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ORIGINAL RESEARCH

Risk Factors for Acute Heart Failure in Older Adults with Hip Fractures After Surgery and Construction of a Nomogram Predictive Model

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Purpose: The frequency of acute heart failure (AHF) is relatively high in older adults undergoing hip fracture surgery. This study aims to explore the possible risk factors and create a nomogram predictive model for quantifying the level of risk.

Patients and Methods: This study retrospectively analyzed older adults who underwent hip fracture surgery at the Orthopaedic Department of Chengdu Fifth People's Hospital affiliated with Chengdu University of Traditional Chinese Medicine between January 2022 and December 2023. Statistical analysis was performed using SPSS 25.0 and R software to develop a nomogram prediction model. The model's predictive precision was evaluated by examining the area under the curve (AUC) of the receiver operating characteristic (ROC) curve. Calibration curves and decision curve analysis (DCA) were also utilized to assess the model's calibration and clinical utility comprehensively.

Results: This study underwent rigorous screening and ultimately included 313 patients. These samples were then divided into two groups in a 7:3 ratio, with 220 cases serving as the training set and 93 cases serving as the validation set. After performing univariate analysis and multivariate logistic regression analysis, we developed a nomogram based on the training set model, with an AUC of 0.861 (95% CI: 0.796–0.925). In the validation set model, the AUC was 0.819 (95% CI: 0.692–0.946). According to the calibration curve, the model shows a good fit. The DCA results suggest that the model holds significant practical value.

Conclusion: Statistical data indicates that the incidence of AHF post-operative in older adults with hip fractures reaches up to 15.34%. Multiple regression analysis revealed that age, cerebrovascular disease, cirrhosis, malnutrition, intraoperative blood loss, and hypoproteinemia are significant risk factors. Based on these findings, this study developed a nomogram prediction model to accurately assess the risk of AHF following surgery in older adults with hip fractures.

Keywords: acute heart failure, hip fracture, older adults, risk factors, nomogram

Introduction

The acceleration of the global aging process is making hip fractures an urgent public health concern. This injury type is relatively common in the older adults and closely linked to falls, with significant mortality and morbidity rates, especially in those aged 65 and above. Relevant data shows that around 1.7 million hip fracture cases occur worldwide annually, with projections suggesting an increase to over 6 million by 2050.[1,2] More than half of these cases are expected to occur in Asia, particularly in China.[3] External factors like falls, traffic accidents, and sports-related trauma primarily cause these injuries. In older adults, osteoporosis significantly raises fracture risk due to reduced bone density and weakened strength.[4] About 95% of patients with hip fractures need surgical intervention to restore lower limb function and ensure stability.[5]

The older adult population is frequently affected by chronic conditions like hypertension, diabetes, and cardiovascular disorders. These underlying health issues significantly raise the risk of hip fractures and worsen postoperative complications, adversely affecting treatment results and recovery.[6] Research shows significant individual differences in postoperative

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complication rates among older adults with hip fractures, which are closely linked to multisystem diseases. Studies show that cardiovascular events are among the most frequent adverse reactions after this surgery, making up about 40% of all complications.[7] A large-scale epidemiological study conducted in Denmark revealed that between 1999 and 2012, the incidence of congestive heart failure(HF) following hip fractures showed an increasing trend, rising from 6.5% to 10.7% in men and from 5.9% to 13.1% in women.[8] HF frequently occurs in older adults undergoing hip fracture surgery, representing a major factor linked to high in-hospital mortality rates, with an incidence between 5.5% and 21.3%.[9] Research shows that the 30-day mortality rate for patients with acute heart failure (AHF) is 65%, and those with AHF both before and after surgery face a much higher risk of all-cause mortality within one year.[10,11] This complication extends hospital stays and significantly affects patients' long-term quality of life and distant prognosis.

AHF is a complex clinical syndrome characterized by the heart's inability to adequately meet the body's metabolic demands, resulting in congestion within the pulmonary and/or systemic circulation. The pathophysiological mechanisms underlying this condition include excessive activation of the neuroendocrine system—such as the renin-angiotensin-aldosterone system and sympathetic nervous system—as well as systemic inflammatory responses and direct damage to myocardial cells.[12] Hip fracture in older adults represents a significant physiological stressor. Factors such as surgical trauma, anesthesia, blood loss, pain, and potential bone cement implantation syndrome can lead to substantial fluctuations in hemodynamics and an increased release of inflammatory mediators. These changes significantly elevate both preload and afterload on the heart, potentially inducing or exacerbating myocardial ischemia. Consequently, this interplay renders older adults particularly vulnerable to severe complications during the perioperative period, including acute exacerbations of heart failure and malignant arrhythmias.[13] HF may be categorised as heart failure with reduced ejection fraction(HFrEF): LVEF ≤ 40%; heart failure with mildly reduced ejection fraction(HFmrEF): LVEF 41%–49%; or heart failure with preserved ejection fraction(HFpEF): LVEF ≥ 50%. Patients with HFrEF exhibit a significant decline in myocardial contractility and have poor tolerance to intraoperative fluid loading, making them susceptible to acute pulmonary edema. The management focus for these patients lies in optimizing volume status and the judicious use of positive inotropic agents.[14,15] In contrast, HFpEF is more commonly observed in older female patients who also present with comorbidities such as hypertension, diabetes mellitus, and atrial fibrillation. These patients experience limitations in cardiac diastolic function and are particularly sensitive to increases in heart rate and blood pressure; thus, maintaining sinus rhythm and strict blood pressure control is crucial. Previous studies indicate that the occurrence of HFpEF following hip fracture surgery is strongly correlated with the patient's baseline condition and postoperative physiological changes, making it the most prevalent type of heart failure encountered clinically.[16,17] Conversely, HFrEF often represents an acute exacerbation of pre-existing cardiac conditions. The onset of heart failure after hip joint surgery constitutes a serious event occurring early postoperatively (primarily within 72 hours but may persist up to 30 days).[18,19] Zhao W et al[20] performed a prospective study on older adults with hip fractures, showing that age over 75 years, a history of coronary artery disease, an admission hemoglobin level below 100 g/L, and an albumin concentration less than 40 g/L are independent risk factors significantly raising the likelihood of AHF. Research by Riaz MH et al[21] shows that the incidence of HF after hip fractures in older adults is notably higher, with independent risk factors being age ≥ 65 years, anemia, hypertension, diabetes mellitus, hypoproteinemia, and surgery lasting ≥ 120 minutes. Systematic identification and precise assessment of these potential triggers and risk factors deepen the exploration of mechanisms underlying complications and offer a theoretical basis for developing targeted prevention strategies. Targeted interventions focusing on modifiable risk factors can enhance physicians' clinical competence, improving the overall prognosis for hip fracture patients.

