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ORIGINAL RESEARCH

Risk Factors and Prediction Model for Postoperative Pneumonia Following Hip Arthroplasty in Older Adults

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Background: Postoperative pneumonia is one of the most common complications following hip arthroplasty in older adults. It often results in delayed recovery, prolonged hospital stays, and increased perioperative mortality rates.

Objective: To analyze the risk factors for postoperative pneumonia in older adults undergoing hip arthroplasty and develop a nomogram-based prediction model using perioperative variables.

Methods: A retrospective analysis was performed on 308 older adults who underwent hip arthroplasty. Relevant clinical data were collected and recorded. Univariate and multivariate logistic stepwise regression analyses were conducted to identify the risk factors for postoperative pneumonia in this population. A risk prediction model for postoperative pneumonia was then developed and visualized using a nomogram.

Results: Among the 308 older adults, 46 developed postoperative pneumonia, with an incidence rate of approximately 14.94%. Multivariate logistic regression analysis revealed that American Society of Anesthesiologists (ASA) classification, intensive care unit (ICU) admission, preoperative anemia, creatine kinase-MB (CKMB), brain natriuretic peptide (BNP), and postoperative aspartate aminotransferase (AST) were independent risk factors for postoperative pneumonia in elderly patients ($P<0.05$). The final prediction model for postoperative pneumonia was: P = 1 / [1 + e^(−3.690 + 0.982×ASA + 0.982×ICU + 0.806×Preoperative Anemia + 1.494×CKMB + 0.843×BNP + 0.917×Postoperative AST)], with Hosmer-Lemeshow $\chi^2 = 5.989$ ($P = 0.541$). Receiver operating characteristic curve analysis showed an area under the curve of 0.792 (95% CI: 0.761–0.823). The Brier score of the calibration curve was 0.103 (close to 0), and decision curve analysis indicated that the threshold probability of the model ranged from 0.01 to 0.8, with net benefits greater than 0 across all probabilities, suggesting the model has good accuracy and clinical utility.

Conclusion: We identified six important predictors—ASA grade, ICU admission, preoperative anemia, CKMB, BNP, and post-operative AST levels—and developed a risk prediction model for postoperative pneumonia following hip arthroplasty in older adults, providing a valuable reference for its prevention in this population.

Keywords: arthroplasty, replacement, hip, pneumonia, risk factors, prediction algorithms, aged

Introduction

The global issue of population aging is becoming increasingly prominent, with growing concerns over the health of elderly individuals. The proportion of elderly populations worldwide continues to rise, and it is projected that by 2050, individuals aged 60 and above will account for 22% of the global population.[1]

As the population ages, the number of elderly patients requiring hip arthroplasty due to conditions such as osteoarthritis, femoral head avascular necrosis, or hip fractures is also on the rise.[2] Over one million hip arthroplasties are performed annually worldwide, and the incidence of both primary and revision surgeries continues to increase.[3] As an effective treatment for hip joint disorders, hip arthroplasty can significantly alleviate pain, improve limb function, and

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enhance the quality of life of patients.[4] However, studies have shown that the incidence of postoperative complications following hip arthroplasty ranges from 2% to 14%.[5]

Postoperative pneumonia is one of the most common complications during the hospitalization period following hip arthroplasty, often leading to slow recovery, prolonged hospitalization, and increased mortality.[6] Therefore, this study aims to retrospectively collect clinical data from older adults undergoing hip arthroplasty, investigate the risk factors for postoperative pneumonia, and develop a risk prediction model to guide clinical prevention and treatment strategies, with the goal of reducing the incidence of postoperative pneumonia in older adults.

Materials and Methods

The study protocol was approved by the Ethics Committee of West China Hospital of Sichuan University (No. 2024–2100). As this study design is retrospective, the ethics committee waived the requirement for informed consent and clinical trial registration. All the data were collected and analyzed anonymously without any potential harm to the patients. The study was conducted in accordance with the Declaration of Helsinki (2013 revision). This study retrospectively collected data from older adults who underwent hip arthroplasty in the department of orthopedics at our hospital between January 2015 and September 2024. The inclusion criteria were as follows: patients aged ≥75 years; patients who had clear surgical indications for hip arthroplasty and successfully underwent the procedure; with complete clinical data. The diagnostic criteria for postoperative pneumonia were new onset pneumonia within 30 days post-surgery which diagnosed according to the definition provided by the Centers for Disease Control and Prevention;[7] The exclusion criteria included: missing clinical medical data, preoperative pneumonia, multiple surgeries during hospitalization, and intraoperative emergencies such as massive bleeding (>3000mL), pulmonary embolism, or cardiac arrest. The flowchart for patients' inclusion is shown in Figure 1.

Clinical data were collected using the hospital's Donghua Digital Information Management System and the Clinical Anesthesia Information System, including patient demographics (age, gender, height, weight), comorbidities (hypertension, diabetes, etc), auxiliary examination results (chest radiograph, pulmonary function, and laboratory indicators), surgical-related factors (surgical approach, duration, blood loss, etc), anesthesia-related factors (anesthesia method, ASA grade, etc), and patient prognosis (postoperative hospitalization duration, discharge status, etc). Preoperative laboratory

