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The geriatric nutritional risk index predicts blood transfusion risk in elderly patients undergoing posterior lumbar interbody fusion: a retrospective study

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Abstract

Background Malnutrition can lead to an increased risk of blood transfusion in elderly patients. The Geriatric Nutritional Risk Index (GNRI) is a tool used to assess nutritional status, but its predictive value for blood transfusion in elderly patients undergoing posterior lumbar interbody fusion (PLIF) is not well established. This study aimed to investigate the association between GNRI and the risk of perioperative blood transfusion in this population.

Methods A retrospective cohort study was conducted on elderly patients aged 60 and above who underwent PLIF at Qingdao University Affiliated Hospital. Preoperative GNRI was calculated using height, weight, and serum albumin levels. The primary outcome was perioperative blood transfusion. Logistic regression analysis was performed, adjusting for potential confounders such as demographic characteristics, comorbidities, surgical factors, and laboratory tests.

Results A total of 1,246 elderly patients were included, with 144 (11.6%) requiring blood transfusion. After adjusting for all confounders, a lower GNRI was associated with a significantly higher risk of blood transfusion (OR = 2.4, 95% CI: 1.9–3.1, $p < 0.001$). Patients with a GNRI score below 92 had a significantly increased transfusion risk compared to those with normal GNRI scores (OR = 5.8, 95% CI: 3.7–9.1, $p < 0.05$). RCS analysis revealed a linear negative relationship between GNRI and transfusion risk.

Conclusion The GNRI is a strong predictor of perioperative blood transfusion risk in elderly patients undergoing PLIF. Preoperative nutritional assessment using GNRI may help identify high-risk patients, enabling tailored interventions to optimize outcomes.

Keywords Geriatric nutritional risk index, Malnutrition, Blood transfusion, Posterior lumbar Interbody Fusion, Elderly, Nutritional Assessment

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Introduction

The global population is aging rapidly, with the number of elderly individuals (aged 60 years and above) expected to reach 2.1 billion by 2050 [1]. This demographic shift presents significant challenges to healthcare systems, as older adults are more susceptible to chronic diseases and often require specialized medical care. As the aging population grows, healthcare providers are confronted with the need to balance surgical benefits with the increased risks of complications in elderly patients. Posterior lumbar interbody fusion (PLIF) is a common surgical procedure in this population to alleviate chronic low back pain caused by degenerative spinal conditions [2]. While PLIF can improve quality of life, it is associated with a higher risk of complications, particularly excessive blood loss and the need for blood transfusions, which can range from 10 to 60% in elderly patients [3–5]. Blood transfusions, though life-saving, come with risks such as transfusion reactions, infections, and increased morbidity, especially in the elderly [6, 7].

Malnutrition is prevalent among elderly individuals, affecting up to 50% of hospitalized patients [8]. It has significant physiological effects that contribute to poor surgical outcomes. Malnourished patients experience reduced protein synthesis and compromised immune function, which impair wound healing, increase susceptibility to infections, and weaken their ability to recover from surgical stress. These factors are particularly concerning in complex surgeries like PLIF, where intraoperative blood loss and perioperative anemia are common. Inadequate nutritional status also leads to decreased muscle mass and diminished functional reserves, further exacerbating postoperative complications and prolonging recovery times. Studies have shown that preoperative malnutrition is associated with poorer surgical outcomes, including higher complication rates and longer hospital stays [9, 10]. However, the relationship between malnutrition and perioperative blood transfusion needs, particularly in elderly patients undergoing PLIF, remains underexplored.

The Geriatric Nutritional Risk Index (GNRI) is a simple tool to assess nutritional status in elderly populations. Developed by Bouillanne et al. [11], it uses serum albumin levels and body weight to categorize patients' nutritional risk, ranging from no risk to severe risk [11–13]. While GNRI has been widely used to predict outcomes such as mortality and morbidity in various settings [14, 15], its utility in predicting perioperative blood transfusion risk in elderly patients undergoing spinal fusion surgeries has not been extensively studied. This study aims to fill this gap by evaluating the association between GNRI and the risk of blood transfusion in elderly patients undergoing PLIF. We hypothesize that lower GNRI scores, indicating poorer nutritional status, are associated with a higher likelihood of perioperative blood transfusion. By adjusting for potential confounders, including demographic factors, comorbidities, and surgical variables, we aim to determine whether GNRI independently predicts transfusion risk.