The occurrence of perioperative AHF is significantly high in older adults with hip fractures, threatening their health through higher mortality rates, more complications, and substantial use of medical resources. Addressing this clinical challenge, the current study emphasizes optimizing preoperative risk assessment systems and innovating refined management strategies. By combining multi-source data, such as medical history and biomarker details, we aim to create accurate predictive models for the early detection of postoperative AHF and refine personalized treatment approaches. This study seeks to refine the preoperative evaluation process to enhance surgical safety and prognosis quality for high-risk patients.

Materials and Methods

Research Population

In this retrospective analysis, 826 cases of orthopedic in-patients with hip fractures at Chengdu 5th People's Hospital, affiliated with Chengdu University of Traditional Chinese Medicine, between 1st January 2022 and 31st December 2023. Inclusion criteria: 65 years or older, hip fracture, surgery (total hip arthroplasty, hemiarthroplasty, internal fixation), no preoperative symptoms of heart failure, and have complete medical records. Exclusion criteria: incomplete data; old fracture and pathological fracture; multiple injuries or multiple surgeries; and those who do not undergo surgery. According to the inclusion and exclusion criteria, 313 people were finally included. Our 313 patients were put into a training group (n = 220) and a test group (n = 93). This study is divided into two groups: patients with AHF vs those without AHF groups. All the patients with AHF had the corresponding disease diagnosis.

In this research, we established a multidimensional data acquisition system encompassing patients' demographics like age, gender, days in hospital, type of fractures, number of comorbiditie and so on, along with lab tests comprising hemoglobin, platelet, albumin, aspartate transaminase(AST), creatinine, and more; likewise, there is surgery-related information such as operating time, intraoperative blood loss, anesthesia method, ASA, surgical procedure, and so on. All the data was collected from the electronic medical records of the Fifth Affiliated Hospital of Chengdu University of Traditional Chinese Medicine, which has been passed by the hospital's ethics committee. This study was conducted using a retrospective design, and there was no need for informed consent. In order for the samples to be homogeneous enough, the research team made sure to follow the established inclusion and exclusion criteria beforehand. One researcher solely entered the data; the same experts as above were used for review. Medical records were revisited to look for and fix any possible biases or strange things that came up.

Definition of Disease

This study is a retrospective analysis, with the diagnostic information regarding HF primarily derived from the electronic medical record system. We included patients by identifying clear diagnosis records documented by attending physicians or higher-level practitioners, predominantly cardiologists or internists, within the medical records. According to the 2021 European Society of Cardiology guidelines and the 2024 Chinese Heart Failure Management Guidelines, AHF is characterized as a short-term clinical syndrome that involves significant alterations in cardiac structure and/or function. The principal feature of AHF is a rapid decline in ventricular filling and pumping capacity, resulting in inadequate blood supply throughout the body. It can be classified into three categories: HFrEF, defined as LVEF ≤ 40%; HFmrEF, defined as LVEF between 41% - 49%; and HFpEF,defined as LVEF ≥ 50%. The diagnosis should encompass several key elements: (i) typical signs such as dyspnea, bilateral pulmonary rales, lower extremity edema, palpitations, jugular vein distension with pulsation, and tachycardia; (ii) detection indicators including serum B-type natriuretic peptide (BNP) levels ≥ 300 pg/mL or elevated N-terminal pro-brain natriuretic peptide (NT-proBNP) levels—reference values being >900 pg/mL for individuals aged 55–75 years and >1800 pg/mL for those aged ≥75 years; and (iii) imaging examinations revealing pulmonary water retention on chest X-ray along with cardiac chamber enlargement observed via echocardiography.[22,23] Clinical studies have indicated that older adults experiencing acute heart failure frequently present atypical symptoms, with left heart failure being particularly prevalent. AHF occurring within one month of hip fracture surgery.

Patient Management

Preoperative Management

A multidisciplinary team manages comorbidities and provides preoperative education for patients and their families. Upon admission, low-molecular-weight heparin is routinely administered to prevent thrombosis. All patients undergo a standard preoperative assessment, including the ASA classification. An individualized anesthesia plan is developed based on the patient's specific condition.

Intraoperative Management

Routine monitoring encompasses electrocardiography, non-invasive blood pressure measurement, pulse oximetry, body temperature regulation, and end-tidal carbon dioxide monitoring. Additionally, invasive arterial pressure measurements,

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central venous pressure assessments, and urine output must also be closely monitored.According to the operating procedures of our hospital, the determination of successful anaesthesia is made by the attending anaesthetist based on specific clinical criteria: absence of spontaneous movement, stable vital signs, and no unexpected intraoperative awakening. In this study cohort, all cases were classified as "anaesthesia successful" in accordance with these established clinical criteria.

Postoperative Management

Following surgery, all patients are transferred to the post-anesthesia care unit for continuous monitoring until they fulfill the established discharge criteria (eg, an Aldrete score of ≥9). Simultaneously, provide guidance to patients and their families on rehabilitation and functional recovery.

Statistical Analysis

Data processing and statistical analyses were conducted using SPSS version 25.0 and R software version 4.0.3. The Kolmogorov–Smirnov test was employed to assess the normality of continuous variables. Data that followed a normal distribution are presented as mean ± standard deviation (X±SD), while data not conforming to a normal distribution are expressed as median and interquartile range(IQR). Categorical variables are reported as absolute numbers and percentages.Chi-squared tests or Fisher's exact test were utilized for categorical variables to compare groups with AHF against those without AHF. Independent *t*-tests were applied for the analysis of normally distributed continuous variables, whereas the Mann–Whitney *U*-Test was used for parameters of non-normally distributed data.

In this study, patients in the training set were categorized into AHF and non-AHF groups based on the occurrence of postoperative heart failure. Differences between these two groups were evaluated accordingly. We identified independent risk factors associated with AHF following hip fracture surgery through both univariate and multivariate logistic regression analyses. The coefficients for each variable were calculated, considering odds ratios (OR) along with P-values within a 95% confidence interval (CI) for relevant characteristics. A nomogram predictive model for postoperative AHF in older adults with hip fractures was developed based on the results from multivariable logistic regression analysis. The model's performance was assessed using receiver operating characteristic (ROC)-based area under the curve (AUC) values, alongside an evaluation of consistency between predicted probabilities from the model and actual label probability distributions via calibrationcurves.Subsequently,we employed the Hosmer-Lemeshow test to assess the goodness of fit of the model. A p-value greater than 0.05 suggests that the predictive model demonstrates an acceptable level of goodness of fit. Finally, decision curve analysis (DCA) curves were generated to estimate net benefits at various threshold probability levels. The packages utilised in R software include "glmnet", "pROC", "caret", "car", "rms", "rmda", and "Resourceselection".