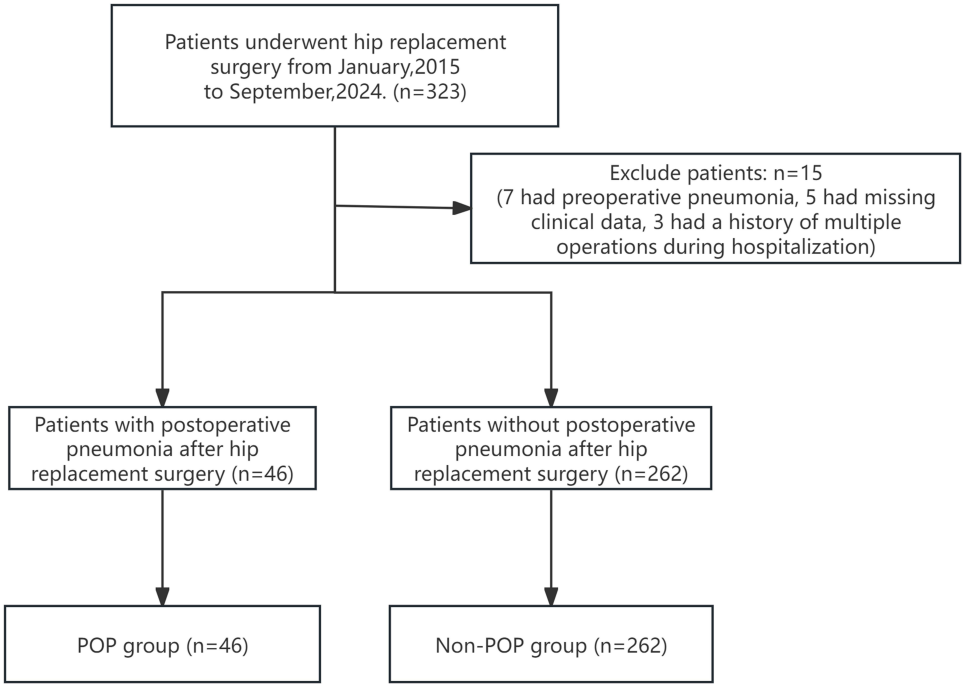

Figure 1 Flow chart of patients' enrollment in this study.

test results were collected on the first day of hospitalization, while postoperative laboratory test results were obtained on the day of surgery.

Statistical analysis was performed using SPSS 26.0 and R 4.4.2. Normally distributed continuous data were described by means and standard deviations, with group comparisons made using independent t-tests. Non-normally distributed continuous data were described by medians and interquartile ranges (IQR), presented as [M (QL, QU)], and group comparisons were made using the Mann–Whitney *U*-test. For categorical variables, counts and percentages were used for description, with group comparisons made using the chi-square test, chi-square test with continuity correction, or Fisher's exact test. All hypothesis tests were two-tailed, with a significance level set at $p < 0.05$. Pneumonia occurrence within 30 days after hip arthroplasty was set as the outcome variable. Stepwise regression was used to select variables, followed by multivariate logistic regression analysis to identify independent risk factors. The independent risk factors were incorporated into a risk prediction model using the R software, and a nomogram was created for visual representation. The model's predictive ability was evaluated using the Receiver Operating Characteristic (ROC) curve and the area under the curve (AUC), and calibration and decision curve analysis (DCA) were performed to assess the prediction model. The nomogram was visualized to illustrate the impact of each variable on the prediction target, with the cumulative effect of all variables leading to the final predicted probability. The prediction model demonstrates the impact of key variables on the target event, clearly expressing the predicted probability corresponding to the input values.

Results

Patient Characteristics

A total of 308 older adults who underwent hip arthroplasty were included in this study. Of these, 46 patients were diagnosed with postoperative pneumonia, resulting in an incidence rate of 14.94% (46/308). Based on the occurrence of postoperative pneumonia, patients were divided into the pneumonia group (POP) and non-pneumonia group (non-POP). The median age and interquartile range (IQR) for the POP group were 83.0 (80.0, 87.0) years, while the median age and IQR for the non-POP group were 81.0 (78.0, 85.0) years (Table 1).

Table 1 Baseline Characteristics and Univariate Analysis

Variables	Patients without Pneumonia (n = 262)	Patients with Pneumonia (n = 46)	P
Age (yr)	81.0 (78.0, 85.0)	83.0 (80.0, 87.0)	0.039
Gender			0.473
Male	177 (67.6%)	28 (60.9%)	
Female	85 (32.4%)	18 (39.1%)	
Weight (kg)	53.0 (49.0, 60.0)	53.0 (48.0, 60.0)	0.646
Height (m)	1.6 (1.5, 1.6)	1.6 (1.5, 1.7)	0.421
BMI (kg/m2)	21.5 (19.5, 23.4)	20.8 (20.0, 23.1)	0.714
Hypertension	140 (53.4%)	31 (67.4%)	0.111
Diabetes	45 (17.2%)	14 (30.4%)	0.057
Cerebral infarction	30 (11.5%)	6 (13%)	0.951
Coronary heart disease	24 (9.2%)	9 (19.6%)	0.065
Heart failure	2 (0.8%)	2 (4.3%)	0.203
Diagnosis			0.215
Avascular necrosis	52 (19.8%)	5 (10.9%)	
Hip fracture	210 (80.2%)	41 (89.1%)	
ASA grade			0.001
<3	134 (51.1%)	11 (23.9%)	
≥3	128 (48.9%)	35 (76.1%)	

(*Continued*)

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Table 1 (Continued).