Methods and materials

Study Design and Population

This retrospective cohort study analyzed 2,481 patients aged 60 to 85 years who underwent PLIF at the Department of Orthopedics, Qingdao University Affiliated Hospital, between January 2020 and September 2024. The following exclusion criteria were applied: 1. Patients with missing data for height, weight, or serum albumin levels, which are essential for calculating the GNRI (N=174); 2. Patients lacking complete clinical records or those who received preoperative blood transfusions (N=86); 3. Patients with a history of severe trauma, malignancy, or those undergoing revision surgery were excluded to minimize confounding factors (N=29). After applying these exclusion criteria, a total of 1,246 patients met the inclusion criteria and were included in the final analysis. The patients were divided into two groups based on their perioperative transfusion status: 1,102 patients did not require blood transfusion, while 144 patients did (Fig. 1).

Data collection

In this study, various data were collected to analyze the relationship between the GNRI and perioperative blood transfusion risk in elderly patients. Key variables included demographic data such as age and gender, with age recorded in years and gender categorized as male or female. BMI was calculated based on the patients' height and weight, expressed in kilograms per square meter. Lifestyle factors, including smoking and drinking status, were also documented, with patients categorized as either smokers or non-smokers and drinkers or non-drinkers. Additionally, data on comorbidities were collected, including hypertension, diabetes, coronary heart disease (CHD), cerebrovascular disease (CVD), and digestive system disease (DSD). The primary surgical indications for posterior lumbar interbody fusion (PLIF) were recorded, including lumbar disc herniation (LDH), lumbar spinal stenosis (LSS), and spondylolisthesis. Surgical factors such as operation time (in minutes), intraoperative bleeding volume (in milliliters), and the number of fusion segments involved (one, two, or three) were also collected. Preoperative laboratory data were obtained, including white blood cell count (WBC), platelet count (PLT), reticulocyte count (RET), mean corpuscular hemoglobin concentration (MCHC), hemoglobin (Hb), albumin (ALB), globulin (GLO), alanine aminotransferase (ALT), and aspartate aminotransferase (AST). These variables were measured using standard hospital

