


# Multivariate Analysis of Shock Risk and Model Development and Validation in Elderly Patients Following Hip Fracture Surgery in the Intensive Care Unit (ICU): A Retrospective Cohort Study

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**Purpose:** This study aimed to identify risk factors for postoperative shock and develop and validate a predictive model based on preoperative variables in elderly patients undergoing hip fracture surgery.

**Patients and Methods:** We conducted a retrospective cohort study of elderly patients (>65 years) admitted to the ICU after hip fracture surgery in a single center between 2020 and 2024. Patients were stratified into shock (defined as a Shock Index  $\geq 1.0$ ) and non-shock groups. Data on demographics, comorbidities, and preoperative laboratory parameters were collected. Patients from 2020–2022 constituted the development cohort, which was randomly divided into training and internal validation sets at a ratio of 7:3, while patients from 2023–2024 formed the external validation cohort. Least absolute shrinkage and selection operator (LASSO) regression was used to identify candidate predictors, followed by multivariable logistic regression to construct the predictive model. Model performance was evaluated using the area under the receiver operating characteristic curve (AUC), and decision curve analysis (DCA).

**Results:** A total of 740 patients were included, with 317 in the training cohort, 136 in the internal validation cohort, and 287 in the external validation cohort. LASSO regression identified four key predictors: body mass index (BMI), Charlson Comorbidity Index (CCI), hemoglobin (HGB), and albumin (ALB). These variables were incorporated into a nomogram. The nomogram demonstrated good discrimination and clinical utility, with AUC values of approximately 0.834 in the internal validation cohort and 0.801 in the external validation cohort. Decision curve analysis further supported its potential clinical benefit.

**Conclusion:** We developed and validated a practical nomogram that effectively predicts the risk of postoperative shock in elderly hip fracture patients using four preoperative parameters. This model may assist clinicians in early risk stratification and perioperative monitoring of elderly hip fracture patients.

**Keywords:** Hip fracture, postoperative shock, shock index, nomogram analysis, internal and external validation

## Introduction

Hip fractures (HF) are common and serious injuries in the elderly, associated with high incidence and mortality.<sup>1,2</sup> With global aging, the number of HF cases is projected to increase from 1.66 million annually to nearly 6 million by 2050, placing further strain on patients and healthcare systems.<sup>3</sup> Although timely surgery improves outcomes, elderly patients remain at high risk for postoperative complications, and frequently experience postoperative hemodynamic instability, which is attributable to factors such as multiple pre-existing comorbidities, diminished cardiovascular reserve, preoperative fasting, and intraoperative blood loss.<sup>4</sup> Therefore, high-risk patients frequently require ICU monitoring and management.<sup>5</sup>

Several predictive models exist for venous thromboembolism, delirium, and mortality in geriatric HF.<sup>6–8</sup> However, there is currently no dedicated predictive model for postoperative shock in this population. The shock index (SI), defined as the ratio of heart rate to systolic blood pressure, has been widely used as a simple and reliable marker of hemodynamic

instability. Previous studies have demonstrated that increased SI values are associated with adverse clinical outcomes, including higher in-hospital mortality and worse short-term prognosis in critically ill and emergency patients.<sup>9,10</sup> Furthermore, perioperative hemodynamic instability has been linked to increased postoperative complications and mortality, among patients with conditions such as cardiogenic shock, sepsis, and COVID-19.<sup>11,12</sup>

This study aims to analyze risk factors for postoperative shock in elderly patients with HF, and to develop a predictive model for postoperative shock status. The proposed model may help facilitate early risk identification and improve perioperative management in this population.