Variables	Patients without Pneumonia (n = 262)	Patients with Pneumonia (n = 46)	P
Electrocardiograph (abnormal)	63 (24%)	13 (28.3%)	0.67
Chest radiograph (abnormal)	89 (34%)	24 (52.2%)	0.028
Preoperative hypoalbuminemia	4 (1.5%)	0 (0%)	0.891
Preoperative anemia	42 (16%)	16 (34.8%)	0.005
Preoperative anticoagulation	166 (63.4%)	31 (67.4%)	0.72
Creatine kinase-MB			0.005
≤25U/L	255 (97.3%)	40 (87%)	
>25U/L	7 (2.7%)	6 (13%)	
Myoglobin			0.009
Male≤72ng/mL; female≤58ng/mL	234 (89.3%)	34 (73.9%)	
Male>72ng/mL; female>58ng/mL	28 (10.7%)	12 (26.1%)	
Brain natriuretic peptide (pg/mL)			0.001
≤100ng/L	148 (56.5%)	11 (23.9%)	
>100ng/L	114 (43.5%)	35 (76.1%)	
C-reactive protein			0.954
≤10mg/L	223 (85.1%)	39 (84.8%)	
>10mg/L	39 (14.9%)	7 (15.2%)	
Deep venous thrombosis	25 (9.5%)	4 (8.7%)	1
Total protein (g/L)	64.0 ± 6.8	63.4 ± 6.4	0.584
Serum albumin (g/L)	35.7 ± 4.4	34.5 ± 3.7	0.09
Alanine transaminase (U/L)	15.0 (11.0, 22.0)	15.0 (10.0, 20.0)	0.432
Aspertate aminotransferase (U/L)	21.0 (17.0, 26.0)	22.5 (18.0, 26.0)	0.528
Total bilirubin (umol/L)	15.6 (11.7, 21.4)	17.2 (12.8, 21.3)	0.366
Direct bilirubin (umol/L)	5.6 (3.9, 7.6)	6.2 (4.4, 7.9)	0.186
Indirect bilirubin (umol/L)	10.4 (7.4, 14.1)	10.9 (8.1, 14.5)	0.478
Lactate dehydrogenase (U/L)	212.0 (183.0, 251.0)	219.5 (176.0, 252.0)	0.843
Hydroxybutyrate dehydrogenase (U/L)	146.0 (128.0, 170.0)	151.0 (128.0, 178.0)	0.563
Creatine kinase (U/L)	99.0 (69.0, 164.0)	93.0 (72.0, 149.0)	0.797
Urea nitrogen (mmol/L)	6.4 (5.2, 7.7)	7.3 (5.1, 7.7)	0.649
Creatinine (umol/L)	71.0 (59.0, 88.0)	70.5 (63.0, 91.0)	0.618
Uric acid (umol/L)	312.5 (235.0, 381.0)	325.5 (271.0, 447.0)	0.224
Triglyceride (mmol/L)	1.1 (0.8, 1.5)	1.1 (0.8, 1.4)	0.721
High densitylipoprotein cholesterol (mmol/L)	1.2 (1.0, 1.5)	1.2 (0.9, 1.5)	0.178
Low density lipoprotein cholesterol (mmol/L)	2.5 ± 0.8	2.4±0.8	0.361
Blood glucose (mmol/L)	5.6 (5.0, 6.6)	5.8 (5.0, 6.9)	0.284
Potassium (mmol/L)	3.8 ± 0.5	4.0 ± 0.5	0.036
Chloridion (mmol/L)	105.4 (102.9, 107.7)	104.3 (101.2, 106.8)	0.14
Calcium (mmol/L)	2.2 (2.1, 2.2)	2.1 (2.0, 2.2)	0.058
White blood cell count (10^9/L)	6.8 (5.7, 8.9)	7.7 (5.7, 9.1)	0.159
Hematocrit (%)	38.2 ± 5.2	36.4 ± 6.8	0.092
Platelet count (10^9/L)	192.0 (160.0, 249.0)	183.0 (150.0, 269.0)	0.764
Prothrombin time (s)	12.7 (11.6, 14.0)	13.2 (11.8, 14.3)	0.115
International normalized ratio	1.1 (1.0, 1.1)	1.1 (1.0, 1.2)	0.068
Activated partial thromboplastin time (s)	30.6 (26.6, 38.5)	34.5 (28.3, 40.9)	0.053
Thrombin time (s)	16.0 (15.2, 16.9)	16.1 (15.4, 16.9)	0.633
Fibrinogen (g/L)	3.8 (3.0, 4.5)	3.9 (3.4, 4.6)	0.251
Antithrombin (g/L)	80.9 (73.5, 89.0)	82.5 (71.1, 90.0)	0.955
D dimer (mg/L)	2.7 (1.6, 6.1)	3.3 (2.3, 7.4)	0.174
Fibrinogen degradation products (mg/L)	9.4 (5.0, 19.0)	10.0 (6.7, 23.7)	0.491

(*Continued*)

Table 1 (Continued).

Variables	Patients without Pneumonia (n = 262)	Patients with Pneumonia (n = 46)	P
Preoperative hospital stay	6.0 (4.0, 8.0)	6.0 (4.0, 8.0)	0.962
Surgical options			0.306
Femoral head replacement	201 (76.7%)	39 (84.8%)	
Total hip replacement	61 (23.3%)	7 (15.2%)	
Anesthesia method			0.884
Intravertebral Anesthesia	194 (74%)	33 (71.7%)	
General Anaesthesia	68 (26%)	13 (28.3%)	
Night surgery	20 (7.6%)	4 (8.7%)	1
Intraoperative heart rate			0.769
Normal	226 (86.3%)	41 (89.1%)	
Abnormal	36 (13.7%)	5 (10.9%)	
Intraoperative systolic blood pressure			0.008
Normal	112 (42.7%)	30 (65.2%)	
Abnormal	150 (57.3%)	16 (34.8%)	
Intraoperative diastolic blood pressure			0.178
Normal	222 (84.7%)	43 (93.5%)	
Abnormal	40 (15.3%)	3 (6.5%)	
Blood loss (mL)	200.0 (100.0, 300.0)	200.0 (150.0, 300.0)	0.155
Duration of surgery (min)	100.0 (90.0, 120.0)	120.0 (90.0, 120.0)	0.333
Total fluidin take (mL)	1500 (1000, 2000)	1500 (1100, 1500)	0.454
Red blood cell transfusion	33 (12.6%)	11 (23.9%)	0.073
Intraoperative urine volume (mL)	200.0(100.0, 400.0)	275.0(100.0, 500.0)	0.547
Postoperative ICU admission	39 (14.9%)	20 (43.5%)	<0.001
Postoperative albumin (g/L)	29.6 ± 4.3	28.0 ± 4.0	0.017
Postoperative direct bilirubin (umol/L)	5.0 (3.7, 6.6)	5.4 (3.6, 8.2)	0.5
Postoperative total protein (g/L)	54.1±6.3	53.8 ± 6.2	0.762
Postoperative alanine transaminase (U/L)	19.0 (13.0, 27.0)	23.5 (17.0, 31.0)	0.007
Postoperative aspartate aminotransferase (U/L)	29.0 (23.0, 36.0)	32.5 (27.0, 48.0)	0.004
Postoperative total bilirubin (umol/L)	12.8 (9.7, 16.5)	13.6 (9.8, 19.1)	0.248
Postoperative indirect bilirubin (umol/L)	7.8 (5.5, 10.2)	7.8 (5.6, 11.8)	0.32
Postoperative urea nitrogen (mmol/L)	7.6 (5.8, 8.5)	7.8 (5.8, 9.6)	0.669
Postoperative creatinine (umol/L)	67.0 (55.0, 81.0)	68.0 (57.0, 88.0)	0.316
Postoperative uric acid (umol/L)	282.0 (208.0, 339.0)	295.5 (223.0, 390.0)	0.166
Postoperative potassium (mmol/L)	4.1 ± 0.6	4.1 ± 0.5	0.566
Postoperative sodium (mmol/L)	139.1 (136.9, 141.5)	138.9 (136.8, 141.9)	0.683
Postoperative chloridion (mmol/L)	106.5 ± 4.5	107.5 ± 4.2	0.164
Postoperative calcium (mmol/L)	2.0 (1.9, 2.1)	2.0 (1.9, 2.1)	0.101
Postoperative white blood cell count (10^9/L)	9.2 (7.5, 11.5)	9.7 (7.8, 12.5)	0.202
Postoperative hemoglobin (g/L)	107.1 ± 16.1	101.4 ± 18.0	0.03
Postoperative hematocrit (%)	32.3 (29.3, 35.2)	30.5 (27.5, 34.5)	0.076
Postoperative blood platelet count (10^9/L)	204.5 (160.0, 254.0)	187.0 (149.0, 266.0)	0.796
Postoperative prothrombin time (s)	13.4 (11.9, 14.2)	13.9 (12.8, 14.8)	0.022
Postoperative international normalized ratio	1.1 (1.0, 1.1)	1.1 (1.1, 1.2)	0.059
Postoperative activated partial thromboplastin time (s)	32.9 (26.6, 35.8)	36.4 (30.5, 41.2)	0.003
Postoperative fibrinogen (g/L)	3.9 (3.2, 4.3)	4.2 (3.4, 4.8)	0.1
Postoperative thrombin time (s)	15.4 (14.8, 16.0)	15.3 (14.3, 16.1)	0.229
Postoperative D dimer (mg/L)	4.3 (2.4, 5.1)	4.4 (2.6, 7.3)	0.343