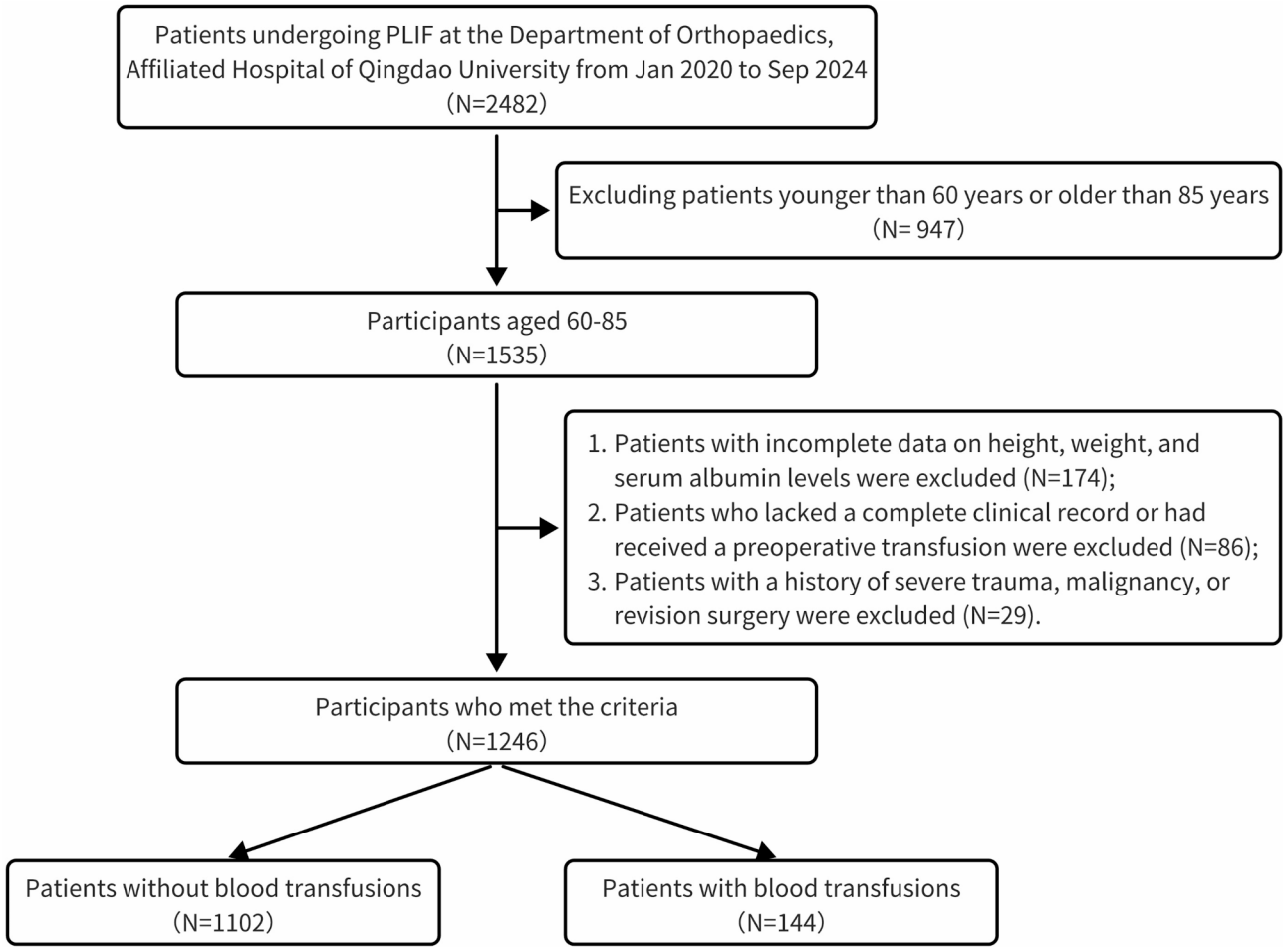

Fig. 1 Flow chart of our study

laboratory procedures. Importantly, the Geriatric Nutritional Risk Index (GNRI) was calculated based on serum albumin levels, body weight, and height. To ensure consistency, GNRI assessment was conducted preoperatively within one week before surgery.

The primary outcome of this study was intraoperative and postoperative blood transfusion, defined as the administration of packed red blood cells either during surgery or within 72 h postoperatively. Patients were divided into two groups based on their transfusion status: those who required a blood transfusion and those who did not. The GNRI was the main independent variable of interest, calculated preoperatively based on serum albumin levels, body weight, and height. Other variables, including demographic characteristics, comorbidities, and surgical factors, were considered covariates and were adjusted for in the statistical analysis to account for potential confounding effects on the relationship between GNRI and blood transfusion risk.

GNRI calculation

The GNRI was calculated for each patient preoperatively as a key measure of nutritional status. GNRI, which includes serum albumin and body mass index (BMI), has been identified as a reliable predictor of perioperative outcomes. The GNRI formula used in this study was as follows [11]:

$$GNRI = 1.489 \times \text{Albumin (g/L)} + 41.7 \times \frac{\text{Body Weight (kg)}}{\text{Ideal Body Weight (kg)}}$$

Ideal body weight was calculated separately for men and women, based on the following equations:

1. For men:
$$\text{Ideal Body Weight (kg)} = \text{Height (cm)} - 100 - \frac{\text{Height (cm)} - 150}{4};$$
2. For women:
$$\text{Ideal Body Weight (kg)} = \text{Height (cm)} - 100 - \frac{\text{Height (cm)} - 150}{2.5}.$$

The GNRI was then categorized into four groups for analysis: severe risk (<82), moderate risk (≥82, <92), mild risk (≥92, <99), and normal (≥99) [13, 16]. This categorization allowed for a more detailed investigation of the association between nutritional status and perioperative blood transfusion risk.