Results

From January 2022 to December 2023, 826 older adults were enrolled in this trial with fractures. Following exclusion of ineligible participants, the final study cohort comprised 313 patients. The study's flowchart is given in Figure 1. Table 1 summarizes the baseline characteristics of 313 older adults with hip fractures, categorized by the presence or absence of AHF. Among the participants, 48 developed AHF, with the majority (75.0%) classified as HFpEF. The range of participating subjects was 65–100, with an average age of 79.96.Females constituted the largest proportion (64.9%), with over 73.0% of participants aged 75 years or older. Most patients had three or fewer comorbidities (63.6%), while 28.1% had more than four. Common comorbidities included hypertension, type 2 diabetes, chronic obstructive pulmonary disease(COPD), coronary heart disease(CHD), cerebrovascular disease, cirrhosis, malnutrition, and hematological diseases. Femoral neck fractures were the most common (53.4%), followed by intertrochanteric fractures (44.1%). The predominant surgical procedure was proximal femoral nail antirotation (45.0%), followed by total hip arthroplasty (32.3%) and hemiarthroplasty (22.7%). Most patients received general anesthesia (75.7%), and over 60% were classified as ASA grade ≥ III. The mean operative time was 128.56 minutes, and 83.1% of patients had a preoperative preparation time exceeding 3 days.

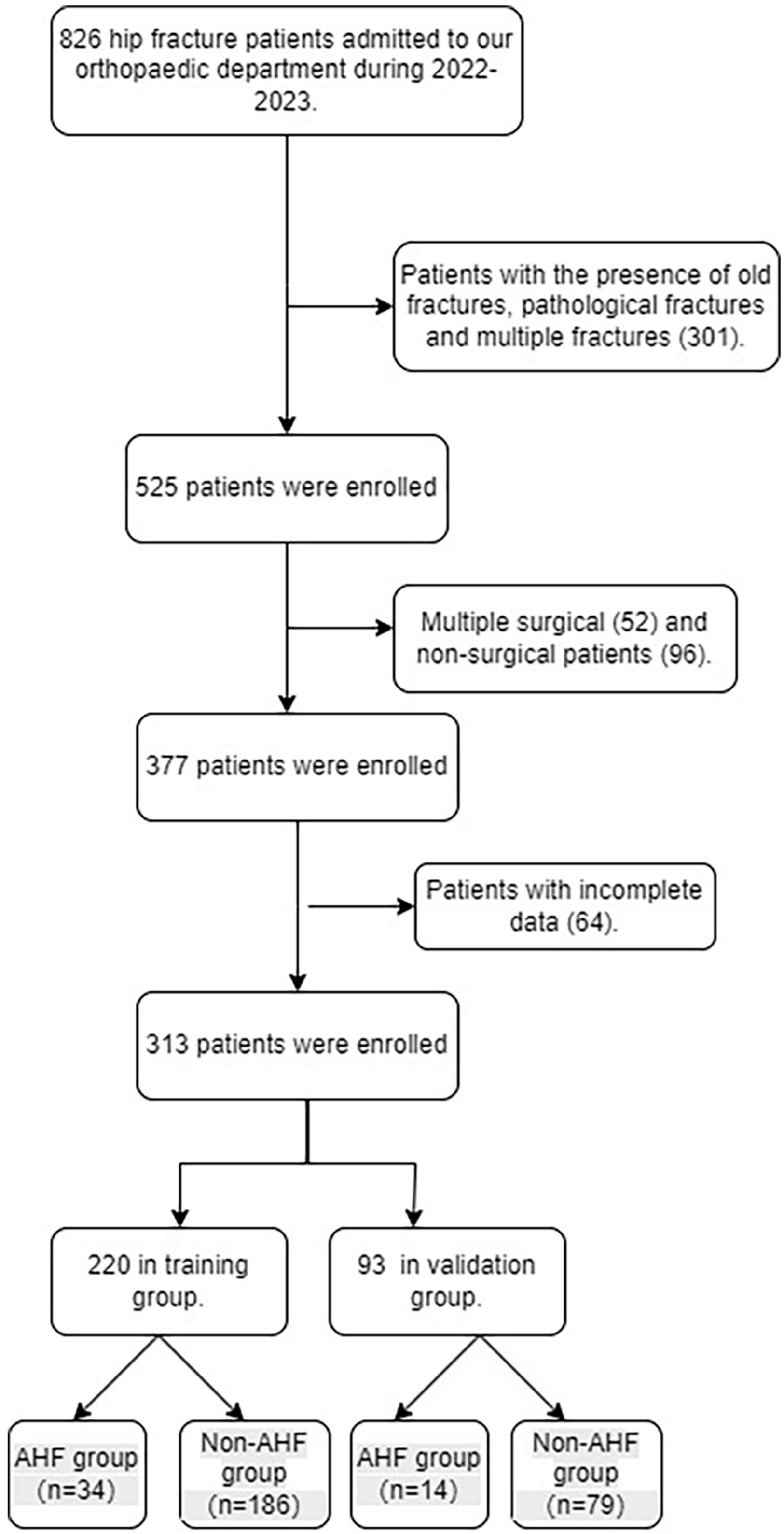

Figure 1 The flowchart showing the selection of research participants.

Table 1 Baseline Characteristics of Elderly Patients with Hip Fractures with or Without Acute Heart Failure