Univariate Analysis

Univariate analysis was performed to identify significant risk factors associated with postoperative pneumonia. Notably, 16 perioperative factors showed a significant correlation with postoperative pneumonia ($P < 0.05$). These factors included age, ASA grade, postoperative ICU admission, preoperative chest radiograph, preoperative potassium (K), preoperative anemia, creatine kinase-MB (CKMB), myoglobin (MYO), Brain natriuretic peptide (BNP), intraoperative systolic blood pressure, postoperative albumin (ALB), postoperative alanine aminotransferase (ALT), postoperative aspartate aminotransferase (AST), postoperative hemoglobin (HB), postoperative prothrombin time (PT), and postoperative activated partial thromboplastin time (APTT) (Table 1).

Multivariate Logistic Regression Analysis

All variables that showed significance in the univariate analysis were included in the stepwise logistic regression analysis. The multivariate analysis revealed that the following six variables were independent risk factors for postoperative pneumonia in elderly patients undergoing hip arthroplasty (Table 2): ASA grade, ICU admission, preoperative anemia, CKMB, BNP, and postoperative AST.

Risk Prediction Model

Based on the results of the multivariate logistic regression analysis, a risk prediction model for postoperative pneumonia in older adults undergoing hip arthroplasty was constructed. The predicted probability of the model is calculated as: P = 1 / [1 + e^(−3.690 + 0.982×ASA + 0.982×ICU + 0.806×Preoperative Anemia + 1.494×CKMB + 0.843×BNP + 0.917×Postoperative AST)]. The risk prediction model was built based on all independent risk factors and visualized using a nomogram (Figure 2). In addition, a case diagram were showed in Figure 3. A random sample was selected from the study cohort, and the nomogram prediction model was applied to this sample. Figure 3 demonstrated the actual prediction result of the selected sample patient, with a risk score of 188 and a risk probability of 0.292 for postoperative pneumonia.

Receiver Operating Characteristic (ROC) curve analysis revealed an area under the curve (AUC) of 0.792 (95% CI: 0.761–0.823), with a sensitivity of 76.7% and specificity of 67.4%, indicating good model performance (Figure 4). Furthermore, the model's C-index was 0.792 (95% CI: 0.761–0.823). The larger the C-index, the better the differentiation of the model, suggesting that the nomogram prediction has high accuracy.

A calibration curve was plotted to evaluate the model's discriminative ability, and the Hosmer-Lemeshow test was conducted. The calibration curve showed a good fit between the nomogram and the reference line (Figure 5), with a Hosmer-Lemeshow $\chi 2$ value of 5.989 and a P-value of 0.541, indicating no significant statistical difference. This suggests that the model fits well with the observed values. The Brier score was 0.103 (close to 0), indicating that the nomogram model's predictions for postoperative pneumonia probability were consistent with the actual infection percentage observed in the sample population, as shown in Figure 5.

Decision Curve Analysis (DCA) was used to evaluate the clinical utility of the nomogram model by determining the net benefit (NB) for each patient at different thresholds of postoperative pneumonia risk. The horizontal axis of the DCA represents the high-risk threshold probability, while the vertical axis represents net benefit. When the nomogram model reaches a certain threshold, the probability of a patient developing pneumonia (denoted as Pi) is recorded. When Pi

Table 2 Multivariate Logistic Regression Analysis

Variables	β	S.E.	Wald	P value	*OR*	OR 95% CI
ASA grade	0.982	0.404	5.901	0.015	2.669	1.209, 5.893
ICU admission	0.982	0.380	6.671	0.010	2.671	1.267, 5.628
Preoperative anemia	0.806	0.400	4.057	0.044	2.239	1.022, 4.906
CKMB	1.494	0.657	5.172	0.023	4.457	1.229, 16.159
BNP	0.843	0.406	4.309	0.038	2.323	1.048, 5.149
Postoperative AST	0.917	0.388	5.598	0.018	2.503	1.171, 5.351

