Article

Analysis of Risk Factors for Perioperative Transfusion in Hip Arthroplasty and Modeling of a Nomogram

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Huaqin Qiu[1], Liqun Jiang[1], Ping Lin[1], Zhijuan Wei[1], Xingyan Wang[2], Junrong Qiu[3]

[1]Department of Clinical Laboratory, Yingtan 184 Hospital, 335000 Yingtan, Jiangxi, China
[2]Department of Clinical Laboratory, The First Affiliated Hospital of Changsha Medical University, 410219 Changsha, Hunan, China
[3]Department of Orthopedics, Yingtan 184 Hospital, 335000 Yingtan, Jiangxi, China

AIM: To investigate the risk factors of perioperative transfusion in hip arthroplasty and to construct a nomogram model to predict the risk of transfusion.
METHODS: A total of 120 patients who underwent hip arthroplasty in our hospital from January 2022 to October 2023 were retrospectively selected and classified as training set. According to the same selection criteria, another 50 patients who underwent hip arthroplasty from December 2023 to December 2024 were selected as validation set. All patients' general information, surgical indicators, laboratory indicators, etc., were collected. Logistic regression analysis was performed to identify risk factors for perioperative transfusion. A risk warning scoring model-based nomogram was constructed using Rstudio 4.2.1. The predictive accuracy of the model was evaluated through internal and external validation.
RESULTS: Among the 120 patients in the training set, 34 of them (28.33%) who received perioperative transfusion were categorized into transfusion group, in which 19 patients (15.83%) received intraoperative transfusion whereas 15 (12.50%) received postoperative transfusion. Patients who did not received perioperative transfusion were categorized into non-transfusion group (n = 86). Compared with subjects in the non-transfusion group, those in the transfusion group were elder, experienced longer surgery, suffered from more severe intraoperative bleeding, and had lower hemoglobin level ($p < 0.05$). Multivariate regression analysis showed that age, operation time, and intraoperative hemorrhage were the independent factors, and that hemoglobin level was an independent protective factor for perioperative transfusion in hip arthroplasty. Receiver operating characteristic (ROC) curve analysis showed that the area under the curve (AUC) for the combined prediction of age, operation time, intraoperative bleeding, and hemoglobin in the context of perioperative transfusion during hip arthroplasty was 0.940, which was higher than that of individual prediction. The difference between the general information of the training set and validation set was not statistically significant ($p > 0.05$). The calibration curves of the nomogram for predicting perioperative transfusion in hip arthroplasty converged to the ideal curve (training set: p = 0.651, validation set: p = 0.181). Decision curve analysis (DCA) curves depict a higher positive net benefit for the nomogram in the probability threshold range of 5% to 97%. The AUC of the ROC curve for predicting perioperative transfusion in hip arthroplasty in the training and validation sets were 0.940 (0.916–0.991) and 0.925 (0.879–0.941), respectively.
CONCLUSIONS: Age, operation time and intraoperative bleeding are independent risk factors, while hemoglobin level is an independent protective factor for perioperative transfusion in hip arthroplasty. The nomogram established based on the above factors has good predictive performance, which is helpful in assessing the risk of perioperative transfusion, formulating personalized transfusion strategies, reducing unnecessary transfusions and related complications.

Keywords: hip arthroplasty; perioperative transfusion; risk factors; nomogram

Introduction

Hip arthroplasty is an effective treatment for severe hip disorders such as necrosis of the femoral head and osteoarthritis of the hip [1]. This procedure entails surgical removal of damaged hip tissue, including diseased femoral head and acetabular cartilage, and subsequent implantation of an artificially manufactured hip prosthesis to replace the original joint [2]. The accelerated aging of the population is accompanied by the rising incidence of hip diseases, underlining the increasing need for hip arthroplasty procedures [3]. Hip arthroplasty aims to relieve patients' pain, improve joint function, and enhance quality of life; however, individuals undergoing the procedure are vulnerable to perioperative bleeding—one of the common complications caused by hip arthroplasty—which necessitates blood transfusion therapy [4]. Transfusion can improve a hemorrhagic patient's anaemic state and maintain the normal physiological

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Correspondence to: Junrong Qiu, Department of Orthopedics, Yingtan 184 Hospital, 335000 Yingtan, Jiangxi, China (e-mail: qiujunrong226@126.com).

function, but perioperative transfusion is closely related to a variety of adverse consequences [5]. In addition, blood transfusion is one of the numerous pathways through which viruses, bacteria and other pathogens are transmitted. According to research statistics, the prevalence rate of infection of hepatitis B virus caused by blood transfusion ranges from 0.06% in low-prevalence countries to 12% in high-prevalence countries. Although such infectious risk can be curtailed through the adoption of modern blood transfusion technology, there is still no guarantee that a complete non-infection can be achieved [6]. Aside from these adverse effects, the input of allogeneic blood components may trigger the patient's immune response, leading to fever, allergy, hemolysis, etc., and affecting postoperative recovery [7]. In addition, transfusion is associated with tumor recurrence and cardiovascular complications, increasing the length of hospital stay and healthcare costs for patients [8]. Therefore, accurately identifying the risk factors for perioperative transfusion in hip arthroplasty and taking effective preventive measures are of great significance in reducing the need for transfusion and lowering the risks associated with transfusion. The aim of this study is to investigate the risk factors of perioperative transfusion in hip arthroplasty and to construct a nomogram model for prediction.

Materials and Methods

General Information

A total of 120 patients who underwent hip arthroplasty in Yingtan 184 Hospital from January 2022 to October 2023 were retrospectively selected and categorized into a training set. Another cohort consisting of 50 patients who underwent hip replacement surgery from December 2023 to December 2024 were selected according to the same criteria and categorized into the validation set. Data derived from the training set were used to construct a nomogram, which was validated, in terms of internal repeatability, in the validation set. Informed consent of all patients was obtained, and the study was conducted in strict adherence to the principles of the Declaration of Helsinki. This project was approved by the Ethics Committee of Yingtan 184 Hospital (184YY-2025-LL-007).