Variables	Total (N=313)	Non-AHF (N=265)	AHF (N=48)	P-value
Age, mean±SD (years)	79.96±7.81	79.52±7.82	82.35±7.35	0.021*
Gender, N (%)				0.966
Male	110(35.1)	93(35.1)	17(35.4)	
Female	203(64.9)	172(64.9)	31(64.6)	
Fracture type, N (%)				0.177
Femoral neck	167(53.4)	145(54.7)	22(45.8)	
Intertrochanteric fractures	138(44.1)	115(43.4)	23(47.9)	
Subtrochanteric fractures	8(2.6)	5(1.9)	3(6.3)	
Number of comorbidities, N (%)				0.008*
0	26(8.3)	24(9.1)	2(4.2)	
1~3	199(63.6)	174(65.7)	25(52.1)	
>4	88(28.1)	67(25.2)	21(43.7)	
Hypertensive, N (%)				0.530
Yes	163(47.9)	136(51.3)	27(56.3)	
No	150(52.1)	129(48.7)	21(43.8)	
Type 2 diabetes, N (%)				0.385
Yes	83(28.1)	77(29.1)	11(22.9)	
No	225(71.9)	188(70.9)	37(77.1)	
COPD, N (%)				0.203
Yes	60(19.2)	54(20.4)	6(12.5)	
No	253(80.8)	211(79.6)	42(87.5)	
CHD, N (%)				0.028*
Yes	51(16.3)	38(14.3)	13(27.1)	
No	262(83.7)	227(85.7)	35(72.9)	
Cirrhosis, N (%)				<0.001*
Yes	5(1.6)	1(0.4)	4(8.3)	
No	308(98.4)	264(99.6)	44(91.7)	
Malnutrition, N (%)				<0.001*
Yes	76(24.3)	53(20.0)	23(47.9)	
No	237(75.7)	212(80.0)	25(52.1)	
Cerebrovascular disease				<0.001*
Yes	16 (16.3)	35 (13.2)	16 (33.3)	
No	35 (83.7)	230 (86.8)	32 (66.7)	
Hematological disease, N (%)				0.019*
Yes	98(31.3)	76(28.7)	22(45.8)	
No	215(68.7)	189(71.3)	26(54.2)	
ASA Classification, N (%)				0.585
Class I	16(5.1)	12(4.5)	4(8.3)	
Class II	100(31.9)	87(32.8)	13(27.1)	
Class III	162(51.8)	139(52.5)	23(47.9)	
Class IV	34(10.9)	27(10.2)	7(14.6)	
Class V–VI	1(3.0)	0(0.0)	1(2.1)	
Intraoperative blood loss, N (%)				0.012*
≤100mL	212(67.7)	185(69.8)	27(56.3)	
100-400mL	88(28.1)	76(28.7)	12(25.0)	
≥400mL	13(4.2)	4(1.5)	9(18.7)	

(*Continued*)

Table 1 (Continued).

Variables	Total (N=313)	Non-AHF (N=265)	AHF (N=48)	P-value
Operating time, mean±SD (min)	128.56±36.61	128.49±34.38	128.96±47.55	0.935
Surgical procedure, N (%)				0.095
Total hip arthroplasty	101(32.3)	93(35.1)	8(16.7)	
Hemiarthroplasty	71(22.7)	55(20.8)	16(33.3)	
PFNA	141(45.0)	117(44.2)	24(50.0)	
Preoperative preparation time, N (%)				0.078
<48h	17(5.4)	15(5.7)	30(62.5)	
48~72h	36(11.5)	31(11.7)	6(12.5)	
72~168h	181(57.8)	159(60.0)	5(10.4)	
>168h	79(25.2)	60(22.6)	7(14.6)	

Notes: Values are presented as mean ± standard deviation, median (interquartile range), or number (percentage), depending on the type of data. "*" means P<0.05.
Abbreviations: ASA, Classification, American society of Aneshesiologists physical status classification system; COPD, chronic obstructive pulmonary disease; CHD, coronary heart disease; IQR, interquartile range; PFNA, proximal femoral nail antirotation; SD, Standard deviation.

Significant differences between the AHF and non-AHF groups were observed in age, number of comorbidities, CHD, cerebrovascular disease, cirrhosis, malnutrition, hematological diseases, and intraoperative blood loss ($p \leq 0.05$). In contrast, no significant differences were found in gender, fracture type, hypertension, type 2 diabetes, COPD, surgical procedure, ASA classification, or operative time.

Univariate Analysis of Laboratory Data

In the laboratory indicators, the AHF group had a significantly higher incidence of anemia and hypoproteinemia than the non-AHF group, $p<0.05$. It showed no significant differences among the two groups regarding Leucocyte, erythrocyte, platelets, AST, alanine aminotransferase(ALT), creatinine and urea nitrogen ($P\geq0.05$), as can be seen from Table 2.

Selection of Risk Factors and Construction of a Nomogram Prediction Model

The patients were divided into a training set (n = 220) and a validation set (n = 93) in a 7:3 ratio. The training group had 34 patients (15.45%) who developed AHF after surgery; those were included in both univariate and multivariate analysis. In the validation set, there were 14 patients (15.05%) who developed AHF after surgery, and these data were used in further model validation.

Table 2 Results of Univariate Analyses of Laboratory Data

Variables	Total (N=313)	Non-AHF (N=265)	AHF (N=48)	P-value
Leucocyte, mean±SD (10^9)	8.80±2.80	8.89±2.75	8.34±3.05	0.212
Erythrocyte, mean±SD (10^9)	3.81±1.44	3.79±0.64	3.90±3.39	0.613
Haemoglobin, mean±SD (g/l)	111.87±21.22	113.47±19.40	103.0±27.94	0.002*
Blood platelet, IQR (10^9)	157.0(122.5~203.5)	158.0(126.0–203.0)	146.0(98.0–213.60)	0.226
AST, IQR (u/l)	21.0(17.0~27.0)	21.0(17.0–26.0)	20.5(16.0–30.0)	0.657
ALT, IQR (u/l)	17.0(13.0~24.0)	17.0(13.0–24.5)	17.5(12.0–23.5)	0.901
Creatinine, IQR (μmol/L)	72.0(55.0~91.0)	71.0(56.0–90.5)	73.0(52.8–98.5)	0.821
Urea nitrogen, IQR (mmol/L)	7.2(5.70~9.6)	7.2(5.7–9.6)	7.8(5.8–9.7)	0.420
Albumin, mean±SD (g/l)	35.92±4.45	36.53±3.96	32.56±5.46	<0.001*

Notes: Values are presented as mean ± standard deviation, median (interquartile range), or number (percentage), depending on the type of data. "*" means P<0.05.
Abbreviations: ALT, alanine aminotransferase; AST, aspartate transaminase; IQR, interquartile range; SD, Standard deviation.

Table 3 Univariate and Multivariate Analysis of Risk Factors for Acute Heart Failure in a Training Cohort

Variables	Univariate Analysis			Multivariate Analysis		
	OR	95% CI	P-value	OR	95% CI	P-value
Age	1.057	1.006–1.115	0.033*	1.115	1.033–1.212	0.007*
Numberof comorbidities	2.447	1.275–4.846	0.008*	0.616	0.202–1.840	0.387
CHD	2.943	1.252–6.669	0.011*	3.348	0.952–11.945	0.058
Cerebrovascular disease	4.286	1.826–9.864	<0.001*	4.887	1.490–16.411	0.009*
Cirrhosis	11.563	1.078–253.127	0.048*	27.199	1.352–937.556	0.036*
Malnutrition	3.650	1.707–7.842	<0.001*	4.096	1.332–13.280	0.015*
Hematological disease	2.509	1.189–5.312	0.015*	1.434	4.228–4.911	0.560
Pre-operative preparation time	1.898	1.113–3.407	0.022*	1.927	4.267–9.221	0.091
Intraoperative blood loss	1.978	1.083–3.555	0.023*	3.026	1.307–7.526	0.012*
Erythrocyte	0.496	0.293–0.828	0.008*	0.254	0.0 43–1.284	0.114
Haemoglobin	0.979	0.961–0.996	0.018*	1.034	0.979–1.096	0.250
Albumin	0.776	0.698–0.855	<0.001*	0.820	0.723–0.918	<0.001*

Note: "*" means P<0.05.
Abbreviation: CHD, Coronary heart disease.