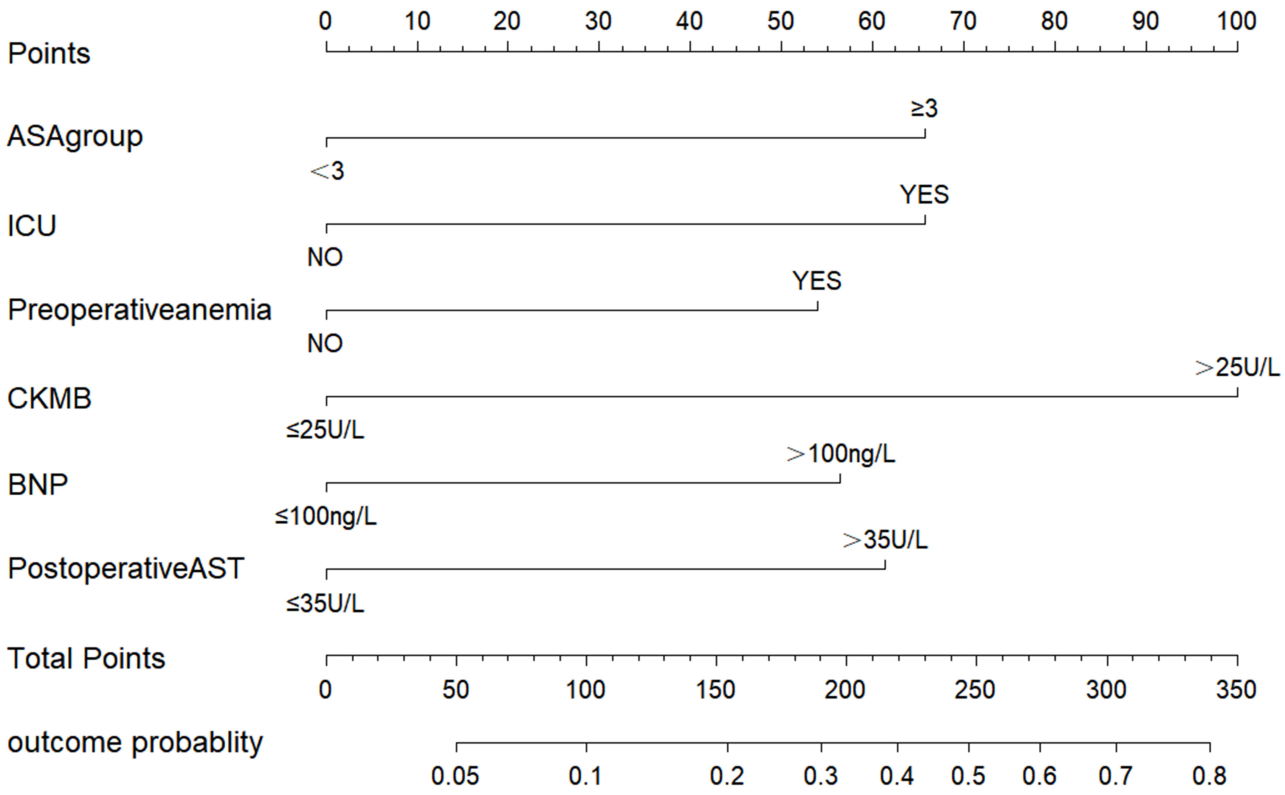

Figure 2 The nomogram prediction model.

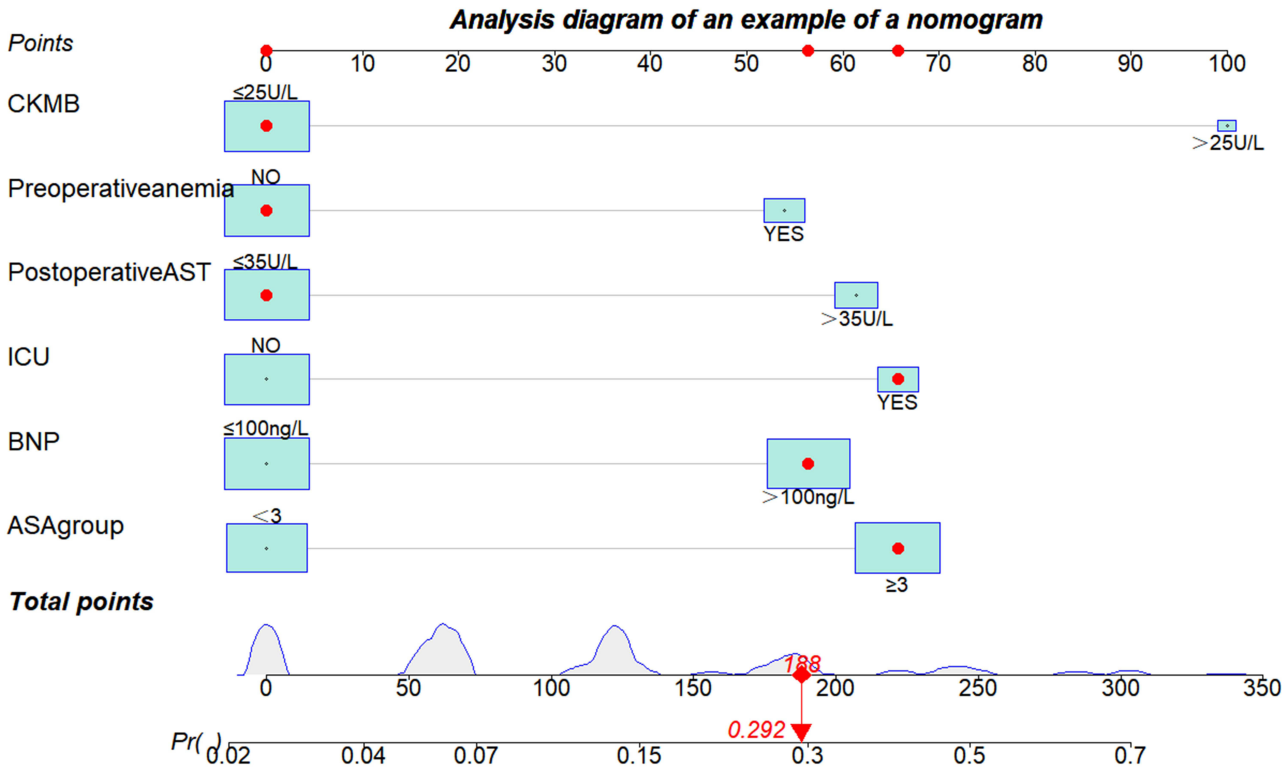

Figure 3 Analysis diagram of an example of a nomogram.