Patients who fulfilled the following criteria were included: (1) having complete clinical data; (2) having undergone hip arthroplasty for the first time in our hospital; (3) aged $\geq$18 years; (4) no hematological diseases; and (5) no immunodeficiency diseases. Exclusion criteria of the present study are as follows: (1) comorbid with malignant tumor; (2) comorbid with severe hepatic or renal insufficiency; (3) pregnant or breastfeeding women; and (4) accompanied by severe cardiovascular and cerebrovascular diseases.

The sample size needed for this study was calculated using the following formula: $n = Z^2{}_{\alpha/2}\ p(1\text{-}p)/d^2$, where n, d, and p are estimated values of sample size, allowable error, and population rate π, respectively. The *p*-value was conservatively estimated, that is, $p = 0.5$ was assumed for each variable. Taking into account the two-sided statistical significance $\alpha = 0.05$, z as the boundary value of the standard normal part, and an allowable error d of 0.075, a sample size consisting of 170 cases was determined.

Methodology

The hospital's electronic medical record system was used to collect clinical information of all patients, including gender, age, body mass index (BMI), place of residence, education level, per capita monthly household income, whether they lived alone, underlying diseases, history of smoking, and history of alcohol consumption.

Surgery-related indicators were collected, including the mode of surgery, duration of surgery, intraoperative bleeding, and whether general anaesthesia was used.

From each of the patients admitted to the hospital, 5 mL of fasting venous blood was taken early in the morning and centrifuged at 4000 r/min for 5 min, with a centrifugal radius of 10 cm. A hematocrit analyzer (Model: BC-6900, Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China) was used to detect the levels of hemoglobin and platelets. A fully automated biochemical analyzer (Model: AU5800, Shanghai Beckman Coulter Trading Co., Ltd., Shanghai, China) was utilized to detect the level of albumin, and an automatic coagulation analyzer (Model: CA-8000, Shanghai Sysmex Medical Electronics Co., Ltd., Shanghai, China) was employed to detect the level of D-dimer.

Perioperative blood transfusion is a treatment method involving intravenous infusion of whole blood or blood components, such as red blood cells, plasma, and platelets, to maintain the patient's blood oxygen carrying capacity, blood volume, coagulation function, etc., during a period before and after surgery [9]. This period can be preoperative, intraoperative, and postoperative until the patient's condition achieves stabilization. The indications for blood transfusion include: moderate to severe anemia (such as hemoglobin $<$70 g/L) before surgery; hemodynamic instability caused by acute blood loss; acute intraoperative blood loss exceeding 20% of total blood volume or progressive bleeding accompanied by coagulation dysfunction; persistent postoperative bleeding; and hemoglobin levels below clinical thresholds (usually $<$80 g/L and accompanied by tissue hypoxia). The perioperative blood transfusion time range is defined as 7 days before surgery to 3 days after surgery, which needs to be dynamically adjusted according to the individual patient's condition and surgical type. The types of blood products include red blood cell suspension (used to enhance oxygen carrying capacity), fresh frozen plasma (used to correct coagulation factor deficiency), single platelet collection (used to treat thrombocytopenia or functional abnormalities), and cryoprecipitation (used to supplement coagulation factors such as fibrinogen).

Statistical Methods

SPSS 26.0 (IBM Corporation, Armonk, NY, USA) was employed for data analysis in this study. Categorical data are expressed as count and percentage. Chi-square test was used to analyze the categorical variables. Quantitative data were tested using Kolmogorov–Smirnov test; normally distributed data were presented as mean ± standard deviation (SD). An independent sample *t*-test was used for intergroup comparison. Logistic regression analysis was conducted to identify risk factors for perioperative transfusion in hip replacement, which were subsequently used to establish a predictive model. The receiver operating characteristic (ROC) curve was plotted, and the area under the curve (AUC) was calculated and compared using the DeLong test. A risk warning scoring model-based nomogram was constructed using Rstudio 4.2.1 (Posit PBC, Boston, MA, USA). For model validation, the Hosmer-Lemeshow test was used to assess the calibration of the predictive model, and the *p*-value of the calibration curve was derived from this test. The bootstrap method for repeated sampling was used to calculate the predicted probability and actual probability. Calibration curves were drawn using Survminer and other packages; AUC was calculated and ROC curves were drawn using the pROC package; and decision curve analysis (DCA) curves were drawn using the rmda package. Results with $p < 0.05$ were considered statistically significant.

Results

Perioperative Transfusion in the Training Set

Among the 120 patients in the training set, 34 of them (28.33%) received transfusion during the perioperative stage were categorized into the transfusion group, in which 19 patients (15.83%) received intraoperative transfusion, and 15 patients (12.50%) received postoperative transfusion. The remaining patients who did not receive perioperative transfusion were categorized into the non-transfusion group ($n = 86$).

Comparison of General Data Between the Two Groups in the Training Set

There was no statistically significant difference in general data between the transfusion and non-transfusion groups ($p > 0.05$). The age of the transfusion group was higher than that of the non-transfusion group. In addition, compared with the subjects in the non-transfusion group, those who received perioperative transfusion experienced longer surgery, suffered from more severe intraoperative bleeding, and had lower hemoglobin level ($p < 0.05$), as shown in Table 1.

Multivariate Regression Analysis for Perioperative Transfusion of Hip Arthroplasty in the Training Set

The results of multiple regression analysis showed that age, operation time, and intraoperative blood loss were independent risk factors for perioperative transfusion during hip arthroplasty, whereas hemoglobin level was identified as the independent protective factor ($p < 0.05$), as shown in Table 2.

