis.^{5,49,50} A study involving 29,377 patients demonstrated that postoperative pneumonia was associated with an eight-fold increased risk of readmission, sepsis, and a three-fold increase in

Table 3 Comparisons of Characteristics and Baseline Covariates Before and After Matching Between Participants with and Without Postoperative Pneumonia

Variables	Before Matching				After Matching			
	No Pneumonia (n=1517)	Pneumonia (n=144)	SMD ^A	P Value	No Pneumonia (n=382)	Pneumonia (n=138)	SMD ^A	P Value
Demographics								
Gender				0.014*				0.745
Male	432 (28.5%)	55 (38.2%)	0.200		138 (36.1%)	52 (37.7%)	0.002	
Female	1085 (71.5%)	89 (61.8%)	-0.200		244 (63.9%)	86 (62.3%)	-0.002	

(Continued)

Table 3 (Continued).

Variables	Before Matching				After Matching			
	No Pneumonia (n=1517)	Pneumonia (n=144)	SMD ^A	P Value	No Pneumonia (n=382)	Pneumonia (n=138)	SMD ^A	P Value
Age, years				<0.001*				0.954
<81	852 (56.2%)	60 (41.7%)	-0.294		165 (43.2%)	60 (43.5%)	0.042	
≥81	665 (43.8%)	84 (58.3%)	0.294		217 (56.8%)	78 (56.5%)	-0.042	
BMI, kg/m ²				0.670				0.838
Normal (BMI<24)	1004 (66.2%)	99 (68.8%)	0.055		269 (70.4%)	94 (68.1%)	-0.055	
Overweight (24≤BMI<28)	400 (26.4%)	37 (25.7%)	-0.015		90 (23.6%)	36 (26.1%)	0.066	
Obesity (BMI≥28)	113 (7.4%)	8 (5.6%)	-0.083		23 (6.0%)	8 (5.8%)	-0.016	
Residence				0.092				0.787
Rural	527 (34.7%)	40 (27.8%)	-0.155		107 (28.0%)	37 (26.8%)	-0.019	
Urban	990 (65.3%)	104 (72.2%)	0.155		275 (72.0%)	101 (73.2%)	0.019	
Smoking status				0.748				0.808
Current	317 (20.9%)	34 (23.6%)	0.064		101 (26.4%)	33 (23.9%)	-0.085	
Past	87 (5.7%)	8 (5.6%)	-0.008		19 (5.0%)	8 (5.8%)	0.026	
Never	1113 (73.4%)	102 (70.8%)	-0.056		262 (68.6%)	97 (70.3%)	0.066	
Drinking status				0.838				0.682
Current	1459 (96.2%)	138 (95.8%)	-0.017		362 (94.8%)	132 (95.7%)	0.030	
Never	58 (3.8%)	6 (4.2%)	0.017		20 (5.2%)	6 (4.3%)	-0.030	
Surgery-related indicators								
Fracture type				0.034*				0.492
Stable (A1.1–A2.1)	804 (53.0%)	63 (43.8%)	-0.186		156 (40.8%)	61 (44.2%)	0.088	
Unstable (A2.2–A3.3)	713 (47.0%)	81 (56.2%)	0.186		226 (59.2%)	77 (55.8%)	-0.088	
Time from injury to hospital admission, hours				0.500				0.770
<9	714 (47.1%)	72 (50.0%)	0.059		191 (50.0%)	67 (48.6%)	-0.010	
≥9	803 (52.9%)	72 (50.0%)	-0.059		191 (50.0%)	71 (51.4%)	0.010	
Time from injury to surgery, days				0.002*				0.475
<6	957 (63.1%)	72 (50.0%)	-0.262		183 (47.9%)	71 (51.4%)	0.082	
≥6	560 (36.9%)	72 (50.0%)	0.262		199 (52.1%)	67 (48.6%)	-0.082	
ASA				<0.001*				0.282
<3	1493 (98.4%)	122 (84.7%)	-0.381		359 (94.2%)	126 (87.7%)	-0.081	
≥3	24 (1.6%)	22 (15.3%)	0.381		23 (5.8%)	12 (12.3%)	0.081	
mECM				0.902				0.830
<2	782 (51.5%)	75 (52.1%)	0.011		198 (51.8%)	73 (52.9%)	0.036	
≥2	735 (48.5%)	69 (47.9%)	-0.011		184 (48.2%)	65 (47.1%)	-0.036	
Type of anesthesia				0.056				0.583
General	597 (39.4%)	45 (31.2%)	-0.175		126 (33.0%)	42 (30.4%)	-0.016	
Regional	920 (60.6%)	99 (68.8%)	0.175		256 (67.0%)	96 (69.6%)	0.016	
Duration of operation, min				0.625				0.452
<90	800 (52.7%)	79 (54.9%)	0.043		219 (57.3%)	74 (53.6%)	-0.075	
≥90	717 (47.3%)	65 (45.1%)	-0.043		163 (42.7%)	64 (46.4%)	0.075	
Intraoperative blood loss, mL				0.263				0.893
<200	642 (42.3%)	54 (37.5%)	0.100		235 (61.5%)	84 (60.9%)	-0.022	
≥200	875 (57.7%)	90 (62.5%)	-0.100		147 (38.5%)	54 (39.1%)	0.022	
Perioperative clinical indicators								
VAS				0.795				0.714
<5	794 (52.3%)	77 (53.5%)	0.023		209 (54.7%)	73 (52.9%)	-0.034	
≥5	723 (47.7%)	67 (46.5%)	-0.023		173 (45.3%)	65 (47.1%)	0.034	
GDS				0.458				0.675
<4	605 (39.9%)	62 (43.1%)	0.064		174 (45.5%)	60 (43.5%)	-0.071	
≥4	912 (60.1%)	82 (56.9%)	-0.064		208 (54.5%)	78 (56.5%)	0.071	
FIM				0.535				>0.999
<83	789 (52.0%)	71 (49.3%)	-0.054		191 (50.0%)	69 (50.0%)	-0.010	
≥83	728 (48.0%)	73 (50.7%)	0.054		191 (50.0%)	69 (50.0%)	0.010	

