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ORIGINAL ARTICLE

Establishment of a predictive model for blood transfusion after femoral head replacement in elderly patients

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ABSTRACT

Objectives: The study aimed to establish a nomogram predictive model for blood transfusion after artificial femoral head replacement surgery in elderly patients with intertrochanteric fractures.

Patients and methods: Two hundred five elderly patients (55 males, 150 females; mean age: 82.1±6.6 years; range, 63 to 103 years) with intertrochanteric femoral fractures who underwent artificial femoral head replacement surgery between January 2015 and May 2023 were retrospectively analyzed. The patients were randomly divided into two groups: the training group (n=143) and the validation group (n=62). Within the training group, patients were further categorized into the nontransfused (n=86) and transfused (n=57) groups. Perioperative data were collected for logistic regression analysis to identify risk factors for postoperative blood transfusion. A nomogram model was developed to predict the need for blood transfusion, with assessments including the C-index, receiver operating characteristic curve, decision curve analysis, and clinical impact curve.

Results: Logistic regression analysis showed that low preoperative hemoglobin levels, high intraoperative bleeding volume, high drainage volume, the use of wire reinforcement, and history of cerebral infarction were the independent risk factors for transfusion after femoral head replacement. Both decision curve analysis and clinical impact curves indicated that the prediction model could be used as a good prediction tool for blood transfusion after artificial femoral head replacement for intertrochanteric femoral fractures in the elderly.

Conclusion: A nomogram prediction model that effectively assesses the risk of blood transfusion in elderly patients undergoing femoral head replacement for intertrochanteric femoral fractures was established in this study. This model demonstrated high predictive accuracy and consistency, providing a valuable tool for clinicians to identify high-risk patients and implement early interventions to reduce the need for postoperative blood transfusions.

Keywords: Artificial femoral head replacement, blood transfusion, elderly, femoral intertrochanteric fracture, nomograms.

Senile intertrochanteric fractures of the femur are a major public health issue. By the end of 2022, there were about 759 million elderly people worldwide, and there were approximately 850,000 intertrochanteric fractures of the femur every year.[1] Intertrochanteric fractures of the femur not only lead to disability and reduced quality of life but also increased mortality. From 2000 to 2018, the overall one-year mortality rate for intertrochanteric fractures of the femur was 17.47%.[2] Artificial femoral head replacement was a common operation for the treatment of femoral intertrochanteric fractures. It has the advantages of allowing patients to become ambulatory early and recover hip function.[3]

Due to the high trauma and long operation time, some elderly patients may suffer from anemia and need blood transfusion after femoral head replacement. Transfusion increases the risk of transmission and development of infectious diseases, hemolysis, immune responses, and joint infection around the incision.[4-8] In addition, blood resources are scarce and precious, and collection, storage, and management require huge economic expenditures.[9]

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A meta-analysis showed that restrictive transfusion strategies had no effect on mortality, functional recovery, and postoperative morbidity in patients after hip surgery.[10] The free transfusion strategy (hemoglobin threshold of 10 g/dL) was more likely to increase the risk of cerebrovascular accidents.[11] Hence, early identification of risk factors for blood transfusion following intertrochanteric fractures to mitigate this risk holds significant clinical value in promoting the judicious utilization of blood products.

Several studies have investigated the risk factors for blood transfusion following artificial femoral head replacement in elderly patients with intertrochanteric fractures. Wang et al.'s[9] study showed that factors such as low preoperative hemoglobin level and high intraoperative blood loss were independently associated with blood transfusion. Testa et al.[12,13] pointed out that patients with low preoperative hemoglobin levels and long operation times had a high risk of blood transfusion. However, a comprehensive evaluation has not been conducted. Therefore, this study aimed to establish a nomogram predictive model to aid in the clinical identification and early intervention of patients at high risk of postoperative blood transfusion.