Combined Prediction of Risk Factors for Perioperative Transfusion During Hip Arthroplasty in the Training Set

The ROC curve analysis showed that the AUC for the combined prediction of age, operation time, intraoperative blood loss, and hemoglobin level for perioperative transfusion during hip arthroplasty was 0.940, which was higher than that of the individual prediction. The sensitivity and specificity were 88.24% and 87.21%, respectively, as shown in Table 3, and the ROC curve is shown in Figs. 1,2,3,4,5,6.

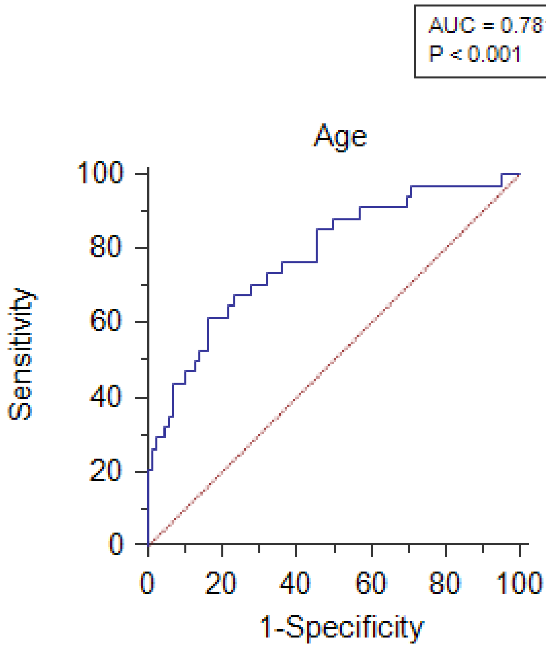

Fig. 1. ROC curve of age for predicting perioperative transfusion in hip replacement. Abbreviations: AUC, area under the curve; ROC, receiver operating characteristic.

Comparison of General Data Between Training and Validation Sets

The difference between the general data between the training and validation sets was not statistically significant ($p > 0.05$), as shown in Table 4.

Modeling Nomogram for Predicting Perioperative Transfusion in Hip Arthroplasty

Results from the logistic regression analysis were used to construct a nomogram model, encompassing four risk factors, namely age, operation time, intraoperative bleeding, and hemoglobin level, for risk scoring, as shown in Fig. 7. Using the bootstrap method to sample 1000 times, calibration curves were plotted to evaluate the model consistency,

Table 1. Comparison of general data between the two groups in the training set.

Variable	Transfusion group (n = 34)	Non-transfusion group (n = 86)	χ^2/t	p-value
Sex (M/F)	21/13	46/40	0.677	0.411
Age (years)	61.17 ± 7.89	54.45 ± 6.68	4.712	<0.001
Body mass index (kg/m^2)	23.17 ± 2.54	23.26 ± 2.39	0.183	0.855
Educational attainment			0.592	0.442
High school and below	25 (73.53)	57 (66.28)		
College and above	9 (26.47)	29 (33.72)		
Current residence			0.169	0.681
Cities and towns	22 (64.71)	59 (68.60)		
Countryside	12 (35.29)	27 (31.40)		
Monthly per capita household income (CNY)			0.036	0.982
<3000	15 (44.12)	39 (45.35)		
3000–5999	13 (38.24)	33 (38.37)		
>6000	6 (17.64)	14 (16.28)		
Living alone			0.209	0.647
Yes	8 (23.53)	17 (19.77)		
No	26 (76.47)	69 (80.23)		
Smoking history	8 (23.53)	23 (26.74)	0.131	0.717
Drinking history	14 (41.18)	39 (45.35)	0.172	0.678
History of hypertension	20 (58.82)	44 (51.16)	0.575	0.448
History of hyperlipidemia	6 (17.65)	21 (24.42)	0.641	0.423
History of diabetes	22 (64.71)	57 (66.28)	0.027	0.870
Surgical procedure			0.161	0.689
Unilateral hip replacement	18 (52.94)	49 (56.98)		
Bilateral hip replacement	16 (47.06)	37 (43.02)		
Types of hip replacement surgery			0.536	0.464
Total hip replacement	11 (32.35)	34 (39.53)		
Hemiarthroplasty	23 (67.65)	52 (60.47)		
Operation time (min)	128.73 ± 19.44	109.97 ± 19.37	4.521	<0.001
Intraoperative bleeding volume (mL)	303.31 ± 45.18	260.39 ± 44.49	4.688	<0.001
General anaesthesia			1.103	0.293
Yes	21 (61.76)	44 (51.16)		
No	13 (38.24)	42 (48.84)		
Hemoglobin (g/L)	118.23 ± 7.45	125.36 ± 7.33	4.780	<0.001
Blood platelet (10^9/L)	218.87 ± 15.37	220.05 ± 17.09	0.350	0.727
Albumin (g/L)	38.06 ± 3.56	38.27 ± 3.63	0.287	0.775
D-dimer (mg/L)	1.45 ± 0.36	1.52 ± 0.41	0.871	0.385
Postoperative hemoglobin (g/L)	116.48 ± 6.86	118.79 ± 7.17	1.540	0.126

M, male; F, female. 1 CNY = 0.1394 USD.

and the results showed that the calibration curves corresponding to the training and validation sets in the nomogram for predicting perioperative transfusion in hip arthroplasty converged to the ideal curves (p = 0.651 and 0.181, respectively), indicating that the predicted perioperative transfusion incidence in hip arthroplasty was in high consistency with the actual incidence (Figs. 8,9).

To further evaluate the clinical utility of the model, DCA curves were plotted with the horizontal coordinate indicating the threshold probability and the vertical coordinate indicating the net benefit. This is concordant with the probability thresholds for the training and validation sets that range from 5% to 97% in the nomogram for perioperative transfusion in hip arthroplasty, indicating a higher positive net benefit, as shown in Figs. 10,11.