(Continued)

Table 3 (Continued).

Variables	Before Matching				After Matching			
	No Pneumonia (n=1517)	Pneumonia (n=144)	SMD ^A	P Value	No Pneumonia (n=382)	Pneumonia (n=138)	SMD ^A	P Value
Anxiety				0.231				0.949
No	1223 (80.6%)	122 (84.7%)	0.114		323 (84.6%)	117 (84.8%)	0.000	
Yes	294 (19.4%)	22 (15.3%)	-0.114		59 (15.4%)	21 (15.2%)	0.000	
The lowest Hb level, g/dL				0.025*				0.608
<89	770 (50.8%)	59 (41.0%)	-0.199		173 (45.3%)	59 (42.8%)	-0.007	
≥89	747 (49.2%)	85 (59.0%)	0.199		209 (54.7%)	79 (57.2%)	0.007	
Blood transfusion				<0.001*				0.502
<4	534 (35.2%)	71 (49.3%)	0.282		170 (44.5%)	66 (47.8%)	0.002	
≥4	983 (64.8%)	73 (50.7%)	-0.282		212 (55.5%)	72 (52.2%)	-0.002	

Notes: Values are presented as the number (%). *P<0.15: statistical significance; ^AStandardized Mean Difference.

Abbreviations: OR, odds ratio; BMI, body mass index; American society of Anesthesiologists physical status classification system; mECM, modified Elixhauser's Comorbidity Measure; VAS, visual analogue scale; GDS, Geriatric Depression Scale; FIM, functional independence measure; ALB, Albumin.

mortality.⁸ Another study conducted in China found that pneumonia led to a 2.25-fold increase in 30-day postoperative mortality.⁵¹ These findings, along with our own, underscore the substantial impact of postoperative pneumonia on patient outcomes and emphasize the critical need for proactive prevention strategies.

The bidirectional relationship between preoperative hypoalbuminemia and post-operative pneumonia can be conceptualized as a “vortex” that worsens the patient’s clinical outcomes. Fortunately, clinicians are in a position to intervene. Previous studies have demonstrated that preoperative nutritional enhancement, including calorie and protein supplementation, can significantly improve immune function and reduce complications.^{52,53} A randomized controlled trial showed that preoperative nutritional supplementation significantly decreased the incidence of complications and mortality within 120 days post-surgery in elderly hip fracture patients.⁵⁴ Similarly, a meta-analysis of 26,281 participants confirmed that preventing malnutrition and