PATIENTS AND METHODS

Elderly patients with intertrochanteric fractures of the femur who received artificial femoral head replacement surgery at the Department of Orthopedics, Huai'an First People's Hospital from January 2015 to May 2023 were enrolled in the retrospective study. Inclusion criteria were as follows: *(i)* age over 60 years; *(ii)* OTA/AO Type (2018 edition) 31A1 and A2; *(iii)* absence of multiple injuries or pathological fractures; *(iv)* no history of hematological diseases. Exclusion criteria were as follows: *(i)* preoperative blood transfusion; *(ii)* taking antiplatelet drugs within one week before surgery; *(iii)* having an open fracture; *(iv)* not having complete clinical data. Out of 212 patients assessed for inclusion, three patients with multiple fractures, one patient with pathological fractures, and three patients with hemophilia were excluded. Finally, 205 patients (55 males, 150 females; mean age: 82.1±6.6 years; range, 63 to 103 years) were included.

Patient information was collected, including sex, age, body mass index, preoperative hemoglobin value (date of admission), duration from injury to final surgery, the American Society of Anesthesiologists (ASA) score, intraoperative bleeding volume, operation duration, whether or not wires were used for reinforcement, comorbidities (hypertension, diabetes, and history of cerebral infarction), and incision drainage volume on the first day after surgery. All patients received standard artificial femoral head replacement surgery using the same type of prosthesis performed by the same surgical team to ensure consistency of treatment. Our hospital followed a restrictive transfusion strategy, in which blood transfusion was performed when there were anemia symptoms or hemoglobin levels were less than 8 g/dL.[14,15]

The patients were divided into two groups in a seven-to-three ratio: the training group (n=143) and the validation group (n=62). The training group was used to develop the nomogram prediction model, while the validation group was used to validate the model's accuracy and effectiveness. The randomization of patients was achieved using a computer-generated randomization sequence. We utilized random number generation to assign each patient a random number. Patients were then sorted by these random numbers, and the top 70% of patients were allocated to the training group, while the remaining 30% were allocated to the validation group. Additionally, the training group was then divided into the nontransfused group (n=86) and the transfused group (n=57) according to whether blood transfusion was given, and the baseline characteristics of the data were compared.

Statistical analysis

Data were analyzed using IBM SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Normally distributed continuous variables were presented as mean ± standard deviation and compared using a t-test. Nonnormally distributed continuous variables were expressed as median (interquartile range) and compared using the Mann-Whitney U test. Categorical variables were presented as frequency and compared using the chi-square test or Fisher's exact probability method. A p-value <0.05 was considered statistically significant.

Variables with a p-value <0.1 in univariate analysis were subjected to multivariate logistic regression analysis, and a nomogram prediction model was constructed using R version 3.6.1 software. The validity of the prediction model was assessed using receiver operating characteristic curves and the area under the curve (AUC). Additionally, decision curve analysis was performed to evaluate the clinical effect, and clinical impact curves were utilized.

RESULTS

The process of case screening and model building is shown in Figure 1. The comparison of baseline