The nomogram features the predictive indicators of perioperative transfusion in hip arthroplasty. According to the ROC curve analysis, the AUC (95% CI) for predicting perioperative transfusion in hip arthroplasty for the training and validation sets were 0.940 (0.916–0.991) and 0.925 (0.879–0.941), respectively, indicating that the model has good predictive value, as shown in Figs. 12,13.

Discussion

Given the rich blood vessel networks surrounding the hip joint, surgical trauma in the region will inevitably lead to

Table 2. Multivariate regression analysis for perioperative transfusion of hip arthroplasty in the training set.

Variable	B	SE	Wald	p-value	OR	95% CI
Age	0.217	0.058	14.062	$<$0.001	1.243	1.109–1.393
Operation time	0.047	0.016	8.919	0.003	1.048	1.016–1.082
Intraoperative bleeding volume	0.026	0.009	9.083	0.003	1.027	1.009–1.044
Hemoglobin level	–0.183	0.051	13.003	$<$0.001	0.833	0.754–0.920

Table 3. Prediction values of perioperative blood transfusion risk factors for hip replacement surgery based on training set.

Variable	AUC	Standard error	95% CI	p-value	Cut-off value	Youden index	Sensitivity (%)	Sensitivity 95% CI	Specificity (%)	Specificity 95% CI
Age	0.781*	0.048	0.697–0.852	$<$0.001	$>$59.785	0.455	61.76	43.60–77.80	83.72	74.50–90.90
Operation time	0.826*	0.042	0.746–0.889	$<$0.001	$>$117.682	0.563	91.18	76.30–98.10	65.12	54.60–75.40
Intraoperative bleeding volume	0.734*	0.053	0.646–0.810	$<$0.001	$>$279.527	0.415	70.59	25.50–84.90	70.93	59.40–79.50
Hemoglobin	0.689*	0.058	0.598–0.770	0.001	$\leq$117.806	0.384	50.00	32.40–67.60	88.37	79.70–94.30
Combined detection	0.940	0.021	0.916–0.991	$<$0.001	-	0.754	88.24	72.50–96.70	87.21	83.30–73.40

Note: $*p < 0.05$ compared with combined detection. AUC, area under the curve.

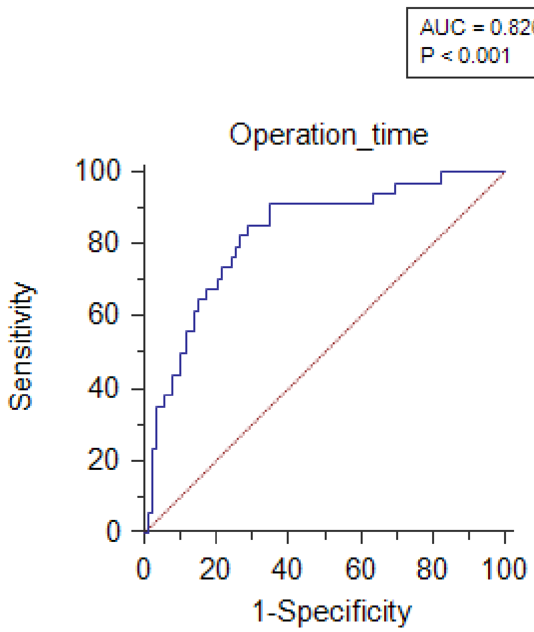

Fig. 2. ROC curve of operation time for predicting perioperative transfusion in hip replacement.

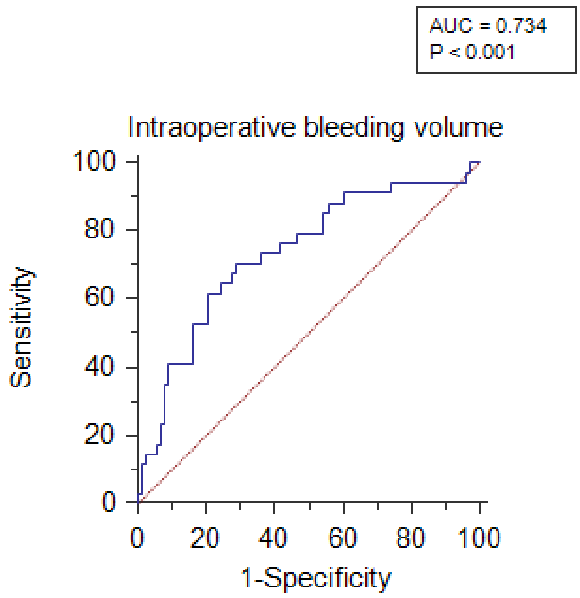

Fig. 3. ROC curve of intraoperative bleeding for predicting perioperative transfusion in hip replacement.

hemorrhage [10]. Excessive blood loss and a significant drop in hemoglobin level to below the threshold necessitate blood transfusion as an essential supportive treatment measure [11]. By improving anemic symptoms, restoring tissue and organ oxygen supply, promoting postoperative recovery, and reducing the risk of various complications due to anemia, such as cardiovascular and cerebrovascular events, infections, etc., adequate transfusion offers protection to patients during surgery and ensures a good prognosis [12,13]. Nevertheless, blood transfusion may augment the risk for tumor recurrence. Through the transfusion procedure, growth factors are infused into the body, stimulating tumor cell proliferation and affecting the process of tumor recurrence through multiple pathways [14]. Blood transfusion can also introduce immune regulatory cells and factors, interfere with the body's anti-tumor immunity, and promote tumor cell immune escape. Thus, accurate identification of risk factors for perioperative transfusion in hip arthroplasty is important for optimizing transfusion strategies and improving patients' surgical safety and prognosis. By analyzing risk factors, clinicians can conduct a comprehensive assessment of patients before surgery and formulate personalized transfusion plans for high-risk patients in advance, such as adopting autologous transfusion and applying erythropoietin and other drugs to improve hemoglobin levels, so as to reduce the need for intraoperative and postoperative allogeneic transfusions. At the same time, implementing

Table 4. Comparison of general data between training and validation sets.