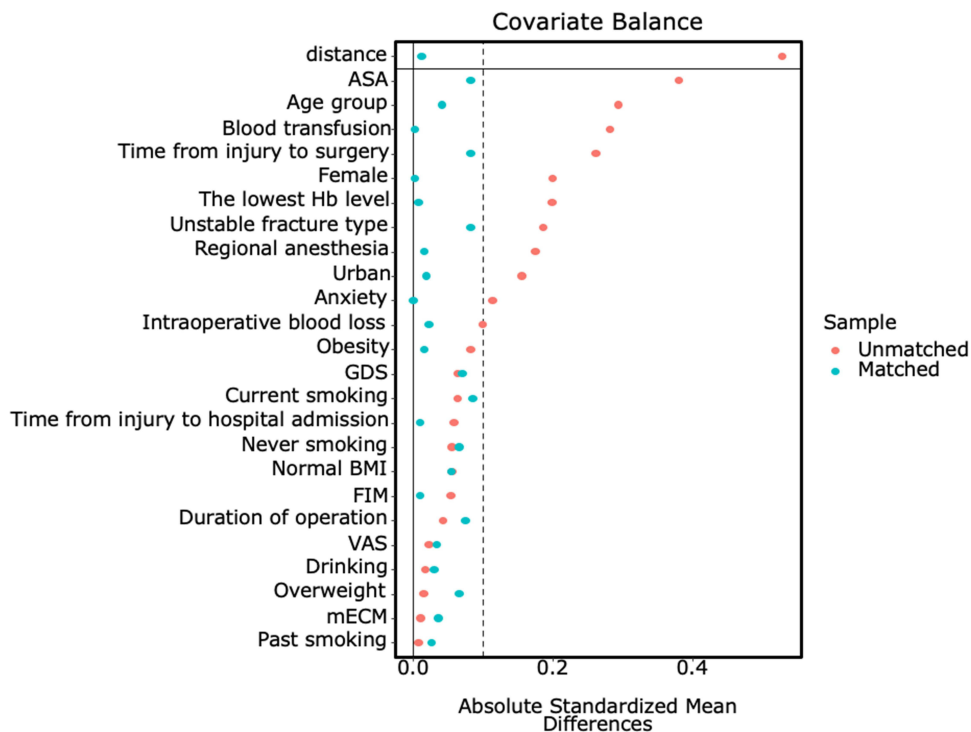


Figure 4 Love plot showed the balance of covariates between the two groups of patients with and without postoperative pneumonia before and after PSM.

Table 4 Comparisons of Complications, Mortality Rates, and LOS Before and After Matching Between Participants with and Without Postoperative Pneumonia