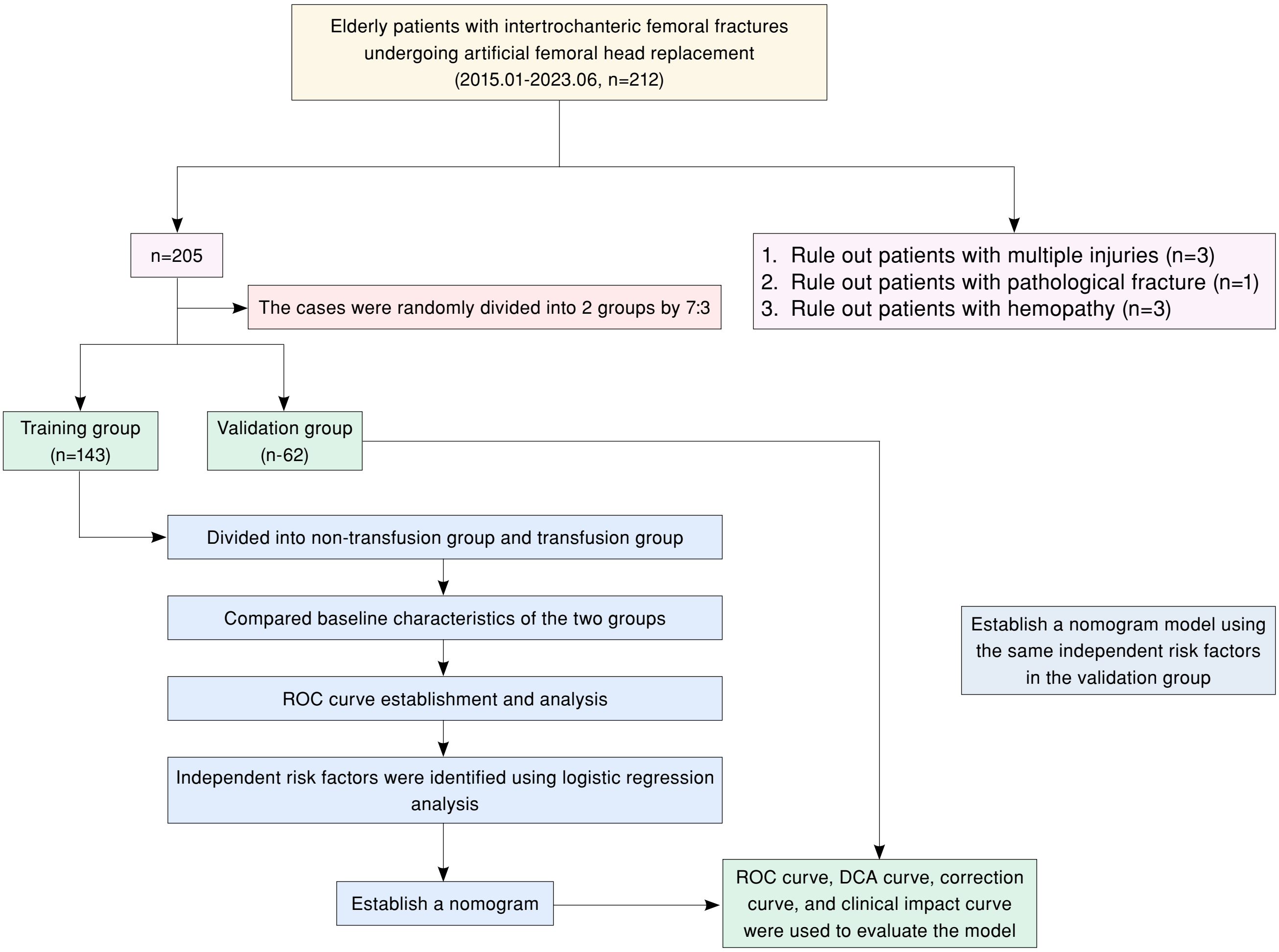

FIGURE 1. Flowchart of the case screening and model construction process in this study.
ROC: Receiver operating characteristic; DCA: Decision curve analysis.

characteristics between the transfusion group and the nontransfusion group showed no statistically significant differences in body mass index, ASA score, operation duration, time from injury to final surgery, hypertension, and diabetes history between the two groups ($p>0.05$). However, there were statistically significant differences between the transfusion group and the nontransfusion group in sex, age, preoperative hemoglobin, intraoperative bleeding volume, drainage volume on the first postoperative day, the use of wire reinforcement, and history of cerebral infarction ($p<0.05$, Table I).

Multivariate logistic regression analysis showed that preoperative low hemoglobin, intraoperative blood loss, high drainage volume on the first day after surgery, the use of wire reinforcement, and history of cerebral infarction were independent risk factors for blood transfusion (Table II). Among these, the AUC values of preoperative hemoglobin, intraoperative blood loss, first-day postoperative drainage volume, and cerebral infarction history were all >0.7, and the above four factors were finally incorporated into the prediction model (Figure 2). The total score of the prognostic index was obtained by summation of each individual score, and it also corresponded to the probability of postoperative transfusion.

The C-index of the model was 0.962 (95% confidence interval, 0.931-0.992), indicating high predictive accuracy. Receiver operating characteristics curves were generated for the training and validation groups, yielding AUC values of 0.962 and 0.947, respectively, demonstrating excellent discriminative ability (Figure 3). The calibration curve revealed good agreement between observed and predicted probabilities (Figure 4). Both