Variable	Training set (n = 120)	Validation set (n = 50)	χ^2/t	p-value
Sex (M/F)	67/53	29/21	0.067	0.795
Age (years)	58.26 ± 6.79	58.34 ± 6.42	0.071	0.943
Body mass index (kg/m^2)	23.22 ± 2.43	23.16 ± 2.24	0.150	0.881
Educational attainment			0.223	0.636
High school and below	82 (68.33)	36 (72.00)		
College and above	38 (31.67)	14 (28.00)		
Current residence			0.875	0.349
Cities and towns	81 (67.50)	30 (60.00)		
Countryside	39 (32.50)	20 (40.00)		
Monthly per capita household income (CNY)			0.295	0.863
<3000	54 (45.00)	21 (42.00)		
3000–5999	46 (38.33)	19 (38.00)		
>6000	20 (16.67)	10 (20.00)		
Living alone			0.527	0.468
Yes	25 (20.833)	8 (16.00)		
No	95 (79.17)	42 (84.00)		
Smoking history	31 (25.83)	16 (32.00)	0.671	0.413
Drinking history	53 (44.17)	19 (38.00)	0.560	0.458
History of hypertension	64 (53.33)	25 (50.00)	0.157	0.692
History of hyperlipidemia	27 (22.50)	16 (32.00)	1.686	0.194
History of diabetes	79 (65.83)	31 (62.00)	0.227	0.633
Surgical procedure			0.209	0.647
Unilateral hip replacement	67 (55.83)	26 (52.00)		
Bilateral hip replacement	53 (44.17)	24 (48.00)		
Types of hip replacement surgery			0.187	0.666
Total hip replacement	45 (37.50)	17 (34.00)		
Hemiarthroplasty	75 (62.50)	33 (66.00)		
Operation time (min)	114.58 ± 19.15	115.23 ± 19.20	0.201	0.841
Intraoperative bleeding volume (mL)	282.54 ± 44.74	281.72 ± 44.56	0.169	0.866
General anaesthesia			0.210	0.647
Yes	65 (54.17)	29 (58.00)		
No	55 (45.83)	21 (42.00)		
Hemoglobin (g/L)	122.19 ± 7.49	122.43 ± 7.32	0.192	0.848
Platelet (10^9/L)	219.56 ± 16.28	218.79 ± 16.45	0.280	0.780
Albumin (g/L)	38.16 ± 3.71	38.42 ± 3.55	0.422	0.674
D-dimer (mg/L)	1.49 ± 0.39	1.44 ± 0.33	0.795	0.428
Postoperative hemoglobin (g/L)	117.89 ± 7.04	117.66 ± 7.13	0.193	0.847

1 CNY = 0.1394 USD.

preventive measures targeting the risk factors, such as optimizing surgical techniques, strengthening intraoperative hemostasis, and rationally using hemostatic drugs, can effectively reduce surgical blood loss, thereby reducing the necessity for blood transfusions.

The results of this study showed that out of 120 patients in the training set, 34 of them (28.33%) received perioperative transfusion, of which 19 (15.83%) received transfusion during surgery and 15 (12.50%) after surgery. Further analysis showed that compared to the non-transfusion group, subjects in the transfusion group were older, experienced longer surgery, suffered from more severe intraoperative bleeding, and had lower hemoglobin levels. Age, operation time, and intraoperative bleeding were identified in this analysis as independent risk factors, whereas hemoglobin level was determined as an independent protective factor for perioperative transfusion in hip arthroplasty. Aging is a normal biological process associated with a gradual decline of organ function, such as bone marrow hematopoiesis [15]. Generally, elderly patients have a lower number of hematopoietic stem cells in the bone marrow, reduced proliferation and differentiation ability of the cells, decreased production of red blood cells, and lower reserve capacity. In the event of surgical blood loss, the body is incapable of quickly and effectively replenishing blood, raising the probability of subjecting patients to an anemic state, which

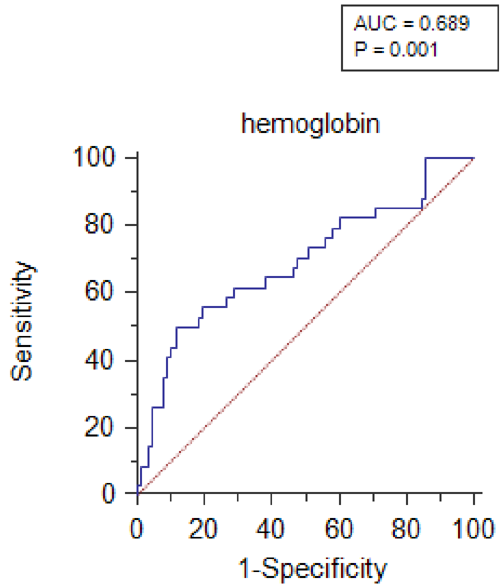

Fig. 4. ROC curve of hemoglobin level for predicting perioperative transfusion in hip replacement.

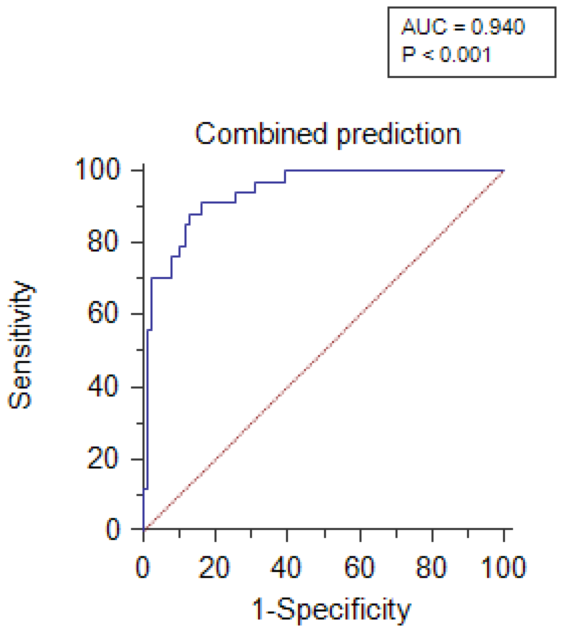

Fig. 5. ROC curve of the combined risk factors for predicting perioperative transfusion in hip replacement.