## Materials and Methods

### Study Description

A retrospective study was conducted in two cohorts and patients with HF admitted between January 2020 and December 2022 were recruited as the development cohort. From this cohort, 70% of the patients were randomly selected as the training set, with the remaining 30% serving as the test set (internal validation set). Subsequently, patients admitted between January 2023 and December 2024 were designated as the external validation cohort. This study was approved by the ethical committee of Beijing Jishuitan Hospital, Capital Medical University (K2023-157-00). This study was reported in accordance with the TRIPOD (Transparent Reporting of a multivariable prediction model for Individual Prognosis Or Diagnosis) guidelines.<sup>13</sup>

### Participants

We collected data from elderly patients who underwent hip fracture surgery in our institution from January 2020 to December 2024. The inclusion criteria were: (1) age > 65 years; (2) diagnosis of unilateral hip fracture (femoral neck, intertrochanteric, or subtrochanteric fracture); (3) underwent spinal anesthesia; (4) admission to the ICU postoperatively. The exclusion criteria were as follows: (1) presence of concomitant multiple fractures or injuries; (2) acute/ chronic atrial fibrillation, presence of ventricular arrhythmia, use of definitive or transitory pacemaker; (3) death within 24 hours postoperatively; (4) preoperative or intraoperative shock.

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Ethics Committee of our institution. Written informed consent was obtained from all enrolled participants.

### Data Collection

Demographic, laboratory, and other perioperative variables were collected from electronic medical record system. Demographic data included age, sex, body mass index (BMI), fracture type, time to surgery, American Society of Anesthesiologists (ASA) physical status classification, Acute Physiology and Chronic Health Evaluation II (APACHE II), and Charlson Comorbidity Index (CCI) score. Preoperative laboratory parameters were recorded from the first test after admission, including white blood count (WBC), hemoglobin (HGB), platelet count (PLT), albumin (ALB), serum creatinine levels, and blood electrolytes. Ejection fraction (EF) and time to surgery were also recorded. Perioperative variables included surgical approach, duration of surgery, estimated blood loss (EBL).

As for vital signs, heart rate (HR) and systolic blood pressure (SBP) were recorded hourly in the ICU. In this study, postoperative shock was operationally defined as a SI  $\geq$  1.0, which reflects significant hemodynamic instability. The maximum SI value obtained postoperatively was used to stratify patients into the shock group (SI  $\geq$  1.0) and the non-shock group (SI < 1.0).

### Sample Size

The current study intends to predict the risk factors for postoperative shock using preoperative variables with the help of regression analysis. For multivariable analyses such as multiple regression, logistic regression, and factor analysis, the required sample size is commonly estimated to be 5–20 times the number of candidate variables.<sup>14</sup> Here, we approximately included 15–20 variables. Based on this principle, a training cohort of approximately 300–400 patients was considered adequate for model development. Similarly, sample size in the validation cohorts can also be estimated based

on this principle. The overall event rate (postoperative shock) was 25.3% in the study population. The number of outcome events in the dataset exceeded the commonly recommended threshold of 10 events per predictor variable.

## Statistical Analysis

SPSS (v26.0) was used for statistical analysis. Continuous variables following a normal distribution are reported as mean  $\pm$  standard deviation (SD) and compared by the independent *t*-test between the two groups; otherwise, they are expressed as median (IQR) and compared by the Mann–Whitney *U*-test. Categorical data, presented as n (%), were analyzed using the Chi-square or Fisher's exact test. Patients with incomplete data for the candidate predictor variables were excluded prior to analysis; therefore, no imputation methods were required.