TABLE I
Comparison of baseline characteristics between the two groups

	No blood transfusion group (n=86)		Blood transfusion group (n=57)		
	n	Mean±SD	n	Mean±SD	*p*
Age (year)		81.4±6.7		84.1±5.5	0.013
Sex					<0.001
Male	32		7		
Female	54		50		
Body mass index (kg/m^2)		22.98±3.37		22.63±3.70	0.562
Preoperative hemoglobin (g/L)		119.73±19.46		99.08±22.02	<0.001
Intraoperative bleeding volume (mL)		108.37±99.36		259.82±168.06	<0.001
ASA score					0.051
Level I	52		25		
Level II	34		32		
Drainage volume on the first postoperative day (mL)		53.31±46.74		143.94±94.55	<0.001
Operation duration (h)		1.57±0.51		1.66±0.45	0.302
Injury to final surgical time (day)		4.48±1.92		4.33±2.37	0.671
Intraoperative steel wire tying	51		16		<0.001
Hypertension	49		29		0.476
Diabetes	21		13		0.826
History of cerebral infarction	12		34		<0.001

SD: Standard deviation; ASA: American Society of Anesthesiologists.

TABLE II
Results of multivariate analysis related to blood transfusion

	Regression coefficient	SE	Wald	OR	95% CI	*p*
Age	0.0058	0.0034	2.855	1.0058	0.9991-1.0126	0.0927
Sex	0.0851	0.0523	2.6473	1.0888	0.9827-1.2064	0.1054
Preoperative hemoglobin	–0.0056	0.0011	25.7239	0.9944	0.9922-0.9966	<0.001
Intraoperative bleeding volume	0.0008	0.0002	24.6868	1.0008	1.0005-1.0011	<0.001
Drainage volume on the first postoperative day	0.0017	0.0003	34.8385	1.0017	1.0011-1.0022	<0.001
Steel cable bundling reinforcement	–0.1677	0.0465	13.0155	0.8456	0.772-0.9263	<0.001
History of cerebral infarction	0.2864	0.052	30.3737	1.3317	1.2027-1.4745	<0.001

SE: Standard error; OR: Odds ratio; CI: Confidence interval.

decision curve analysis and clinical impact curves demonstrated that the model served as an effective predictive tool for blood transfusion after artificial femoral head replacement in elderly patients with intertrochanteric fractures (Figure 5).

DISCUSSION

The model used in this study facilitates assessing the risk of blood transfusion following artificial femoral head replacement in elderly patients with intertrochanteric fractures, and it is a good guide for doctors to take corresponding measures to reduce blood transfusion rate and ensure perioperative safety.[16]

Anemia is a common perioperative complication of intertrochanteric femur fractures. Hart et al.[17] noted that blood transfusions can lead to transfusion reactions, such as fever and chills, extend hospital