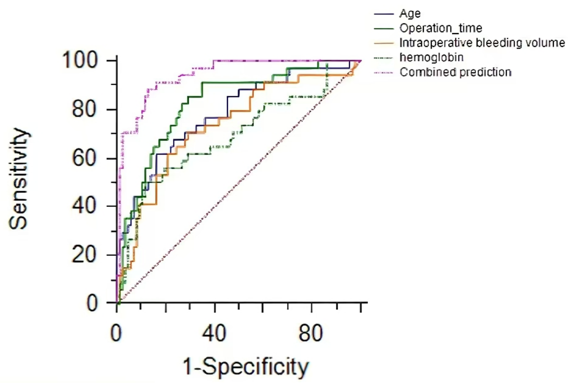

Fig. 6. ROC curves of all identified risk factors for predicting perioperative transfusion in hip arthroplasty. Abbreviation: ROC, receiver operating characteristic.

necessitates perioperative transfusion for life sustenance. Longer duration of surgery is associated with greater volume of blood lost [16]. Besides, prolonged surgical operations can result in more blood vessels being cut or damaged, and despite intraoperative hemostatic measures that have been done, it is challenging to avoid bleeding during surgery, which leads to blood loss at a level beyond the body's compensatory capacity—a situation that warrants blood transfusion. Extended operation time also suggests more extensive operations such as tissue separation and retraction, which causes more trauma to the surrounding tissues [17]. Tissue trauma activates the body's inflammatory response and coagulation system. Under this circumstance, inflammatory mediators may affect the function of vascular endothelial cells, leading to increased vascular permeability and aggravating the bleeding tendency. Excessive activation of the coagulation system may trigger an abnormal coagulation state such as disseminated intravascular coagulation, which further depletes the coagulation factors, further compounding difficulty to achieve hemostasis, which unfortunately increases risks for blood loss that require transfusion support. Hemoglobin is a special protein that transports oxygen within erythrocytes and can directly reflect the oxygen-carrying capacity of the body [18]. A high preoperative hemoglobin level suggests that the patient's blood is able to carry enough oxygen to supply the tissues and organs throughout the body under normal physiological conditions. Despite a certain amount of blood loss during surgery, a higher level of hemoglobin ensures an effective and sustained oxygen supply to satisfy the body's needs, coupled with the body's compensatory mechanisms, such as increasing cardiac output and improving the uptake and utilization of oxygen by the tissues, minimizing the need for blood transfusions to correct anemia and maintain oxygen supply. Erben *et al.* [19] suggested that age and hemoglobin levels are important influencing factors for perioperative transfusion during hip arthroplasty, and the risk of transfusion can be assessed by the above-mentioned indicators. Song *et al.* [20] suggested that prolonged operation time, high intraoperative blood loss, and low hemoglobin level are independent risk factors for perioperative transfusion in hip arthroplasty, and that appropriate interventions targeting these factors should be formulated for patients during the perioperative period to reduce the need for blood transfusion. Their findings are consistent with our results.

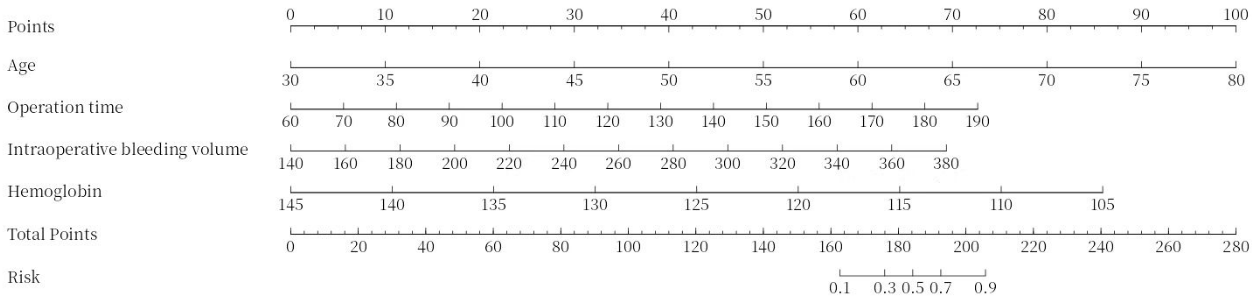

Fig. 7. Nomogram featuring risk factors for perioperative transfusion in hip arthroplasty.

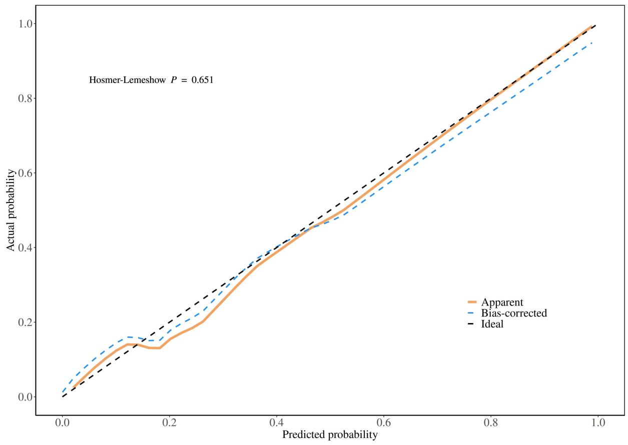

Fig. 8. Predictive probability of perioperative transfusion in hip arthroplasty for the training set.