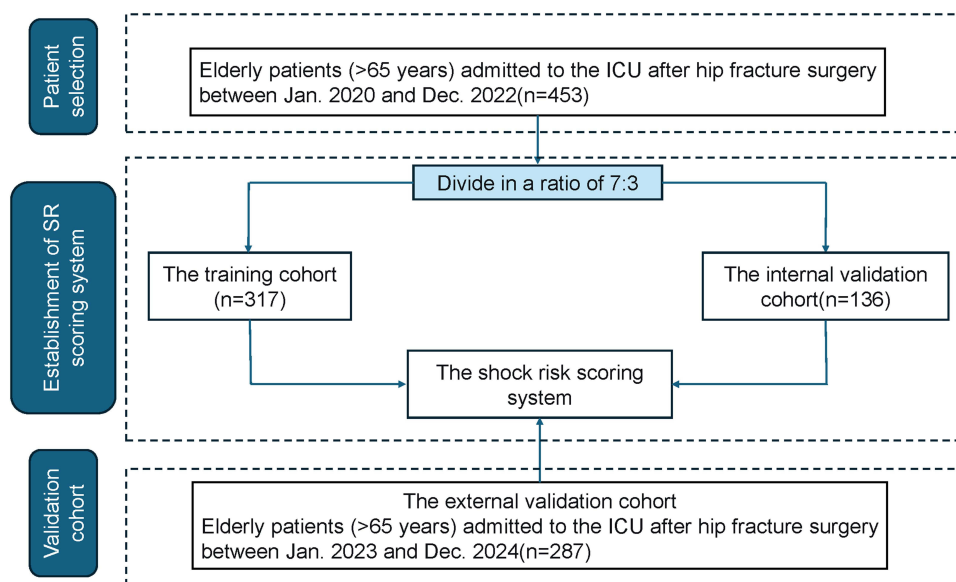
To address potential multicollinearity and to avoid relying solely on univariate screening for variable selection, least absolute shrinkage and selection operator (LASSO) regression was performed to identify the most relevant preoperative predictors of postoperative shock. All candidate preoperative variables were entered into the LASSO model. The optimal penalty parameter ( $\lambda$ ) was determined using ten-fold cross-validation. Variables with non-zero coefficients in the LASSO model were subsequently entered into the multivariate logistic regression model to identify independent predictors and to construct the nomogram. The model was examined using the receiver operating characteristic (ROC) area under the curve (AUC), and decision curve analysis (DCA).  $P < 0.05$  was considered statistically significant.

## Results

### Patient Characteristics and Clinical Information

A total of 740 patients were enrolled. The patients were divided into a training group (n=317), an internal validation group (n=136), and an external validation group (n=287). The flow chart of the three cohorts is shown in Figure 1. The baseline characteristics of the development cohort (training and internal validation) and external validation cohort were summarized in Table 1. No significant difference ( $p = 0.66$ ) in the shock incidence was found between the two cohorts. Compared with the external validation cohort, the development cohort had significantly lower serum creatinine and phosphate levels, a higher D-dimer level, and a longer ICU length of stay (Table 1).

In the development cohort, 70% of the patients (n = 317) were divided into the training set, and the other 30% (n = 136) were selected as the internal validation set. The patient characteristics in the training set are shown in Table 2. Compared with the non-shock group, the shock group had a higher BMI, a higher CCI, lower HGB and ALB, higher



**Figure 1** Flow chart of patient grouping.  
**Abbreviation:** SR, shock risk.

**Table 1** Patient Characteristics and Preoperative Parameters of the Cohort 1 and Cohort 2

Variable	Cohort 1 (n= 453)	Cohort 2 (n= 287)	P value
Shock (n)			0.66
No	336	217	
Yes	117	70	
Age (years)	83.4 ± 7.6	83.2 ± 6.8	0.71
Sex (n)			0.14
Male	305	208	
Female	148	79	
BMI (Kg/m <sup>2</sup> )	23.0 ± 3.9	22.7 ± 4.1	0.36
Fracture type (n)			0.86
Intertrochanteric	230	145	
Subtrochanteric	7	6	
Femoral neck	216	136	
CCI	3.0 ± 2.1	2.9 ± 1.9	0.41
APACHE II	15.3 ± 4.0	15.3 ± 4.1	0.96
ASA grade (n)			0.86
1	0	0	
2	121	79	
3	294	187	
4	38	21	
Time to surgery(days)	7 (4, 14)	7 (4, 13)	0.73
Surgical approach (n)			0.96
THA	14	9	
Hemiarthroplasty	171	111	
Internal fixation	268	167	
Length of surgery (hours)	1.0 (1.0, 1.3)	1.0 (1.0, 1.3)	0.77
EBL (mL)	200 (150, 200)	200 (150, 200)	0.66
EF (%)	64 (61, 67)	63 (61, 66)	0.26
WBC (×10 <sup>3</sup> /μL)	9.0 ± 2.8	9.5 ± 3.8	0.083
HGB (g/L)	103.0 ± 18.6	105.4 ± 18.4	0.088
PLT (×10 <sup>3</sup> /μL)	208.2 ± 79.7	208.0 ± 107.0	0.98
ALB (g/L)	35.8 ± 4.8	35.1 ± 5.1	0.07
CREA (μmol/L)	71 (57, 92)	88 (62, 123)	<0.01*