This research conducted univariate and multivariate logistics regression analysis on the risk factors of AHF post-hip fracture surgery (Table 3). Univariate analysis showed that age, number of comorbidities, CHD, cerebrovascular diseases, cirrhosis, malnutrition, hematological disease, preoperative preparation time, intraoperative blood loss, erythrocyte, hemoglobin, and albumin were all meaningful (P<0.05). After multivariate logistic analysis, among the six independent predictive factors were: age: OR = 1.115, 95% CI: 1.033–1.212, P = 0.007; cerebrovascular disease: OR = 4.887, 95% CI: 1.490–16.411, P = 0.009; cirrhosis: OR = 27.199, 95% CI: 1.352–937.556, P = 0.036; malnutrition: OR = 4.096, 95% CI: 1.332–13.280, P = 0.015; intraoperative blood loss: OR = 3.026, 95% CI: 1.307–7.526, P = 0.012; albumin: OR = 0.820, 95% CI: 0.723–0.918, P < 0.001.To visually illustrate the influence of each variable on the incidence of postoperative AHF, a nomogram prediction model was developed, as depicted in Figure 2.

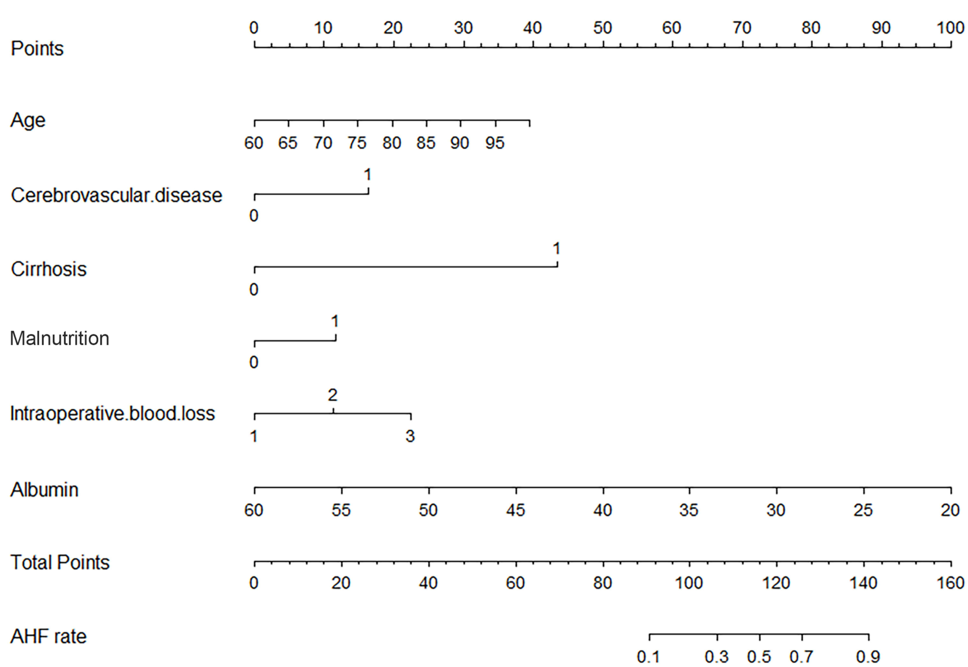

Figure 2 Nomogram showing the risk of AHF in older adults with Hip fractures after surgery.

AHF risk assessment model formula: Logit(P) = −3.165+ 0.086 * (partial regression coefficient for age)+1.419 * (partial regression coefficient for cerebrovascular disease) +3.779 * (partial regression coefficient for cirrhosis)+ 1.014 * (partial regression coefficient for malnutrition)+0.977 * (partial regression coefficient for intraoperative blood loss)-0.217 * (partial regression coefficient for albumin). Diagnosis by the variance inflation factors (VIFs) indicates that all the independent variables have VIFs much lower than the common cutoff of 5. Specific figures included age at 1.162, cerebrovascular disease at 1.045, cirrhosis at 1.025, malnutrition at 1.063, intraoperative blood loss at 1.122, and albumin at 1.052.

Performance of the AHF Risk Nomogram

Figure 3 compares the ROC curves for the nomogram and other risk factors. Research data indicate that the nomogram demonstrates superior performance, with an AUC value of 0.861 (95% CI: 0.796–0.925) for the training set and 0.819 (95% CI: 0.692–0.946) for the validation set, surpassing other risk factors (Figure 4A and B). The calibration curve analysis reveals a strong alignment between the data and predicted values. The Hosmer-Lemeshow test results show the nomogram successfully passed the goodness-of-fit test in both the training set (p = 0.561, chi-square value = 1.157, degrees of freedom = 2) and the validation set (p = 0.236, chi-square value = 2.884, degrees of freedom = 2), indicating a satisfactory model fit (Figure 4C and D). The DCA was utilized to assess the clinical net benefit of the proposed model. As shown in Figure 4E and F, the nomogram exhibited a positive net benefit across a broad range of threshold probabilities, outperforming both the “treat all” and “treat none” strategies. Importantly, the DCA curve derived from the validation cohort closely paralleled that of the training cohort, suggesting consistent and robust clinical applicability