Variables	Before Matching				After Matching			
	No Pneumonia (n=1517)	Pneumonia (n=144)	OR (95% CI)	P Value	No Pneumonia (n=382)	Pneumonia (n=138)	OR (95% CI)	P Value
Complications								
Sudden death				0.063				0.119
No	1509 (99.47%)	141 (97.92%)	Reference		380 (99.48%)	135 (97.83%)	Reference	
Yes	8 (0.53%)	3 (2.08%)	4.01 (0.87, 14.00)		2 (0.52%)	3 (2.17%)	4.22 (0.70, 25.54)	
Acute heart failure				<0.001*				0.013*
No	1400 (92.29%)	115 (79.86%)	Reference		346 (90.58%)	114 (82.61%)	Reference	
Yes	117 (7.71%)	29 (20.14%)	3.03 (1.90, 4.67)		36 (9.42%)	24 (17.39%)	2.02 (1.15, 3.52)	
Acute respiratory failure				<0.001*				<0.001*
No	1496 (98.62%)	121 (84.03%)	Reference		373 (97.64%)	116 (84.06%)	Reference	
Yes	21 (1.38%)	23 (15.97%)	13.50 (7.28, 25.30)		9 (2.36%)	22 (15.94%)	7.86 (3.63, 18.40)	
Myocardial infarction				0.120				0.173
No	1511 (99.60%)	142 (98.61%)	Reference		381 (99.74%)	136 (98.55%)	Reference	
Yes	6 (0.40%)	2 (1.39%)	3.55 (0.52, 15.6)		1 (0.26%)	2 (1.45%)	5.60 (0.53, 12.1)	
Cerebral infarction				0.548				0.960
No	1468 (96.77%)	138 (95.83%)	Reference		365 (95.55%)	132 (95.65%)	Reference	
Yes	49 (3.23%)	6 (4.17%)	1.30 (0.49, 2.87)		17 (4.45%)	6 (4.35%)	0.98 (0.35, 2.40)	
Delirium				0.873				0.782
No	1386 (91.36%)	131 (90.07%)	Reference		349 (91.36%)	125 (90.58%)	Reference	
Yes	131 (8.64%)	13 (9.93%)	1.05 (0.55, 1.84)		33 (8.64%)	13 (9.42%)	1.10 (0.54, 2.11)	
Stress ulcer				<0.001*				0.038*
No	1492 (98.35%)	135 (93.75%)	Reference		374 (97.91%)	130 (94.20%)	Reference	
Yes	25 (1.65%)	9 (6.25%)	3.98 (1.73, 8.40)		8 (2.09%)	8 (5.80%)	2.88 (1.04, 7.97)	
Arrhythmia				0.005*				0.933
No	1259 (82.99%)	106 (73.61%)	Reference		292 (76.44%)	105 (76.09%)	Reference	
Yes	258 (17.01%)	38 (26.39%)	1.75 (1.17, 2.57)		90 (23.56%)	33 (23.91%)	1.02 (0.64, 1.60)	
Electrolyte disbalance				0.044*				0.025*
No	808 (53.26%)	64 (44.44%)	Reference		206 (53.93%)	59 (42.75%)	Reference	
Yes	709 (46.74%)	80 (55.56%)	1.42 (1.01, 2.01)		176 (46.07%)	79 (57.25%)	1.57 (1.06, 2.33)	
Stress hyperglycemia				0.915				0.471
No	1121 (73.90%)	107 (74.31%)	Reference		294 (76.96%)	102 (73.91%)	Reference	
Yes	396 (26.10%)	37 (25.69%)	0.98 (0.65, 1.43)		88 (23.04%)	36 (26.09%)	1.18 (0.75, 1.84)	
DVT				0.427				0.481
No	895 (58.90%)	80 (55.56%)	Reference		227 (59.42%)	77 (55.80%)	Reference	
Yes	622 (41.10%)	64 (44.44%)	1.15 (0.81, 1.62)		155 (40.58%)	61 (44.20%)	1.16 (0.78, 1.72)	
Hypoproteinemia				<0.001*				<0.001*
No	1082 (71.32%)	67 (46.53%)	Reference		260 (68.06%)	66 (47.83%)	Reference	
Yes	435 (28.68%)	77 (53.47%)	2.86 (2.02, 4.04)		122 (31.94%)	72 (52.17%)	2.32 (1.56, 3.46)	
Mortality								
Overall mortality				<0.001*				0.002*
No	1149 (75.74%)	90 (62.50%)	Reference		289 (75.65%)	85 (61.59%)	Reference	
Yes	368 (24.26%)	54 (37.50%)	1.87 (1.30, 2.67)		93 (24.35%)	53 (38.41%)	1.94 (1.28, 2.93)	
One-month mortality				<0.001*				0.062
No	1507 (99.34%)	138 (95.83%)	Reference		378 (98.95%)	133 (96.38%)	Reference	
Yes	10 (0.66%)	6 (4.17%)	6.55 (2.20, 17.90)		4 (1.05%)	5 (3.62%)	3.55 (0.93, 14.50)	
Three-month mortality				0.004*				0.045*
No	1496 (98.62%)	137 (95.14%)	Reference		377 (98.69%)	132 (95.65%)	Reference	
Yes	21 (1.38%)	7 (4.86%)	3.64 (1.41, 8.32)		5 (1.31%)	6 (4.35%)	3.43 (1.02, 12.1)	
Six-month mortality				<0.001*				0.007*
No	1477 (97.36%)	131 (90.97%)	Reference		371 (97.12%)	126 (91.30%)	Reference	
Yes	40 (2.64%)	13 (9.03%)	3.66 (1.84, 6.85)		11 (2.88%)	12 (8.70%)	3.21 (1.38, 7.58)	
One-year mortality				<0.001*				0.014*
No	1422 (93.74%)	124 (86.11%)	Reference		356 (93.19%)	119 (86.23%)	Reference	
Yes	95 (6.26%)	20 (13.89%)	2.41 (1.41, 3.97)		26 (6.81%)	19 (13.77%)	2.19 (1.15, 4.08)	

(Continued)

Table 4 (Continued).