(Continued)

**Table 1** (Continued).

Variable	Cohort 1 (n= 453)	Cohort 2 (n= 287)	P value
Blood phosphates (mmol/L)	0.95 ± 0.25	1.20 ± 0.39	<0.001*
BNP (pg/mL)	946 (354, 2507)	1176 (400, 2595)	0.31
hsTnl (ng/L)	13.8 (7.8, 25.1)	13.0 (7.2, 22.9)	0.35
D-dimer (mg/L FEU)	5.55 (2.83, 14.53)	4.75 (2.32, 13.10)	0.04*
Duration of ICU (hours)	43 (21, 69)	35 (24, 45)	<0.01*
Hospital length of stay (days)	6 (5, 8)	6 (4, 8)	0.48

Note: \* p < 0.05.

**Abbreviations:** BMI, body mass index; CCI, Charlson Comorbidity Index; APACHE II, Acute Physiology and Chronic Health Evaluation II; ASA, American Society of Anesthesiologists Physical Status Classification; THA, total hip arthroplasty; EBL, estimated blood loss; EF, ejection fraction; WBC, white blood cell; HGB, hemoglobin; PLT, platelet; ALB, albumin; CREA, creatinine.

**Table 2** The Univariate Analysis in the Training Set

Variable	Non-Shock Group (n=236)	Shock Group (n=81)	P value
Age (years)	83.1 ± 7.2	82.9 ± 7.4	0.725
Sex (n)			0.286
Male	73	28	
Female	163	53	
BMI (Kg/m <sup>2</sup> )	22.8 ± 3.6	24.7 ± 3.4	<0.001*
Fracture type (n)			
Intertrochanteric	109	51	0.08
Subtrochanteric	5	1	
Femoral neck	122	29	
CCI	2.6 ± 1.7	4.0 ± 2.4	<0.001*
APACHE II	15.1 ± 3.9	15.5 ± 4.2	0.422
ASA grade (n)			0.31
1	0	0	
2	68	17	
3	151	56	
4	17	8	
Time to surgery(days)	7 (4, 15)	7 (4, 12)	0.807
Surgical approach (n)			0.286
THA	9	1	

(Continued)

**Table 2** (Continued).

Variable	Non-Shock Group (n=236)	Shock Group (n=81)	P value
Hemiarthroplasty	91	26	
Internal fixation	136	54	
Length of surgery (hours)	1.0 (1.0, 1.5)	1.0 (1.0, 1.2)	0.273
EBL (mL)	200 (150, 200)	200 (100, 200)	0.85
EF (%)	64 (61, 67)	64 (61, 67)	0.853
WBC ( $\times 10^3/\mu\text{L}$ )	9.2 $\pm$ 2.9	8.8 $\pm$ 3.0	0.302
HGB (g/L)	101.3 $\pm$ 13.7	94.3 $\pm$ 9.1	<0.001*
PLT ( $\times 10^3/\mu\text{L}$ )	210.7 $\pm$ 81.3	209.2 $\pm$ 84.8	0.89
ALB (g/L)	36.9 $\pm$ 4.7	32.9 $\pm$ 4.4	<0.001*
CREA ( $\mu\text{mol/L}$ )	69 (54, 90)	83 (66, 113)	0.03*
Blood phosphates (mmol/L)	0.9 $\pm$ 0.3	1.0 $\pm$ 0.3	0.07
BNP (pg/mL)	838 (300, 2279)	1209 (529, 2593)	0.236
hsTnl (ng/L)	13.8 (7.2, 25.0)	13.4 (8.3, 20.7)	0.924
D-dimer (mg/L FEU)	6.04 (2.91, 15.28)	4.86 (2.89, 12.26)	0.169
Duration of ICU (hours)	39 (19, 52)	42 (37, 78)	<0.01*
Hospital length of stay (days)	6 (5, 8)	6 (5, 8)	0.512

**Note:** \*  $p < 0.05$ .

**Abbreviations:** BMI, body mass index; CCI, Charlson Comorbidity Index; APACHE II, Acute Physiology and Chronic Health Evaluation II; ASA, American Society of Anesthesiologists Physical Status Classification; THA, total hip arthroplasty; EBL, estimated blood loss; EF, ejection fraction; WBC, white blood cell; HGB, hemoglobin; PLT, platelet; ALB, albumin; CREA, creatinine.