Definition of blood transfusion

The primary outcome of this study was perioperative blood transfusion, defined as the administration of packed red blood cells (PRBCs) either during the surgical procedure or within 72 h postoperatively. Blood transfusion was indicated based on established clinical guidelines at Qingdao University Affiliated Hospital, which included a combination of hemoglobin levels, hemodynamic stability, and clinical signs of anemia.

For this study, patients who received at least one unit of PRBCs within the perioperative period were classified as having undergone a blood transfusion. The decision to transfuse was guided by the following criteria [4, 17, 18]: (1) A hemoglobin level below 7.0 g/dL in stable patients; (2) A hemoglobin level below 8.0 g/dL in patients with cardiovascular disease or those who were hemodynamically unstable; (3) Significant blood loss during surgery (as determined by the attending surgeon) requiring transfusion for volume replacement or stabilization.

Patients were categorized into two groups based on their transfusion status: those who received a transfusion and those who did not. This dichotomous outcome served as the dependent variable in the statistical analysis, allowing for an assessment of the relationship between GNRI and the need for perioperative blood transfusion.

Statistical analysis

All statistical analyses were conducted using R software (version 4.4.1, https://www.R-project.org), with a two-sided p-value of less than 0.05 considered statistically significant. Descriptive statistics were used to summarize the demographic and clinical characteristics of the study population. Continuous variables were presented as mean±standard deviation (SD) for normally distributed data or median with interquartile range (IQR) for skewed distributions. Categorical variables were expressed as frequencies and percentages. Comparisons between different GNRI groups were conducted using the Student's t-test or Mann-Whitney U test for continuous variables, and the Chi-square test or Fisher's exact test for categorical variables.

The primary outcome of this study was perioperative blood transfusion. To evaluate the association between GNRI and the risk of blood transfusion, GNRI was analyzed both as a continuous variable (per SD) and as a categorical variable, divided into four groups: normal (GNRI≥99 g/L), mild risk (GNRI 92 to 99 g/L), moderate risk (GNRI 82 to 92 g/L), and severe risk (GNRI<82 g/L). The association between GNRI and transfusion risk was assessed using logistic regression models with OR and 95% CIs. Four different models were applied to adjust for various covariates: **Crude model**: No variables were adjusted; **Model 1**: Adjusted for age, gender, smoking status, drinking status, hypertension, diabetes, CHD, CVD, and DSD; **Model 2**: Further adjustments were made for surgical factors, including surgical indications (LDH, LSS, spondylolisthesis), intraoperative bleeding volume, operation time, and the number of fusion segments. **Model 3**: In addition to the adjustments in Model 2, laboratory test results were included, such as WBC, PLT, Hb, RET, MCHC, GLO, ALT, and AST. Adjusted odds ratios (aOR) with 95% CIs were reported for each model, allowing for a comprehensive assessment of the relationship between GNRI and perioperative blood transfusion risk. To ensure the robustness of our logistic regression model, we conducted 10-fold cross-validation.

To explore potential nonlinear relationships between GNRI and transfusion risk, we employed restricted cubic splines (RCS). RCS is a flexible method that allows us to model relationships that are not strictly linear by fitting smooth curves to the data. In this analysis, we used three knots (points) to fit the curve, which helps capture potential changes in the relationship between GNRI and transfusion risk. The three knots were placed at the 10th, 50th, and 90th percentiles of GNRI, based on standard practice to ensure an appropriate balance between flexibility and model stability. The results were visualized using spline plots, allowing for a clearer understanding of how transfusion risk varies across different GNRI values. Additionally, subgroup analyses were conducted to assess the consistency of the GNRI-transfusion risk association across different patient subgroups. These subgroups included age (<70 years vs.≥70 years), gender, and the presence of comorbidities. Interaction analyses were performed to determine whether the association between GNRI and transfusion risk was modified by these factors.