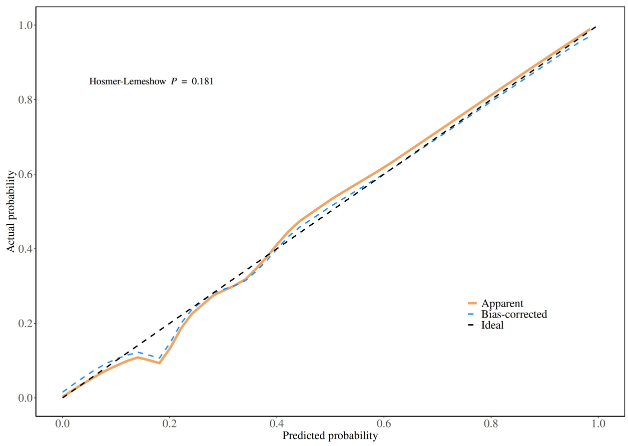

Fig. 9. Predictive probability of perioperative transfusion in hip arthroplasty for the validation set.

This study also showed that the AUC of the combined risk factors, namely age, operation time, intraoperative blood loss, and hemoglobin level for predicting perioperative transfusion in hip arthroplasty was 0.940, which was higher than that of prediction by individual risk factors, indicating that the combined usage of identified risk factors for predicting blood transfusion in hip arthroplasty holds relatively high promise. Furthermore, age, operation time, intraoperative blood loss, and hemoglobin level were integrated in the construction of a prediction model in the form of a nomogram. The calibration curves showed good predictive values, and the model predictions of perioperative transfusion in hip arthroplasty converged to the ideal curve, indicating high agreement between the predicted and actual incidence rates. The AUCs (95% CI) for the training and validation sets in risk prediction of perioperative transfusion in hip arthroplasty were 0.940 (0.916–0.991) and 0.925 (0.879–0.941), respectively, indicating that the model has good predictive value. These metrics suggest that the nomogram constructed in this study is a robust and trustworthy tool for blood transfusion prediction. The risk factors for perioperative transfusion, which can be identified by collecting relevant indicators and patients' general information, can help pinpoint high-risk patients and offer insights into developing personalized treatment plans. Based on the above findings, clinicians can assess the necessity for transfusion using the nomogram according to their patient's specific situation. Zang *et al*. [21] found that their prediction model, constructed with surgical time and preoperative hemoglobin level, held high value in predicting perioperative transfusion for elderly patients undergoing unilateral total hip replacement surgery, which is similar to the results of this study. In the clinical context of hip replacement surgery, a perioperative blood transfusion prediction model based on age, intraoperative blood loss, operation time, and hemoglobin level can help improve patient care and treatment outcomes. A presurgical assessment can help identify high-risk patients using the model, for whom physicians can formulate personalized transfusion plans, such as pre-adjustment of hemoglobin level for anemic individuals and adjustment of blood component preparation. During the operation, the risk factors indicated by the prediction model should be closely monitored, while controlling operation time and implementing appropriate interventive measures to reduce bleeding. Once the bleeding volume approaches the predicted threshold, timely measures should be taken to stop bleeding or for blood transfusion. Postop-

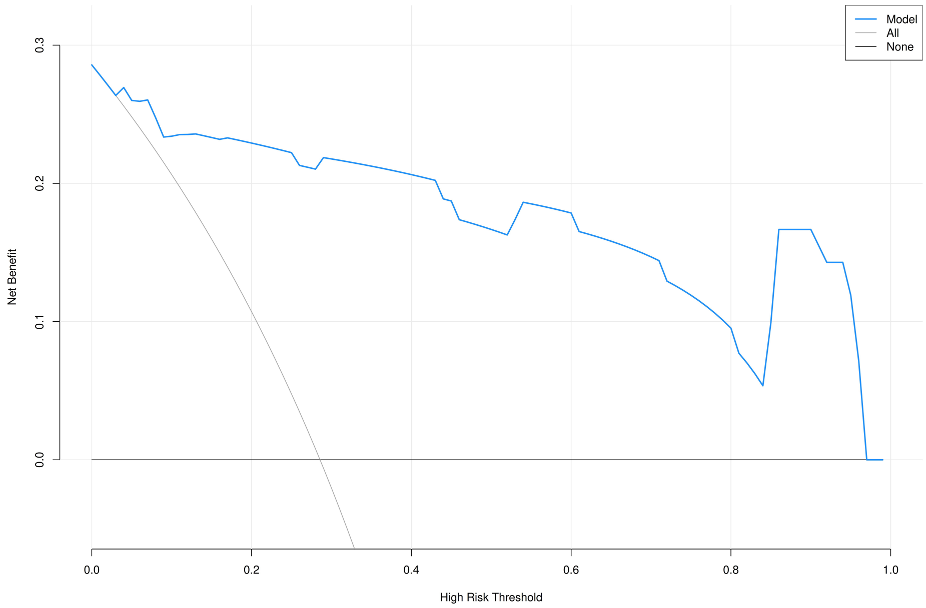

Fig. 10. DCA curve for predicting perioperative transfusion in hip arthroplasty for the training set. DCA, decision curve analysis.