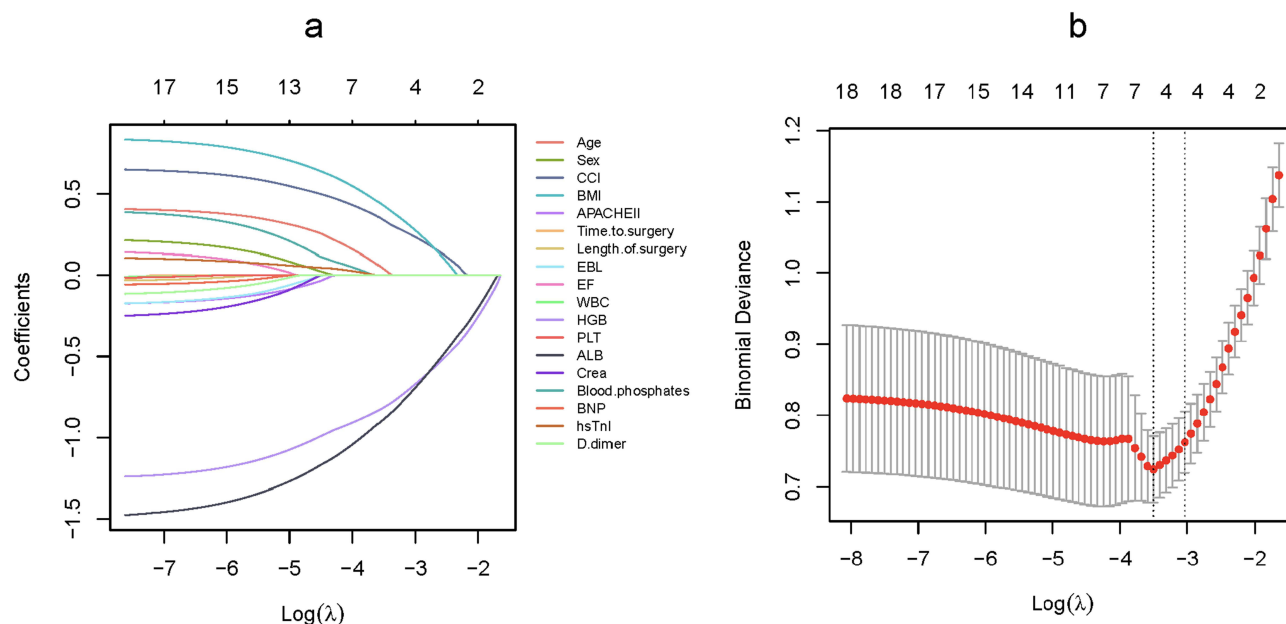
serum creatinine, and a longer ICU length of stay. The characteristics of patients for the internal and external validation were summarized in the [supplementary material](#) (See [supplemental Table 1](#) and [Table 2](#)).

## Prediction Model Construction and Evaluation

LASSO regression analysis was performed to select the most relevant predictors from the candidate preoperative variables ([Figure 2](#)). Using ten-fold cross-validation, four variables with non-zero coefficients were identified: BMI, CCI, HGB, and ALB. These variables were subsequently included in the multivariate logistic regression analysis. The results revealed that BMI, CCI, HGB, and ALB were independent risk factors for postoperative shock ([Table 3](#)). The predictive model was presented as a nomogram to provide a quantitative estimation of the risk factors for postoperative shock in elderly patients with HF ([Figure 3](#)). [Figures 4 and 5](#) summarize model performance (ROC, decision curve analysis) in the internal and external validation set. The area under the ROC curve (AUC) was 0.834 and 0.801 for the internal and external validation sets, respectively.