Results

Baseline characteristics of elderly patients stratified by GNRI score

The baseline characteristics of the 1,246 elderly patients undergoing PLIF were analyzed and stratified according to the GNRI scores (Table 1). Patients were divided into three groups: normal GNRI (n=817), mild nutritional risk (n=237), and moderate to severe nutritional risk (n=192). Statistically significant differences were observed across several variables between these groups.

Patients with normal GNRI scores had the highest mean GNRI (113.09±9.47 g/L), while those in the moderate to severe risk group had significantly lower GNRI

Table 1 Characteristics and baseline of elderly patients undergoing PLIF

Variable	Total (*n* = 1246)	Normal GNRI (*n* = 817)	Mild GNRI (*n* = 237)	Moderate and Severe GNRI (*n* = 192)	*P*-value
GNRI (g/L)	105.60 ± 13.35	113.09 ± 9.47	95.66 ± 2.00	85.99 ± 4.91	**< 0.001**
Age (Years)	66.29 ± 5.30	66.25 ± 5.25	65.70 ± 4.92	67.20 ± 5.83	**0.01**
Gender (*n*, %)					0.31
Female	686(55.06)	462(56.55)	126(53.16)	98(51.04)	
Male	560(44.94)	355(43.45)	111(46.84)	94(48.96)	
BMI (kg/m^2)	27.28 ± 3.62	28.41 ± 3.49	26.15 ± 2.42	23.90 ± 2.79	**< 0.001**
Smoking (*n*, %)					0.43
No	1039(83.39)	687(84.09)	198(83.54)	154(80.21)	
Yes	207(16.61)	130(15.91)	39(16.46)	38(19.79)	
Drinking (*n*, %)					0.88
No	1068(85.71)	703(86.05)	201(84.81)	164(85.42)	
Yes	178(14.29)	114(13.95)	36(15.19)	28(14.58)	
Hypertension (*n*, %)					0.93
No	828(66.45)	546(66.83)	156(65.82)	126(65.63)	
Yes	418(33.55)	271(33.17)	81(34.18)	66(34.38)	
Diabetes (*n*, %)					0.94
No	996(79.94)	653(79.93)	191(80.59)	152(79.17)	
Yes	250(20.06)	164(20.07)	46(19.41)	40(20.83)	
CHD (*n*, %)					0.42
No	1063(85.31)	697(85.31)	207(87.34)	159(82.81)	
Yes	183(14.69)	120(14.69)	30(12.66)	33(17.19)	
CVD (*n*, %)					**< 0.01**
No	1204(96.63)	800(97.92)	224(94.51)	180(93.75)	
Yes	42(3.37)	17(2.08)	13(5.49)	12(6.25)	
DSD (*n*, %)					0.70
No	1170(93.90)	764(93.51)	225(94.94)	181(94.27)	
Yes	76(6.10)	53(6.49)	12(5.06)	11(5.73)	
Indications (*n*, %)					0.94
LDH	628(50.40)	408(49.94)	122(51.48)	98(51.04)	
LSS	535(42.94)	356(43.57)	100(42.19)	79(41.15)	
Spondylolisthesis	83(6.66)	53(6.49)	15(6.33)	15(7.81)	
Operation Time (min)	166.06 ± 65.07	165.51 ± 65.18	161.23 ± 62.20	174.39 ± 67.60	0.10
Bleeding (ml)	519.21 ± 209.59	503.90 ± 190.32	555.38 ± 238.23	539.69 ± 241.71	**< 0.01**
Fusion segment (*n*, %)					0.26
1	565(45.35)	382(46.76)	108(45.57)	75(39.06)	
2	478(38.36)	304(37.21)	87(36.71)	87(45.31)	
3	203(16.29)	131(16.03)	42(17.72)	30(15.63)	
WBC (10^9/L)	8.47 ± 2.24	8.50 ± 2.27	8.56 ± 2.23	8.20 ± 2.15	0.19
PLT (10^9/L)	176.14 ± 51.75	177.63 ± 52.18	174.20 ± 49.06	172.16 ± 53.08	0.34
RET (10^9/L)	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.02	0.06 ± 0.02	**0.03**
MCHC (g/L)	332.90 ± 11.35	332.57 ± 11.49	333.26 ± 10.76	333.88 ± 11.42	0.31
Hb (g/L)	98.07 ± 14.88	98.86 ± 14.58	97.39 ± 15.11	95.57 ± 15.58	**0.02**
ALB (g/L)	36.33 ± 7.54	39.92 ± 6.41	31.12 ± 3.17	27.47 ± 3.76	**< 0.001**
GLO (g/L)	25.30 ± 4.01	25.32 ± 3.99	24.99 ± 4.11	25.61 ± 3.95	0.27
ALT (U/L)	23.60 ± 15.77	23.66 ± 15.65	22.67 ± 14.72	24.49 ± 17.46	0.48
AST (U/L)	19.25 ± 7.90	19.36 ± 8.03	18.82 ± 7.70	19.33 ± 7.62	0.64
Blood transfusion (*n*, %)					**< 0.001**
No	1102(88.44)	755(92.41)	215(90.72)	132(68.75)	
Yes	144(11.56)	62(7.59)	22(9.28)	60(31.25)	