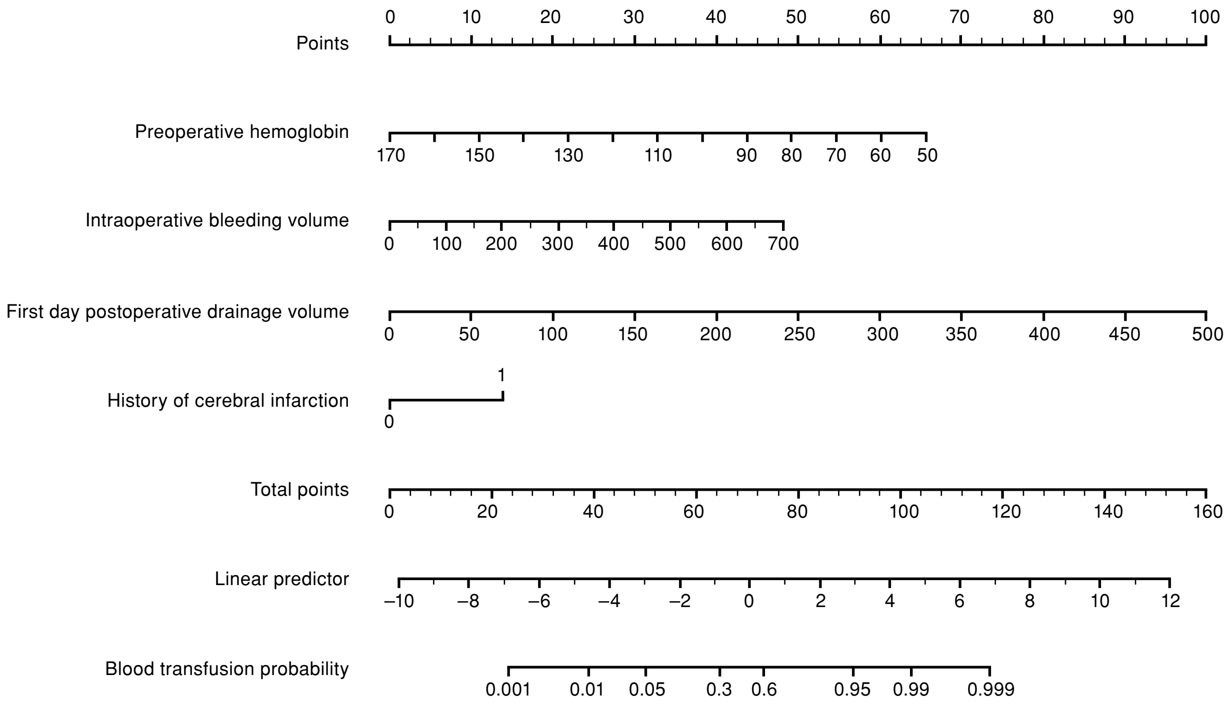

FIGURE 2. A nomogram model to predict the risk of blood transfusion in elderly patients with femoral intertrochanteric fractures.

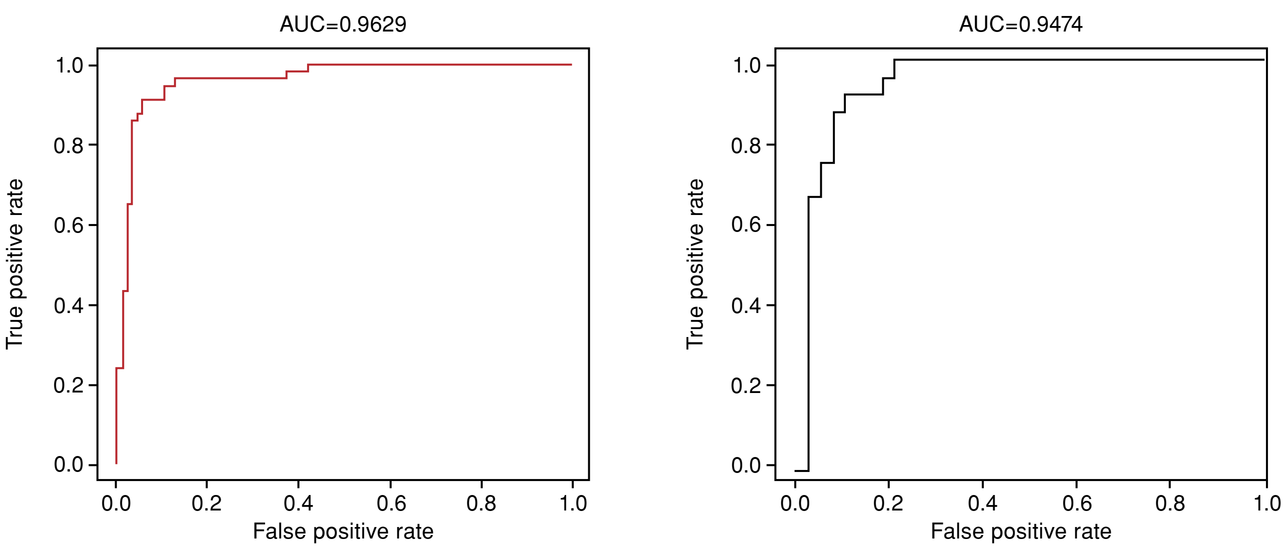

FIGURE 3. Receiver operating characteristic curves and AUC of the prediction in the validation group and the training group.
AUC: Area under the curve.

stays, and increase hospitalization costs. Additionally, transfusions can cause immunosuppression and elevate the risk of mortality. These issues are well-documented and tend to be more severe in older and frail patients.[18]

This study suggested that the need for blood transfusion was related to preoperative hemoglobin levels, intraoperative blood loss, incision drainage volume on the first day after surgery, and history of cerebral infarction. Preoperative