## Discussion

To our knowledge, few studies have specifically developed prediction models for postoperative shock in elderly patients undergoing hip fracture surgery. Most existing predictive studies in this population have focused on other clinically significant outcomes, such as postoperative delirium, venous thromboembolism or mortality.<sup>7,15,16</sup> For example, Kim et al developed a prediction model for postoperative delirium in elderly hip fracture patients, identifying factors such as



**Figure 2** LASSO coefficient profiles (a) and cross-validation plot (b).

age, comorbidity burden, and functional status as key predictors.<sup>7</sup> Similarly, Xiang et al constructed a nomogram model to predict deep vein thrombosis in patients with hip fractures, demonstrating improved risk stratification compared with traditional scoring systems.<sup>15</sup> In addition, Harris et al developed prediction models for postoperative mortality and major complications following hip fracture surgery, highlighting the importance of age, functional status, and comorbidities in determining postoperative outcomes.<sup>16</sup>

While these studies provide valuable insights into predicting postoperative complications, few have specifically focused on postoperative shock. The present study therefore extends the current literature by developing a predictive model for postoperative shock, a critical manifestation of hemodynamic instability that may precede severe complications and mortality. Our study identified BMI, CCI, HGB, and ALB as independent factors associated with postoperative shock in elderly HF patients. To improve model stability and reduce the risk of overfitting, LASSO regression was used for variable selection instead of traditional univariate screening. The nomogram integrating these four parameters demonstrated robust predictive performance, with good calibration and clinical utility upon internal and external validation, which could be considered as a practical tool for early risk stratification in this vulnerable patient population.

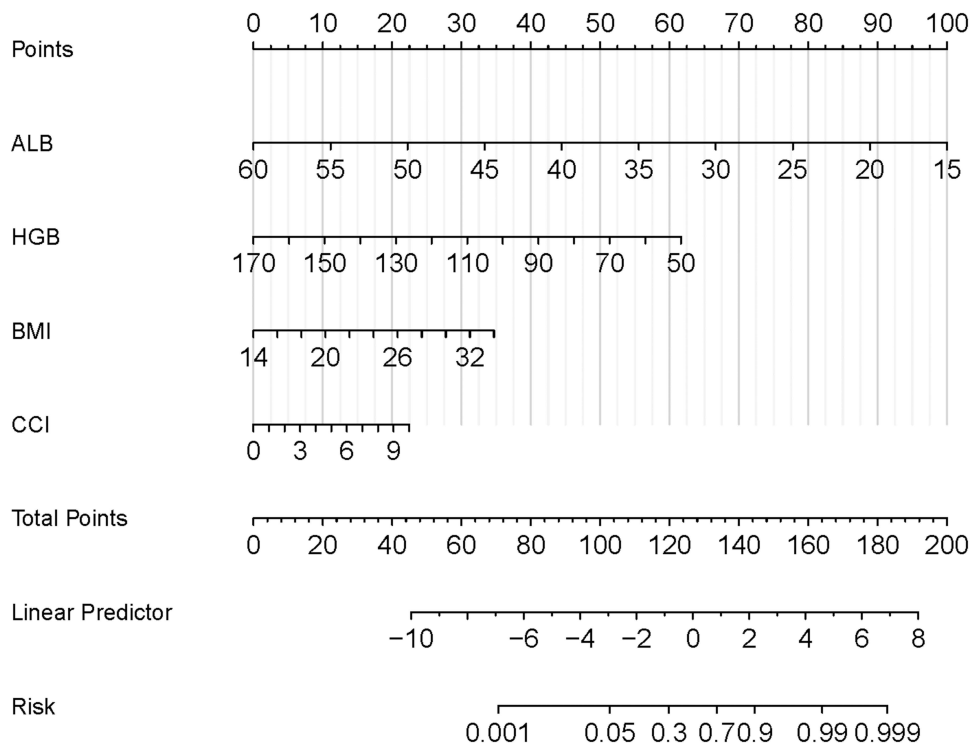
Hemodynamic instability is a frequent and serious complication after hip fracture surgery, linked to adverse outcomes. For instance, immediate postoperative hypotension has been identified as a strong predictor of 30-day mortality.<sup>17</sup> We selected the SI as our outcome measure due to its well-established role in identifying shock and its clinical