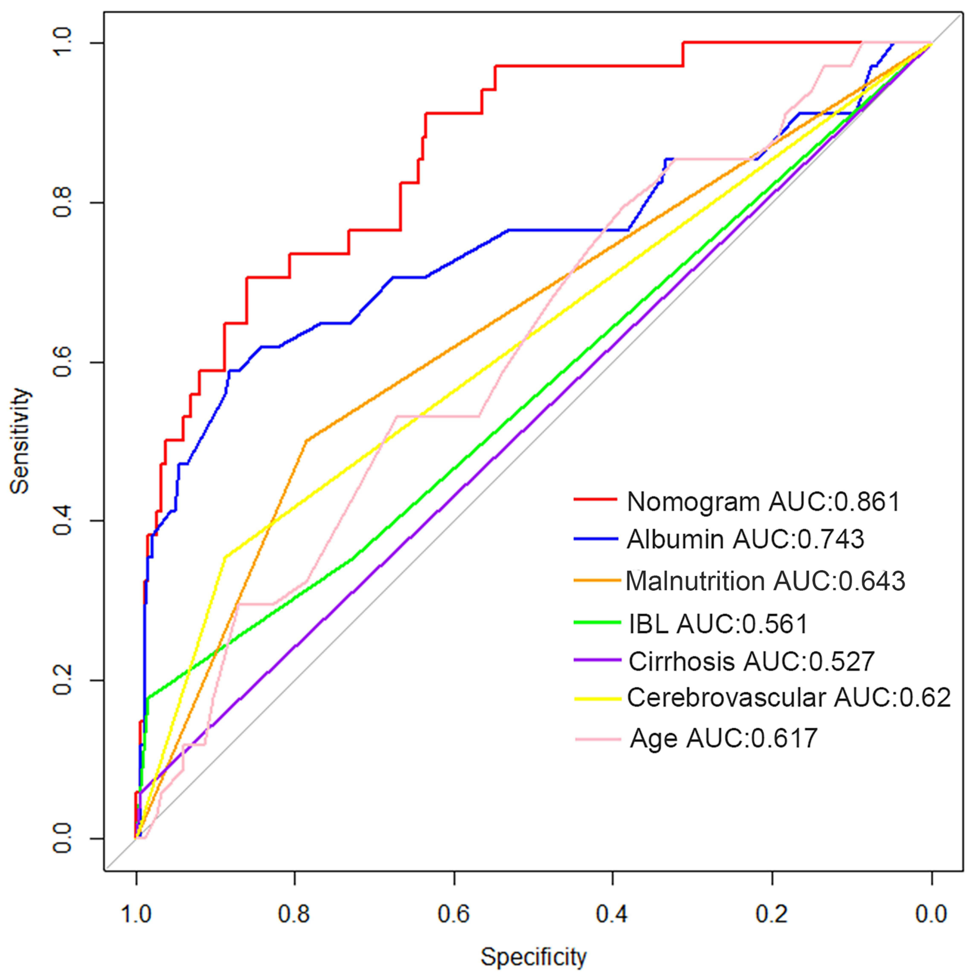

Figure 3 The receiver operating characteristic curves of nomogram and different risk factors.

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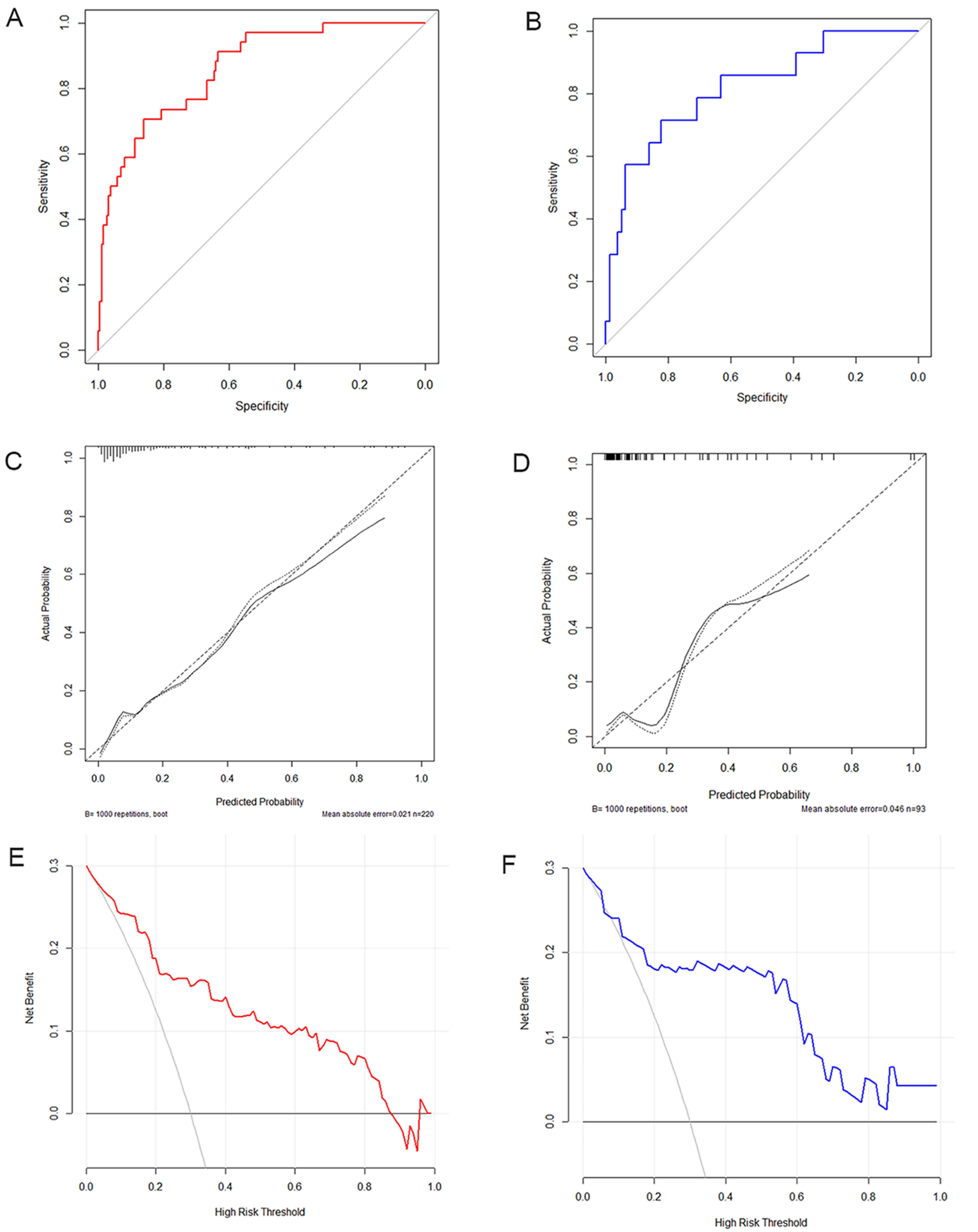

Figure 4 (**A**) The receiver operating characteristic curves of nomogram in training set. (**B**) The receiver operating characteristic curves of nomogram in validation set. (**C**) The calibration curve of the nomogram in the training set. (**D**) The calibration curve of the in the validation set.(**E**)The decision curve analysis of the nomogram in the training set. (**F**) The decision curve analysis of the nomogram in the validation set.

of the model. The model conferred a clinically meaningful net benefit within a threshold probability range of 10% to 83%, with the maximum net benefit observed at approximately 50%.