Note: GNRI: Geriatric Nutritional Risk Index; BMI: Body Mass Index; CHD: Coronary Heart Disease; CVD: Cerebrovascular Disease; DSD: Digestive System Disease; LDH: Lumbar Disc Herniation; LSS: Lumbar Spinal Stenosis; WBC: White Blood Cell count; PLT: Platelet count; RET: Reticulocyte count; MCHC: Mean Corpuscular Hemoglobin Concentration; Hb: Hemoglobin; ALB: Albumin; GLO: Globulin; ALT: Alanine Aminotransferase; AST: Aspartate Aminotransferase

scores (85.99±4.91 g/L, $p<0.001$). Age was slightly higher in the moderate to severe risk group compared to the other groups (67.20±5.83 years, $p=0.01$). Gender distribution was not significantly different across GNRI groups ($p=0.31$), with females comprising a larger proportion in all groups. BMI was significantly lower in the moderate to severe risk group (23.90±2.79 kg/m²) compared to the normal group (28.41±3.49 kg/m², $p<0.001$). There were no significant differences in smoking ($p=0.43$) or drinking status ($p=0.88$) between the groups. Comorbidities, including hypertension, diabetes, and CHD, were not significantly different among the groups. However, CVD was more prevalent in the moderate to severe GNRI group (6.25%) compared to the normal group (2.08%, $p<0.01$). Surgical indications, such as LDH, LSS, and spondylolisthesis, were similar across all GNRI groups ($p=0.94$). Although there was no significant difference in operation time between the groups ($p=0.10$), patients in the moderate to severe risk group had a higher mean intraoperative bleeding volume (539.69±241.71 mL, $p<0.01$). Laboratory data revealed significant differences in Hb levels, which were lowest in the moderate to severe risk group (95.57±15.58 g/L, $p=0.02$). Albumin levels were also notably lower in the moderate to severe risk group (27.47±3.76 g/L) compared to the normal group (39.92±6.41 g/L, $p<0.001$). Other laboratory parameters, including WBC, PLT, RET, MCHC, and liver function tests (ALT and AST), showed no significant differences across the groups. In terms of blood transfusion, there was a significant association between GNRI and transfusion rates, with the moderate to severe risk group having the highest percentage of transfusions (31.25%) compared to the normal group (7.59%, $p<0.001$).

Association between GNRI and blood transfusion risk in elderly patients

The association between GNRI and perioperative blood transfusion risk in elderly patients undergoing PLIF was assessed using multivariate logistic regression models (Table 2). GNRI was evaluated both as a continuous variable (per SD) and as a categorical variable, stratified into three groups: normal GNRI, mild nutritional risk, and moderate to severe nutritional risk.