**Table 3** Multivariate Logistic Regression Analysis

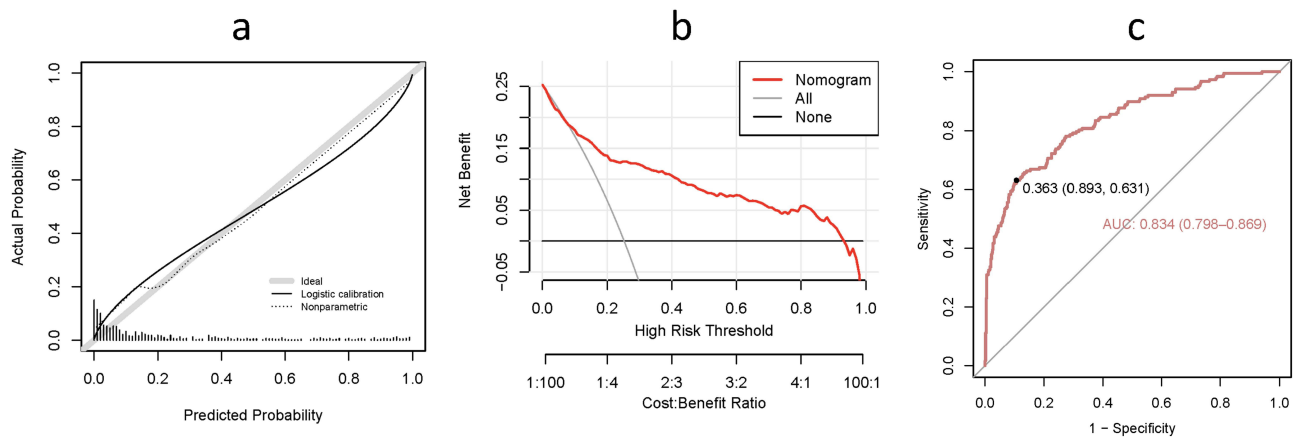
Variable	$\beta$	SE	OR (95% CI)	P value
ALB	-0.274	0.047	0.761 (0.694–0.834)	<0.001*
HGB	-0.063	0.012	0.939 (0.917–0.961)	<0.001*
BMI	0.213	0.051	1.238 (1.121–1.367)	<0.001*
CCI	0.276	0.087	1.318 (1.111–1.563)	0.002*

**Note:** \* P < 0.05.

**Abbreviations:** BMI, body mass index; CCI, Charlson Comorbidity Index; HGB, hemoglobin; ALB, albumin; SE, standard error; OR, odds ratio; CI, confidence interval.