Variables	Before Matching				After Matching			
	No Pneumonia (n=1517)	Pneumonia (n=144)	OR (95% CI)	P Value	No Pneumonia (n=382)	Pneumonia (n=138)	OR (95% CI)	P Value
Two-year mortality				<0.001*				0.014*
No	1316 (86.75%)	110 (76.39%)	Reference		326 (85.34%)	105 (76.09%)	Reference	
Yes	201 (13.25%)	34 (23.61%)	2.02 (1.32, 3.03)		56 (14.66%)	33 (23.91%)	1.83 (1.12, 2.95)	
LOS	14.4 (6.3)	18.7 (10.8)	-	<0.001*	15.3 (6.5)	18.3 (10.5)	-	<0.001*

Notes: Values are presented as the number (%) or mean (SD). * $P < 0.15$: statistical significance; [^]Standardized Mean Difference.

Abbreviations: OR, odds ratio; LOS, length of hospital stay; SD, standard deviation.

administering preoperative nutritional supplements can improve recovery and mitigate complications following hip fracture surgery.⁵⁵ Given the adverse cycle initiated by preoperative hypoalbuminemia, we recommend that early nutritional assessment and intervention be integrated into preoperative care protocols for elderly hip fracture patients. For particularly frail individuals, nutritional optimization can be achieved through dietary modifications and intravenous albumin supplementation, both of which have been shown to improve postoperative outcomes.

To the best of our knowledge, this is the first study to elucidate the bidirectional relationship between hypoalbuminemia and postoperative pneumonia in elderly patients with hip fractures through bidirectional and prognostic analyses. By employing multiple statistical algorithms and robust multivariate analysis, we have minimized confounding factors and provided a clear insight into the key variables that influence these outcomes. The PSM analysis of prognosis also served as a sensitivity analysis for postoperative pneumonia and postoperative hypoalbuminemia, further enhanced the reliability of our findings by balancing potential confounders between groups. Additionally, the real-world, multicenter, prospective design of the study strengthens its external validity and generalizability. Despite the strengths, this study does have limitations. First, our primary outcome of postoperative pneumonia was limited to events that occurred during hospitalization, which may not fully capture the long-term incidence of pneumonia following discharge. Future studies should explore the incidence of postoperative pneumonia in the post-discharge period to provide a more comprehensive understanding. Second, while our study focused on mortality and major postoperative complications, it did not fully encompass the multifaceted nature of recovery, including functional status and quality of life. Third, the generalizability of our findings is limited to patients undergoing surgical intervention for hip fractures, and the applicability of these results to non-surgical patients with hip fractures, who represent a significant portion of the population, remains to be determined. Fourth, factors such as cognitive impairment, pre-fracture mobility, and bone mineral density, which are critical in the elderly, were not included in this analysis. These variables could provide additional insights into the patient outcomes and should be considered in future studies. Lastly, while our follow-up period of two years is adequate for assessing short-term and medium-term outcomes, a longer follow-up period would be valuable for evaluating the long-term impact of perioperative interventions on survival and functional recovery.

Conclusions

In this prospective multicenter study, our findings reveal a bidirectional relationship that preoperative hypoalbuminemia is a significant independent risk factor for the development of postoperative pneumonia in elderly patients with hip fractures while postoperative pneumonia itself exacerbates hypoalbuminemia, creating a detrimental cycle that negatively impacts patient outcomes. Given the substantial burden of both hypoalbuminemia and pneumonia on patient health and healthcare systems, our study advocates for early detection, routine screen, and management of hypoalbuminemia, emphasizing the critical role of nutritional optimization in preventing this cycle and ultimately improving the prognosis.

Abbreviations

LOS, Length of hospital stays; ITHF, Intertrochanteric hip fractures; COPD, Chronic obstructive pulmonary disease; CDC, Centers for Disease Control and Prevention; BMI, Body mass index; ASA, American society of Anesthesiologists physical status classification system; mECM, modified Elixhauser comorbidity method; VAS, Visual analogue scale; GDS, Geriatric depression scale; FIM, Functional independence measures; DVT, Deep vein thrombosis; VIF, Variance

inflation factor; OR, Odds ratio; CI, Confidence interval; PSM, Propensity score matching; ALB, Albumin; SMD, Standardized mean differences; SD, Standard deviation.

Data Sharing Statement

All the data supporting the study findings are within the manuscript. Additional detailed information and raw data are available from the corresponding author (Junfei Guo) on reasonable request.

Institutional Review Board Statement

This study protocol was reviewed and approved by ethics committee of Honghui Hospital, Xi'an Jiaotong University (202312020) in compliance with the principles of the 1964 Declaration of Helsinki and its later amendments. All data were anonymized before the analysis to safeguard patient privacy.

Informed Consent Statement

Written informed consent was obtained from all participants for publication.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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