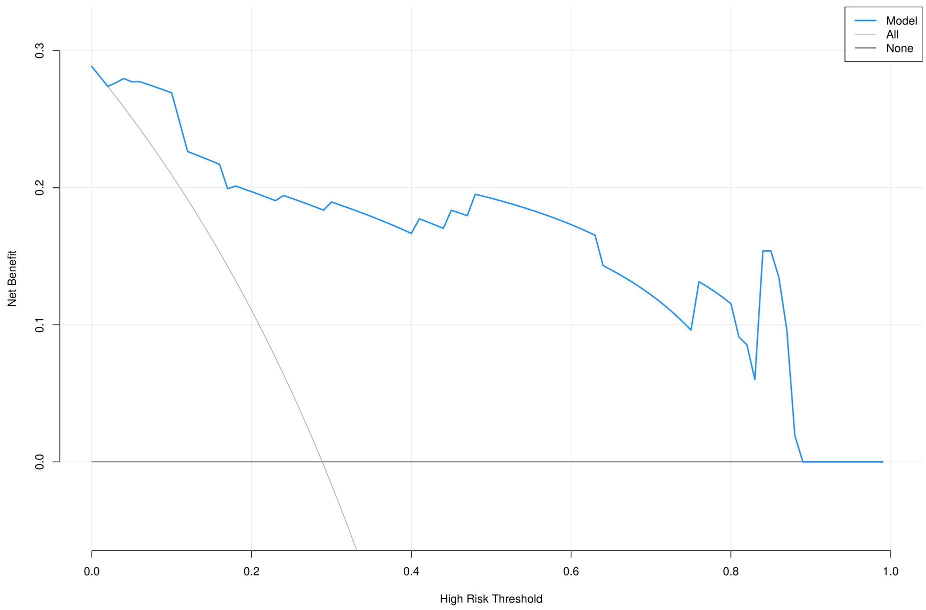

Fig. 11. DCA curve for predicting perioperative transfusion in hip arthroplasty for the validation set.

erative uses of the prediction model include evaluating the patient's recovery status, monitoring patients who are predicted to require blood transfusion, ensuring safety and effectiveness of blood transfusion, and adjusting nursing priorities to prevent transfusion-related complications such as infection and fever, all of which are critical for improving quality of patient care and enhancing overall treatment effect of hip replacement surgery. For high-risk patients, personalized strategies can be developed in advance [22,23]. For example, autologous blood transfusion can be carried out before surgery for patients who are very likely to need a blood transfusion. The autologous approach involves transfusing the patient's blood, which is preoperatively collected and stored for a period of time, during surgery to effectively reduce the complications commonly seen after allogeneic transfusion. Protective measures during intraoperative blood transfusion, such as controlling blood pressure, should be carried out to reduce intraoperative bleeding by

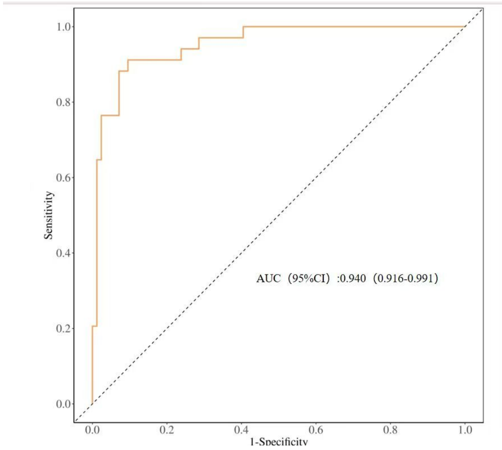

Fig. 12. ROC curve for predicting perioperative transfusion in hip arthroplasty for the training set.

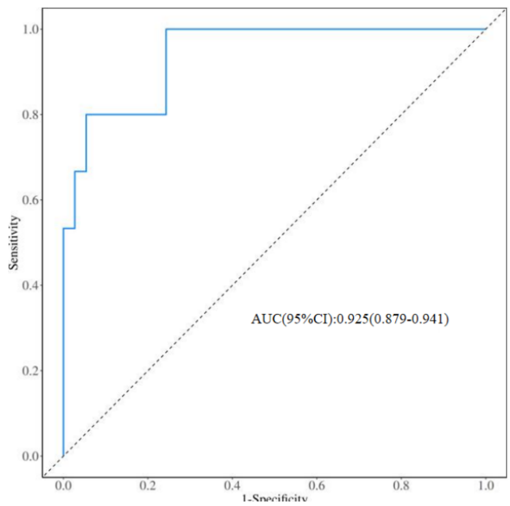

Fig. 13. ROC curve for predicting perioperative transfusion in hip arthroplasty for the validation set.

lowering blood pressure. Autologous re-transfusion, which involves re-transfusing the blood lost intraoperatively or postoperatively back to the patient after processing, can be considered to reduce the need for allogeneic blood transfusion [24,25]. In addition, the nomogram can be used in clinical research as a tool for screening high-risk patients, which helps in conducting targeted clinical trials and studies.

A few limitations of this study should be highlighted. Given the retrospective nature of the current study, only historical data were collected, which is prone to selection bias. Secondly, the research was only conducted in a specific population, without external validation in other populations, therefore substantially lowering the generalizability of the findings. In addition, the varying levels of experience and technical expertise of surgeons who performed the operations for this sample may impact the accuracy of our findings and conclusions. Furthermore, important confounding factors such as etiological diagnosis, surgical approach, use of anticoagulant and hemostatic drugs were not fully considered in the analysis, and many key coagulation indicators were also not included. These factors may interfere with the research results and affect the accuracy and universality of the conclusions. In the future, prospective multicenter studies with expanded sample sizes need to be conducted to overcome the selection bias common in retrospective studies and to improve the generalizability of the current conclusions through external validation of results in diverse regions and ethnic groups. Further considerations for optimizing similar studies in the future also include standardizing surgical procedures and minimizing individual differences across various surgical aspects.

Conclusions

In summary, age, operation time and intraoperative bleeding are independent risk factors for perioperative transfusion in hip arthroplasty, whereas hemoglobin level is an independent protective factor. The nomogram constructed in the present study holds a high degree of accuracy in predicting perioperative transfusion during hip arthroplasty, offering a promising tool for early identification of high-risk patients in the clinic and implementation of appropriate interventions.

Availability of Data and Materials

The data used and/or analyzed during the current study are available from the corresponding author JQ.

Author Contributions

HQ and LJ designed this study. HQ, LJ, and ZW conducted this study. PL, JQ and XW analyzed the data. HQ and ZW drafted the manuscript. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Informed consent of patients was obtained, and the study was conducted in strict adherence to the principles of the Declaration of Helsinki. This project was approved by the Ethics Committee of Yingtan 184 Hospital (184YY-2025-LL-007).

Acknowledgment

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

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