Discussion

Multimorbidity and the decline in organ function due to aging significantly contribute to postoperative complications in older adults with hip fractures. In this population, HF has become one of the most severe perioperative complications, significantly impacting patients' post-surgical survival rates.[22,23] The onset of AHF in the perioperative period stems from various interacting mechanisms, such as surgical stress, fluid overload, blood loss, anemia, hypoxia, worsening of pre-existing cardiac conditions, and age-related reductions in cardiac function. These factors increase myocardial oxygen consumption and disrupt the balance between oxygen supply and demand, ultimately causing myocardial injury and HF.[24,25] This retrospective study examined the risk factors for postoperative AHF in older adults with hip fractures. The findings showed that age, cerebrovascular disease, cirrhosis, malnutrition, intraoperative blood loss, and hypoproteinemia were significant risk factors. These conditions also offered crucial predictive insights into the postoperative risk of AHF occurrence. This study developed a predictive model for assessing the risk of AHF following hip fracture surgery in older adults based on the six key risk factors mentioned above. Since the chosen variables exhibit strong operability and clinical relevance, this model offers substantial practical worth and supplies reliable theoretical backing for clinical decision-making. The model achieved an AUC of 0.861 in the training set and 0.819 in the validation set, reflecting a high level of predictive accuracy. The Hosmer-Lemeshow goodness-of-fit test produced a P-value exceeding 0.05, indicating that the model's calibration is adequate. Moreover, employing nomogram tools enables an intuitive display of predictions, vastly boosting the model's practical utility and scientific importance.

Based on the study data, the incidence of AHF following hip fracture surgery in older adults is 15.34%. Prior research has uncovered notable variability in the occurrence of AHF after hip fractures in older adults, with incidence rates reported at 13.64%[24,25] in some studies and 18.37% in others.[10] At the same time, reports suggest that the overall incidence of perioperative ischemic heart disease or HF after hip fracture surgery is about 35%-42%.[26] This discrepancy could be due to various factors, such as regional differences, individual health conditions, perioperative interventions, and medical resource allocation.

HF is a chronic progressive condition, with its prevalence rising sharply with age, from 1% in the 20 to 39 years age group to about 20% in individuals over 80.[27] Prior research has indicated that the incidence of cardiovascular complications after hip replacement surgery in patients aged ≥70 years is 7.9%.[28] The study by Riaz M H et al[21] showed that age ≥ 65 years is an independent risk factor for postoperative AHF (OR=2.606, 95% CI 1.035–4.160, p=0.010). Our study further suggests that age is a risk factor for AHF, with the likelihood of AHF rising alongside advancing age (OR=1.115, 95% CI 1.033–1.212, p=0.007). As age increases (particularly in individuals aged ≥65 years), the perioperative risk of HF rises significantly for older adults with hip fractures, requiring improved cardiovascular assessment and intervention before surgery. The association between age and HF constitutes a complex network involving structural remodelling, functional decline, cellular ageing, and molecular damage. While age itself represents an unalterable epidemiological risk factor, the underlying biological processes offer potential therapeutic targets. Therefore, for older adults, a more thorough preoperative examination and assessment should be carried out. Enhanced consultations with anesthesiologists are essential, internal medicine management should be refined, and careful attention must be given to intraoperative anesthesia management to reduce surgical trauma, operation duration, and blood loss. Postoperatively, strict monitoring and enhanced multidisciplinary perioperative management are necessary.

Hypoproteinemia represents a complex clinical syndrome triggered by various factors, frequently observed in pathological conditions like cardiovascular disorders, hepatic and renal dysfunctions, and infectious diseases. Its pathogenesis is closely linked to the body's nutritional status and metabolic regulation.[29] Low serum albumin levels correlate with a higher risk of HF development and progression. Indeed, hypoalbuminemia can worsen pulmonary congestion, myocardial edema and dysfunction, diuretic resistance, fluid retention, and diminish antioxidant capacity and anti-inflammatory effects.[30,31] Hypoproteinaemia, once established, exacerbates the pathological process of heart failure, creating a vicious cycle rather than being the primary cause of its onset. Growing evidence indicates that hypoalbuminemia serves as a robust predictive factor in HF patients.[30,31] Multiple clinical studies have demonstrated that reduced serum albumin levels are closely linked to the occurrence of adverse cardiovascular events and mortality in patients with chronic heart failure.[32,33] In older adults with AHF, severe hypoalbuminemia serves as a predictive marker for adverse hospitalization outcomes. Ancion A and colleagues[34] also argue that hypoalbuminemia is closely linked to the onset of HF and independently predicts mortality risk in patients with both acute and chronic HF. In older adults with hip fractures, hypoalbuminemia indicates a state of physiological decline and may raise the incidence of fractures and the rate of surgical complications.[35] Maintaining sufficient albumin levels is vital to prevent postoperative complications in older adults, as low albumin levels are linked to postoperative AHF. Prior research has shown that hypoalbuminemia is an independent risk factor for AHF after hip fracture surgery in older adults.[20,21] Our research findings further suggest that lower albumin levels are linked to an increased risk of postoperative AHF. If the patient's albumin level drops below 30 grams per liter, an albumin infusion will be administered. However, dietary supplementation is preferable to medicinal supplementation; we will strive to encourage patients to obtain nutrition through oral intake.

Hypoproteinemia and malnutrition frequently form a "vicious cycle", wherein malnutrition hinders protein synthesis, and hypoproteinemia causes metabolic disturbances that worsen the severity of malnutrition. Malnutrition and HF form a complex bidirectional vicious cycle through mechanisms including chronic inflammation, neurohormonal activation, gut dysfunction, and specific nutrient deficiencies. It is not merely a late marker of HF, but an active driver of disease progression.Clinical studies show that preoperative malnutrition significantly increases the risk of complications after orthopedic surgery, yet it can be effectively addressed through intervention. This phenomenon could result in a range of serious consequences, including surgical site infections, respiratory conditions, cardiovascular incidents, and compromised wound healing.[36,37] For older adults with hip fractures, enhancing perioperative nutritional support strategies can significantly lower the incidence of postoperative complications, reduce readmission rates, and improve quality of life.

Stroke (cerebral infarction or cerebral hemorrhage) represents the most critical type of cerebrovascular disease and is a key element in perioperative comprehensive risk assessment protocols. Relevant research shows that stroke is a key risk factor impacting poor postoperative outcomes in patients undergoing non-cardiac surgery.[38] Jorgensen et al[39] conducted a study showing that patients with a history of stroke face significantly higher risks of severe cardiovascular complications after elective non-cardiac surgery. Statistical data shows that the likelihood of fatal cardiac events within 30 days after surgery is about ten times higher for these patients than for those without a stroke history. The literature further suggests that a history of stroke may act as a significant independent risk factor for predicting HF.[40] Stroke patients face a significantly heightened risk of HF during the perioperative period, attributed to mechanisms such as autonomic nervous imbalance, neuroendocrine activation, inflammatory response, myocardial ischemia, and structural remodeling. These processes reinforce each other, ultimately resulting in cardiac functional decompensation.[41,42] For hip fracture patients with a history of stroke, clinical management should balance stroke rehabilitation and fracture treatment while preventing cardiac complications. Future efforts should concentrate on boosting multidisciplinary collaboration, personalized interventions, and the investigation of new therapeutic methods to enhance outcomes in this high-risk group.