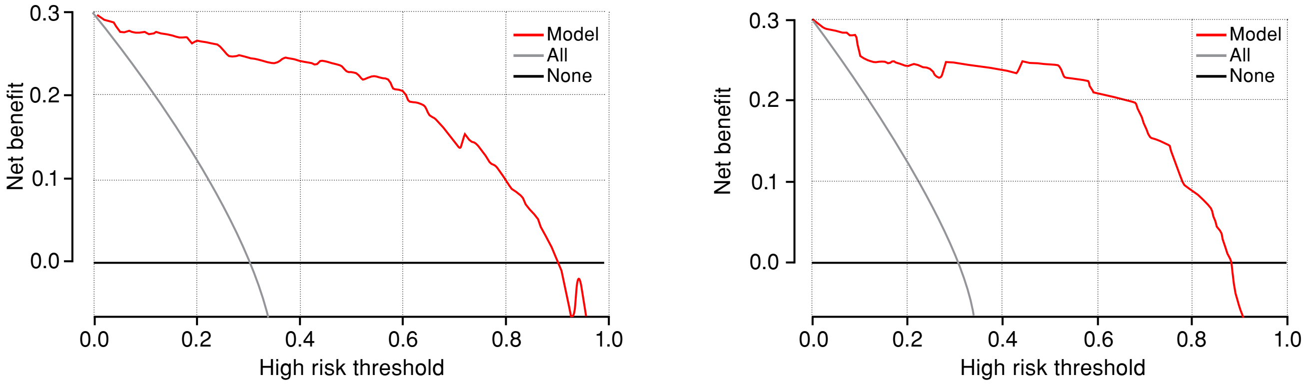

FIGURE 4. Decision curve analysis of the training group and the validation group.

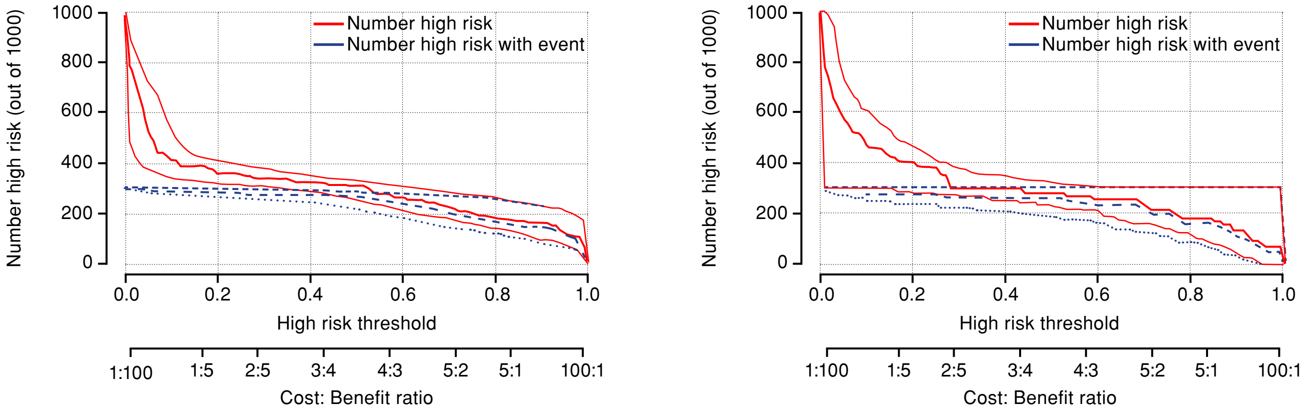

FIGURE 5. Clinical impact curves of the training group and the validation group.

hemoglobin emerged as an independent risk factor for transfusion, consistent with previous findings.[9] In our study, preoperative hemoglobin was 119.73±19.46 g/L in the transfusion group and 99.08±22.02 g/L in the nontransfusion group. Preoperative hemoglobin reflects the number of red blood cells in the patient's body and is the most common parameter to guide blood transfusion. Therefore, for preoperative anemia patients, preoperative iron supplementation combined with a restricted blood transfusion strategy should be adopted to improve the body reserve and reduce the blood transfusion rate.

There were different views on the influence of intraoperative blood loss on the need for transfusion. Consistent with the majority of the literature,[9] our data suggested that there was an important association between intraoperative blood loss and transfusion. Under standard procedures, increased intraoperative blood loss can lead to increased effective blood loss, which increases the risk of postoperative transfusion. Therefore, the surgeon should carefully operate during the operation to avoid unnecessary vascular damage.