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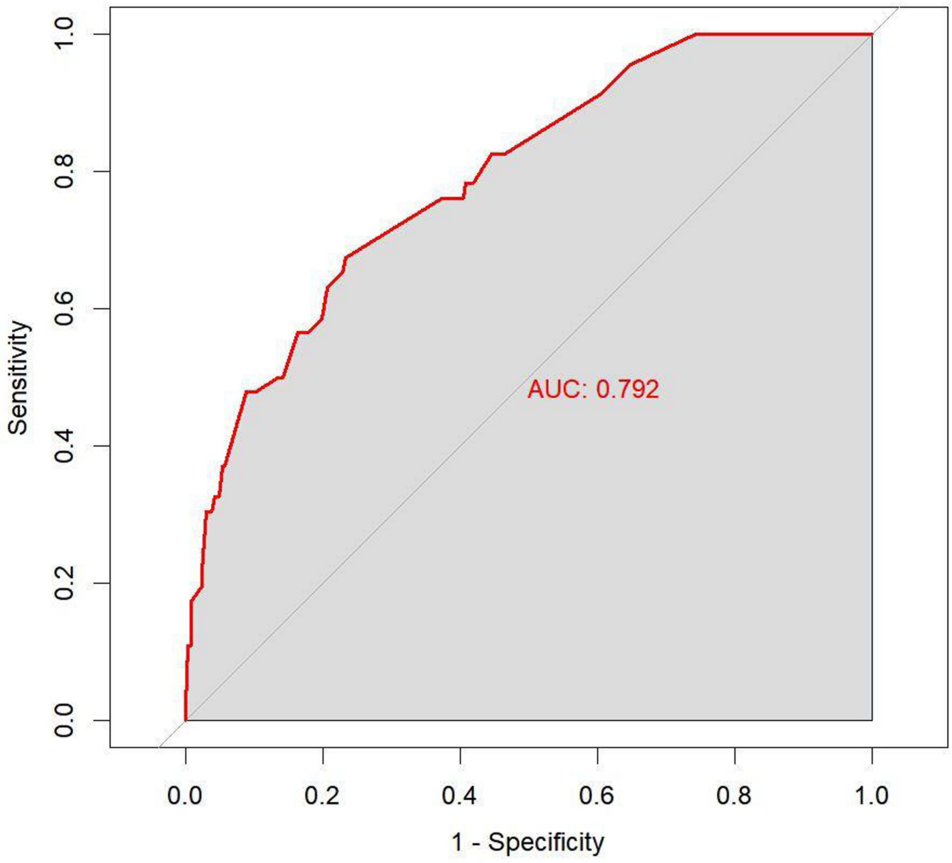

Figure 4 ROC curve and AUC value of the risk prediction model.

exceeds a specific threshold, it is classified as positive (denoted as Pt). The model's net benefit rate is evaluated by subtracting false positive cases. The threshold probability of the model was found to range from 0.01 to 0.8, with net benefit rates consistently greater than 0, indicating clinical applicability. This suggests that the model has good clinical value in predicting postoperative pneumonia in elderly patients undergoing hip arthroplasty (Figure 6).

Outcomes

A retrospective analysis was conducted on the outcomes of older adults undergoing hip arthroplasty. The results revealed that the postoperative length of hospital stay in the POP group was 15.0 (10.0, 22.0) days, significantly longer than the non-POP group, which had a median of 13.0 (10.0, 18.0) days ($P < 0.05$). The total hospitalization costs for the POP group were 41,295.0 (33,287.6, 52,456.1) CNY, notably higher than the non-POP group, which had a median of 36,870.7 (31,657.7, 44,810.2) CNY ($P < 0.05$). Additionally, the proportion of patients in the POP group who required hospitalization for more than 14 or 30 days was significantly higher than that of the non-POP group ($P < 0.05$). Furthermore, the postoperative mortality rate in the POP group was significantly higher than in the non-POP group ($P < 0.05$), as shown in Table 3.

Discussion

Pneumonia is a serious and potentially life-threatening complication following hip arthroplasty in older adults.[8,9] Preventing and reducing the incidence of postoperative pneumonia is of significant clinical importance. Our study identified ASA grade, ICU admission, preoperative anemia, CKMB, BNP, and postoperative AST as independent risk factors for pneumonia after hip arthroplasty in older adults; all were incorporated into the prediction model. Furthermore, we attempted to apply the prediction model to preoperative clinical decision-making by constructing a simple nomogram.