**Figure 3** A nomogram for predicting postoperative shock.

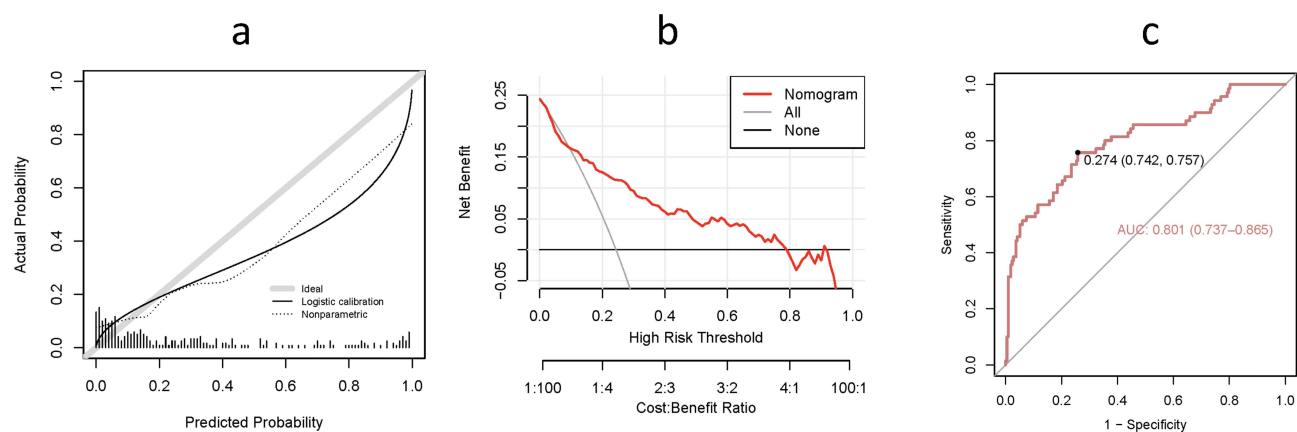


**Figure 4** The calibration curve (a), decision curve (b) and ROC curve (c) of the internal validation set.

practicality.<sup>18</sup> Interestingly, we found no significant association between intraoperative hypotension and postoperative shock in our study, possibly because brief hypotensive episodes were promptly corrected and thus had no sustained effect.

Our results indicate that CCI is an independent risk factor for an elevated SI following HF surgery in elderly patients. The CCI has been used as a guide to predict 30-day and one-year mortality rates of the HF patients, and its usefulness has been shown to be valuable. Numerous studies have shown the association of pre-fracture comorbidity with post-operative complications and mortality.<sup>19,20</sup>

This study also revealed that a higher BMI was associated with an increased risk of postoperative shock. This may be attributed to the greater burden of obesity-related comorbidities. Obesity has been shown to compromise immune



**Figure 5** The calibration curve (a), decision curve (b) and ROC curve (c) of the external validation set.

function, promote systemic inflammation, and exacerbate cardiometabolic disease, leading to complications such as diabetes, metabolic syndrome, and hypertension.<sup>21–23</sup> Furthermore, elevated BMI has been shown to be associated with increased risk of hospital admission and severe disease progression.<sup>24,25</sup>

Our study further identified hypoalbuminemia and low hemoglobin as independent risk factors. Perioperative nutritional status will affect postoperative efficacy and recovery, as an indicator of nutritional status, hypoalbuminemia is a strong independent risk factor for length of stay after HF surgery in the elderly.<sup>20</sup> Additionally, a decrease in hemoglobin may lead to a reduction in local tissue oxygen content and impair perfusion, thereby contributing to the development of shock.

The discriminative ability, predictive accuracy, and clinical net benefit of the predictive model in our study were validated by AUC and DCA, respectively. Both validation sets showed very good performance, suggesting robust performance and potential clinical utility. By utilizing a predictive model to identify patients at high risk of postoperative shock, our study facilitates timely ICU admission and targeted monitoring. This approach enables the prompt correction of underlying abnormalities, thereby reducing the incidence of major postoperative complications and ultimately improving patient outcomes.

With the aging global population, the incidence of hip fractures is rising worldwide,<sup>3</sup> increasing the demand for critical care resources. While proactive ICU admission is crucial for managing complications, the decision often relies on subjective clinical judgment. The identification of high-risk patients is therefore critical for optimizing outcomes. This study therefore aimed to establish a quantitative predictive model for postoperative shock.

This study has several limitations. First, as a single-center retrospective study, causal relationships cannot be established and the clinical implications of the findings should be interpreted cautiously. Prospective multicenter studies are needed to further validate the robustness and generalizability of the model. Second, while the SI is clinically practical, it may not fully capture the complex pathophysiology of shock, which involves parameters beyond blood pressure and heart rate. Third, due to data availability constraints, we could not account for the potential impact of certain intraoperative factors, such as the level of anesthesia or the use of bone cement, on prolonged hemodynamic instability.

## Conclusion

This study developed a nomogram incorporating four variables—BMI, CCI, hemoglobin, and albumin—to predict postoperative shock in elderly hip fracture patients. The model demonstrated robust performance, offering a practical tool for early risk stratification and perioperative monitoring of elderly hip fracture patients.

## Disclosure

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article. This work had no funding support. The study received approval from our institution's Ethics Committee (K2023-157-00). All participants included in this study have obtained informed consent and agreed to publication.

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