Secondary bleeding may occur after femoral head replacement, resulting in joint swelling, incision fluid leakage, delayed healing and other problems. These problems can greatly affect the early recovery of joint function. Therefore, more and more doctors choose to routinely place drainage tubes to promote the discharge of blood in the joint cavity. The drainage volume on the first postoperative day was also included in this study. With the increase of drainage flow, the further reaction of effective blood loss increased. Increased anemia may lead to blood transfusions. Therefore, careful hemostasis at the end of the operation and rational use of antifibrinolytic drugs are crucial.

The results of this study also indicated that a history of cerebral infarction was an independent risk factor for postoperative transfusion. Atherosclerosis was identified as an important vascular pathological manifestation in cerebral infarction patients.[19] These patients have poor vascular elasticity. Affected by perioperative blood pressure fluctuations and soft tissue injury during operation, it is more likely to cause blood vessel rupture and bleeding in these patients. Patients can easily have an increase in invisible blood loss in the perioperative period, thus increasing the need for blood transfusion. The study by Manning et al.[20] also showed that patients who took aspirin and other antiplatelet drugs for a long time were more likely to develop anemia after surgery and were more likely to receive blood transfusions.

We found no significant relationship between ASA, duration from injury to final surgery, and perioperative blood transfusion. Consistent with our findings, Hou et al.[21] also reported that ASA classification at admission and duration of preoperative stay had no significant impact on perioperative blood transfusion.[9] In addition, our findings also showed that there was no significant relationship between surgical duration and perioperative blood transfusion, consistent with a previous study.[22] In multivariate regression analysis, sex was not associated with postoperative transfusion. However, in univariate analysis, blood transfusion rates increased in female patients. This might be because the association between sex and postoperative blood transfusion was affected by other factors in the univariate analysis, resulting in a false association phenomenon, which was adjusted to disappear in the multivariate analysis.

This study established a nomogram model to predict the risk of blood transfusion after artificial femoral head replacement in elderly patients with intertrochanteric fractures based on four risk factors: preoperative hemoglobin, intraoperative blood loss, drainage volume on the first postoperative day, and history of cerebral infarction. Receiver operating characteristic curves showed that the AUC values of the training group and the validation group were 0.962 and 0.947, respectively. These values indicated that the model had good differentiation and high scientific value. In addition, preoperative hemoglobin, intraoperative blood loss, drainage volume on the first postoperative day, and cerebral infarction history were easily obtained during the perioperative period. They do not need to be detected separately by other methods, which shows that the model has strong practicability. Hence, this model offers improved guidance for perioperative patient intervention, facilitating timely measures, such as hypotension control, intravenous iron supplementation, and antifibrinolytic drug administration.

Several limitations warrant consideration in our study. Primarily, the study was retrospective in design, and the sample size was relatively small. Hence, further prospective investigations with larger cohorts are imperative to corroborate our findings. Additionally, this nomogram prediction model was solely validated within our single center, necessitating validation with multicenter data for broader applicability.

In conclusion, preoperative hemoglobin levels, intraoperative blood loss, drainage volume on the first postoperative day, and history of cerebral infarction were independent risk factors for blood transfusion after artificial femoral head replacement in elderly patients with intertrochanteric fractures. The nomogram prediction model based on the above factors had high prediction accuracy and good consistency between the actual incidence and predicted incidence. This model facilitates assessing the risk of blood transfusion following artificial femoral head replacement in elderly patients with intertrochanteric fractures. It is a good guide for doctors to take corresponding measures to reduce blood transfusion rate and ensure perioperative safety.

Ethics Committee Approval: The study protocol was approved by the Huai'an First People's Hospital Ethics Committee (date: 16.01.2024, no: KY-2023-224-01). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Were responsible for study design and conception, organized the database: Y.Z., J.M.; Carried out statistical analyses: J.D., X.T.; Was in charge of manuscript drafting: Y.Z.; Wrote sections of the manuscript: Y.Z., J.D., X.T., J.M.; Participate in table and image drawing: Y.Z., J.M. The authors participated in the manuscript revision, and read, and agreed with the eventual version for submission.

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