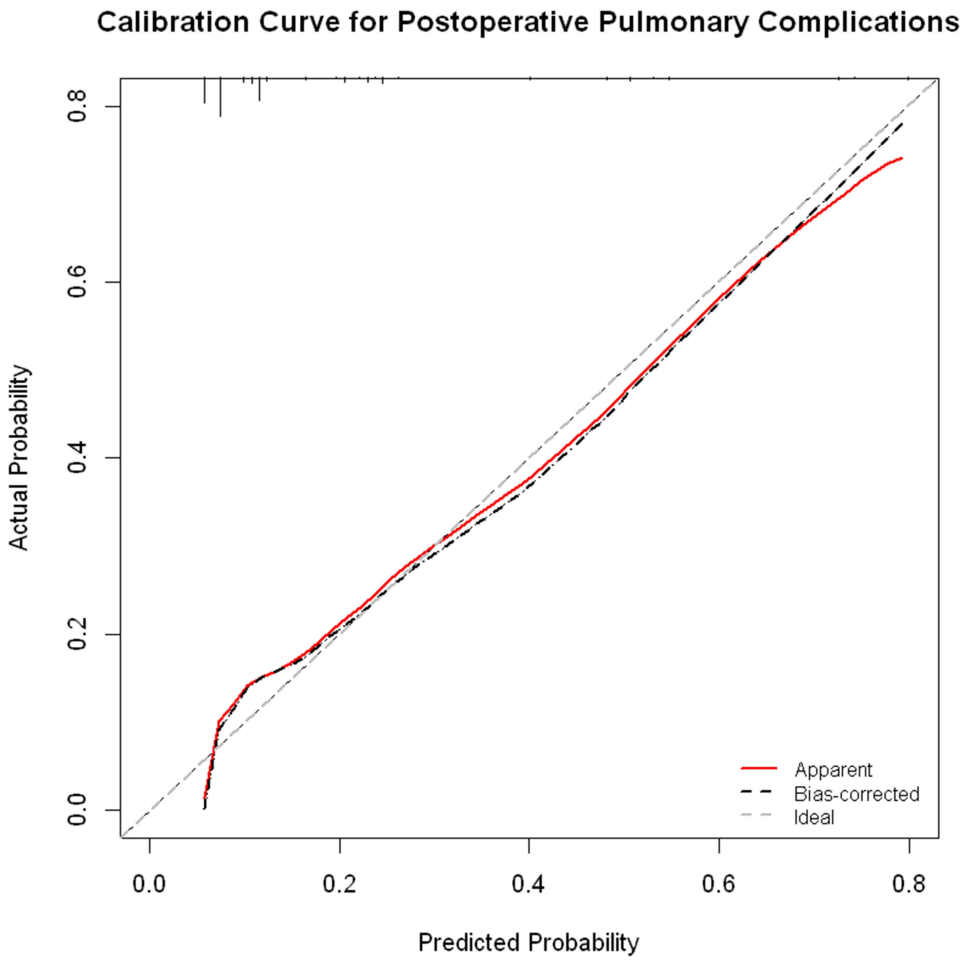

Figure 5 The calibration curve of the risk prediction model.

ASA grade is a useful indicator of perioperative health status.[10] Our study demonstrated that ASA grade ≥ 3 is significantly associated with pneumonia after hip arthroplasty in older adults. This finding is consistent with previous reports,[10–12] as a higher ASA grade typically reflects more severe comorbidities and a greater risk of postoperative complications. ICU admission was also identified as a risk factor for pneumonia in older adults undergoing hip arthroplasty. Obviously, patients admitted to the ICU are generally more severely ill,[13,14] and many require endotracheal intubation and mechanical ventilation, which inherently increase the risk of respiratory infection.[15] Moreover, the incidence of postoperative pneumonia rises with longer ICU stays.[16] Preoperative anaemia is common in patients with hip fracture, with a prevalence of 18.8%, in line with previous reports (12.3–55.4%).[17–19] We found that preoperative anaemia was associated with a higher risk of postoperative pneumonia, corroborating earlier studies.[19,20] Anaemia may indicate poor nutritional status and impaired immunity, thereby predisposing patients to infection. In addition, preoperative anaemia was associated with an increased likelihood of perioperative blood transfusion ($P < 0.001$), which can suppress immunity and cause transfusion-related lung injury, further elevating the risk of pneumonia.

CK-MB, BNP, and AST are widely used clinical laboratory indicators and were confirmed in our study as important predictors of postoperative pneumonia. CK-MB is generally regarded as a specific marker of myocardial injury and plays an essential physiological role in cardiomyocytes. We found that older adults with elevated CK-MB had a four-fold greater risk of postoperative pneumonia compared with those with normal levels. Although 53% of patients with hip fracture develop myocardial infarction, the risk of symptomatic myocardial infarction after hip fracture is 29% higher than in the general population.[21] The pathophysiological link between CK-MB and postoperative pneumonia remains unclear; whether a cardiopulmonary interaction mechanism underlies this association warrants further investigation. BNP

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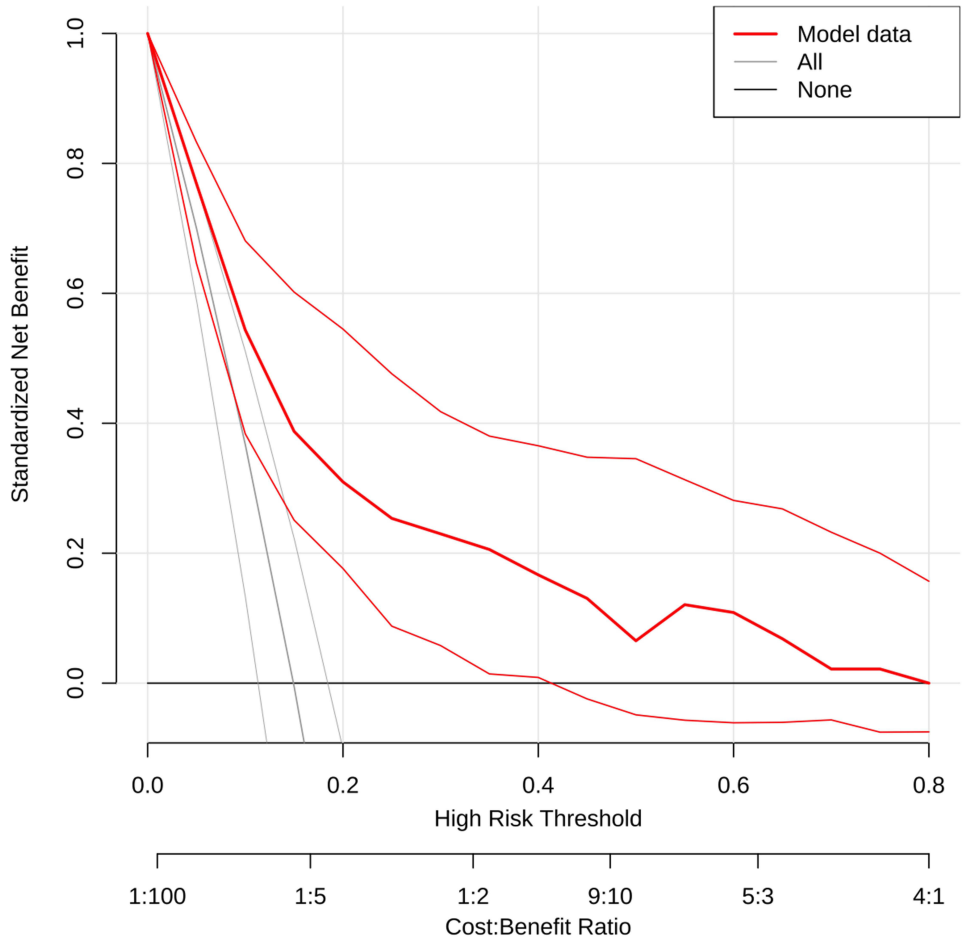