Patients with cirrhosis who undergo total hip arthroplasty face significantly higher rates of perioperative complications and mortality risk.[43] These patients frequently display multiple systemic dysfunctions after surgery, such as acute kidney injury, hemorrhagic anemia, pneumonia, HF, and deep tissue infections. Compared to individuals without cirrhosis, these patients typically experience longer average hospital stays and higher medical costs.[44] Related studies indicate that older adults with hip fractures and cirrhosis face higher rates of unplanned discharge, extended hospital stays, and increased complications, leading to a greater economic burden overall[45] The occurrence of HF is notably high in patients with cirrhosis, potentially linked to cirrhosis-induced cardiomyopathy, characterized by compromised cardiac systolic and diastolic function.[46] Currently, there is a paucity of research on AHF following hip fracture surgery in patients with cirrhosis, particularly concerning the underlying mechanisms in older adult population. Our study suggests that cirrhosis constitutes a significant risk factor for AHF after hip fracture surgery among older adults, thereby offering new insights and theoretical support for foundational research in this area.

Statistical data shows that about 16% of patients undergoing hip fracture surgery face a bleeding risk, mainly older males with high ASA classification, notable physiological decline, and a high rate of comorbidities.[47] Intraoperative blood loss may hinder the patient's recovery and potentially cause severe complications like acute kidney injury or organ dysfunction.[48] Intraoperative blood loss reduces the effective circulating blood volume, which in turn decreases cardiac output and blood pressure. This leads to myocardial ischemia and hypoxia, heightened cardiac workload, increased oxygen consumption, and an inflammatory response. Together, these factors lead to internal disturbances causing myocardial damage and reduced contractile function, ultimately triggering postoperative HF.[49] Patients with pre-existing cardiac conditions face a notably high risk of bleeding. Thus, for older adults with hip fractures, preventing and managing intraoperative blood loss is crucial. This involves preoperative comprehensive assessments, precise surgical techniques, vigilant monitoring during surgery, and prompt management of intraoperative bleeding. These measures help implement more proactive preventive strategies and precise management approaches during the perioperative period, reducing postoperative complication rates.

By developing a visualization tool, specifically a nomogram, we have significantly improved the readability and practical applicability of our predictive model. Furthermore, our model integrates several variables that have been infrequently addressed in prior research, such as cirrhosis and intraoperative blood loss, which may pave the way for new avenues of investigation in future studies. While the ROC curve is widely recognized as a standard metric for assessing model discrimination, it does not provide insights into the practical utility of the model at specific clinical decision thresholds. Clinical decision analysis often involves balancing sensitivity and specificity; it can also quantify the net clinical benefit of the model across various probability thresholds. The results from the DCA curve presented in this study indicate that our developed nomogram not only exhibits strong discriminatory power but also demonstrates substantial clinical utility within the validation set. This suggests that clinicians utilizing this nomogram can effectively avoid unnecessary interventions for numerous low-risk patients while accurately identifying high-risk individuals who genuinely require treatment, thereby optimizing medical resource allocation. However, it is important to note that the DCA curve derived from this study is based on theoretical calculations; thus, its actual clinical benefits warrant further validation through prospective real-world studies.

Limitations

This study has several limitations: first, the single-center retrospective design is prone to selection bias and data collection issues. Certain key variables—including anaesthetic technique details, fluid balance, intraoperative haemodynamics, BNP/NT-proBNP biomarkers, and long-term follow-up protocols—were excluded from the analysis due to incomplete data; second, the small sample size limits the comprehensive reflection of statistical effects for some rare variables; Due to the limited sample size of the cirrhosis subgroup, caution is warranted in interpreting the associated results; third, while internal validation shows good discriminatory ability, its real-world effectiveness needs further verification. In addition, this study primarily concentrated on the systemic and surgery-related risk factors associated with patients, while neglecting to incorporate the local biomechanical variables pertinent to hip fractures in the analysis. Thus, future work will involve large-scale prospective multicentre studies to validate the reliability and efficacy of existing risk models while exploring more granular risk factors (such as anaesthetic technique details, BNP, fluid management, etc). Through collaboration across multiple centers, we seek to expand sample size, improve study representativeness, and enhance the effectiveness of external validation. We also aim to create and validate new risk prediction models that combine clinical, laboratory, and imaging data to enhance predictive accuracy. Future research could leverage biomechanical modeling techniques, such as finite element analysis,[50] to quantify the specific effects of postoperative gait alterations on cardiac load. This approach would facilitate the development of a more accurate predictive model that integrates multiple dimensions of biomechanics and physiology. Additionally, randomized controlled trials will evaluate the impact of various interventions, including pharmacological treatments and lifestyle changes, on reducing postoperative AHF risks. Through these efforts, we aim to deepen our understanding of AHF risk after hip fractures in older adults and offer more robust guidance for clinical practice.

Conclusion

The occurrence of AHF following hip fracture surgery in older adults reaches up to 15.34%. Multivariate logistic regression analysis shows that age, cerebrovascular disease, cirrhosis, malnutrition, intraoperative blood loss, and hypoproteinemia are independent risk factors for postoperative AHF. This study successfully developed a predictive model for postoperative AHF in older adults with hip fractures, offering clinicians a valuable tool to assess the risk of

AHF following surgery. Precise evaluation and forecasting can minimize surgical risks, tackle postoperative issues effectively, lower complication and mortality rates, and enhance patient recovery.

Abbreviations

AHF, acute heart failure; ALT, alanine aminotransferase; AUC, area under the curve; AST, aspartate transaminase; BMI, body mass index; BNP, B-type natriuretic peptide; COPD, chronic obstructive pulmonary disease; CI, confidence interval; CHD, coronary heart disease; DCA, decision curve analysis; HF, heart failure; HFpEF, heart failure with preserved ejection fraction; HFrEF, heart failure with reduced ejection fraction; HFmrEF, heart failure with mildly reduced ejection fraction; IQR, interquartile range; NT-proBNP, N-terminal form of BNP; OR, odds ratio; ROC, receiver operating characteristic; VIFs, variance inflation factors; X±SD, mean ± standard deviation.

Data Sharing Statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Review Committee of Chengdu Fifth People's Hospital Affiliated to Chengdu University of Traditional Chinese Medicine, in accordance with the Helsinki Declaration, and informed consent was waived. All data were anonymized before analysis to protect patient privacy.

Consent for Publication

We hereby declare that the manuscript we have submitted has not been published previously and is not currently under consideration for publication in any other journal. All listed authors have carefully reviewed and approved this manuscript. We all agree to submit it to this journal for publication and understand and accept the journal's publication policy.

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 report no competing interests in this work.

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