Figure 6 Decision curve analysis of the risk prediction model.

is another widely used biomarker closely related to cardiopulmonary disease.[22] Recent studies indicate that pro-inflammatory cytokines and activation of the sympathetic nervous system induce BNP secretion.[23,24] Li Wet al further demonstrated that BNP is an independent factor for severe pneumonia, with higher BNP levels indicating more severe pneumonia.[25] This association may reflect increased alveolar exudation leading to consolidation, oedema, and impaired gas exchange; the resulting rise in inflammatory mediators and hypoxaemia causes pulmonary vasoconstriction and increased cardiac afterload, thereby elevating BNP levels.[26] We also found that postoperative AST was associated with

Table 3 The Outcomes of Patients with Postoperative Pneumonia

Outcomes	Non-POP group	POP group	P
Total cost of hospitalization (CNY)	36870.7 (31657.7, 44810.2)	41295.0 (33287.6, 52456.1)	0.017
Total length of stay (days)	13.0 (10.0, 18.0)	15.0 (10.0, 22.0)	0.011
≥30 days	42 (13.95%)	4 (57.14%)	0.008
<30 days	259 (86.05%)	3 (42.86%)	
Postoperative hospital stay (days)	7.0 (5.0, 10.0)	9.5 (6.0, 14.0)	0.006
≥14days	31 (12.25%)	15 (27.27%)	0.005
<14 days	222 (87.75)	40 (72.73%)	
≥30 days	43 (14.14%)	3 (75%)	0.011
<30 days	261 (85.86%)	1 (25%)	
Mortality	43 (14.14%)	3 (75%)	0.011

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a higher risk of postoperative pneumonia—an observation not previously reported. Elevated AST has been linked to H1N1 and COVID-19 pneumonia,[27,28] and the AST/ALT ratio has been proposed as both a predictor of community-acquired pneumonia in older adults and a potential predictor of 1-year mortality after femoral-neck fracture.[29,30]

Results of this study indicate that postoperative pneumonia typically leads to a significant prolongation of hospitalization. Additionally, the total hospitalization costs for patients with postoperative pneumonia are significantly increased, and the postoperative mortality rate is also considerably higher. These findings are consistent with previous studies, which have identified pneumonia as the third most common postoperative complication, frequently resulting in a 7–9 day extension of hospital stay and an increased mortality rate.[31] Moreover, the occurrence of pneumonia elevates the risk of readmission and exacerbates the burden on healthcare systems.[32,33]

Previous studies have developed clinical prediction models to identify risk factors for postoperative pneumonia.[34–36] However, nomograms specifically designed to predict postoperative pneumonia in older adults undergoing hip arthroplasty remain scarce. Earlier models included only a limited range of predictors. To address this gap, we incorporated multidimensional patient data—baseline characteristics, surgical and anaesthetic variables, and diverse physiological and biochemical markers. Moreover, past prediction models have often lacked performance validation, making them difficult to apply and improve in clinical practice.[34–36] In contrast, our nomogram is concise, objective, and has undergone extensive performance evaluation. Notably, earlier research often excluded laboratory indices such as CK-MB, BNP, and AST, which may appear unrelated to postoperative pneumonia based on clinical experience. Instead, investigators frequently focused on blood index like anaemia and hypoalbuminaemia, overlooking other routinely collected laboratory tests in older surgical patients.[34,35] Our findings confirm that anaemia and hypoalbuminaemia are important risk factors for postoperative pneumonia, but CK-MB, BNP, and AST are likewise significant predictors. CK-MB, in particular, demonstrated an odds ratio (OR) of 4.457, far exceeding that of other factors—a contribution clearly reflected in the nomogram. By including these objective, routinely measured laboratory variables, our model is more realistic, reliable, and easy to implement. We therefore propose its use in preoperative assessments of older adults undergoing hip arthroplasty to help clinicians quantify the risk of postoperative pneumonia.

Given the limitations of clinical prediction models, our goal is to use robust statistical methods to develop a model that offers more reliable predictions. Although the model's performance was evaluated through calibration curves and decision curve analysis, and the results indicate good discrimination and validity, this study has some limitations. Firstly, as a retrospective clinical study, there is a potential for bias in the data collection, as all data were obtained from a single hospital. Therefore, results may differ in other regions or among different populations. In addition, the study's inclusion criteria were fixed and limited, and the sample size was relatively small, which could lead to potential bias in the results. Finally, not all perioperative variables were captured: pre-operative laboratory indices were obtained only on the first hospital day, and post-operative indices only on the day of surgery, potentially omitting key predictors. We hypothesize that larger, multicenter studies will yield more accurate predictive models.

Conclusion

Postoperative pneumonia is associated with adverse clinical outcomes in older adults undergoing hip arthroplasty. In this retrospective, single-center study, we identified six independent risk factors for postoperative pneumonia: ASA grade, ICU admission, preoperative anemia, CKMB, BNP, and postoperative AST levels. We also developed a risk prediction model based on these six predictors, providing a valuable reference for the prevention of postoperative pneumonia in this population. The model may aid clinical decision-making by enabling early identification of high-risk patients and facilitating more tailored preventive strategies.

Data Sharing Statement

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

This study protocol was approved by the Institutional Ethics Committee of West China Hospital of Sichuan University (Chengdu, China, approval number: 2024-2100). The requirement of written informed consent was waived due to the retrospective nature of the study, and all the data were collected and analyzed anonymously without any potential harm to the patients. The study was conducted in accordance with the Declaration of Helsinki (2013 revision).

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 that there are no competing interests in this work.

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