In the unadjusted **crude model**, GNRI as a continuous variable was significantly associated with an increased risk of blood transfusion (OR=2.447, 95% CI: 1.986–3.015, $p<0.001$). After adjusting for age, gender, smoking, drinking, hypertension, diabetes, CHD, CVD, and DSD in **Model 1**, GNRI remained a significant predictor of transfusion risk (OR=2.437, 95% CI: 1.958–3.033, $p<0.001$). The association persisted in **Model 2**, which included additional adjustments for surgical factors such as surgical indications (LDH, LSS, spondylolisthesis), intraoperative bleeding, operation time, and the number of fusion segments (OR=2.383, 95% CI: 1.904–2.982, $p<0.001$). In the fully adjusted **Model 3**, which accounted for laboratory variables (WBC, PLT, Hb, RET, MCHC, GLO, ALT, AST), GNRI remained strongly associated with blood transfusion risk (OR=2.432, 95% CI: 1.934–3.059, $p<0.001$).

When GNRI was analyzed as a categorical variable, patients with moderate to severe nutritional risk (GNRI<82) had a significantly higher likelihood of receiving a blood transfusion compared to those with normal GNRI scores (OR=5.778, 95% CI: 3.671–9.096, $p<0.001$ in Model 3). This association was consistent across all models. In contrast, patients with mild nutritional risk (GNRI 92–99) did not show a statistically significant increased risk of transfusion compared to the normal GNRI group (OR=1.287, 95% CI: 0.748–2.216, $p=0.362$ in Model 3). The trend test further confirmed a significant linear association between worsening GNRI categories and increasing blood transfusion risk across all models (p for trend<0.001).

In addition to the logistic regression models with various adjustments, we conducted 10-fold cross-validation to validate the robustness of our findings. The results showed that the GNRI was a significant protective factor for blood transfusion risk (OR=0.41, $p<0.001$), along with other factors such as age, diabetes, cerebrovascular disease, and surgical bleeding volume. The model achieved an average accuracy of 89.24%, confirming its

Table 2 Multivariate logistic regression analysis of GNRI and blood transfusion in elderly patients undergoing PLIF

Character	Crude Model		Model 1		Model 2		Model 3	
	95%CI	*P*-value	95%CI	*P*-value	95%CI	*P*-value	95%CI	*P*-value
GNRI Per SD	2.447(1.986,3.015)	< 0.001	2.437(1.958,3.033)	< 0.001	2.383(1.904,2.982)	< 0.001	2.432(1.934, 3.059)	< 0.001
GNRI Group								
Normal GNRI	ref		ref		ref		ref	
Mild GNRI	1.246(0.749,2.074)	0.397	1.357(0.800,2.303)	0.258	1.248(0.727,2.140)	0.422	1.287(0.748, 2.216)	0.362
Moderate and Severe GNRI	5.535(3.710,8.259)	< 0.001	5.649(3.679,8.674)	< 0.001	5.539(3.557,8.627)	< 0.001	5.778(3.671, 9.096)	< 0.001
P for trend		< 0.001		< 0.001		< 0.001		< 0.001

Crudel model: None of the variables were adjusted; **Model 1**: Age, Gender, Smoking, Drinking, Hypertension, Diabetes, CHD, CVD, DSD; **Model 2**: Model 1+Indications, Bleeding, Surgery_Time, Fusion_segment; **Model 3**: Model 2+WBC, PLT, Hb, RET, MCHC, GLO, ALT, AST

overall predictive ability. The AIC for the final model was 752.43, indicating a good fit to the data.

Restricted cubic splines (RCS) analysis

To better understand the relationship between GNRI and the risk of perioperative blood transfusion, we used restricted cubic splines (RCS). This statistical method allows us to model complex, potentially non-linear relationships between variables. In simpler terms, instead of assuming the relationship between GNRI and transfusion risk is a straight line, RCS helps us see if the relationship changes or bends at certain points. The analysis revealed that as GNRI increases, the risk of needing a blood transfusion decreases. In the crude model (Fig. 2), there was a significant bending or non-linearity in the relationship (p-nonlinear = 0.0208), meaning the transfusion risk doesn't decrease at a constant rate. However, after adjusting for factors such as age and comorbidities in Model 1, the non-linearity was less pronounced (p-nonlinear = 0.067), but the overall decreasing trend remained strong (p-overall < 0.001).

Further adjustments in Model 2 (for surgical factors) and Model 3 (for laboratory results) showed that the relationship between GNRI and transfusion risk became more linear (p-nonlinear = 0.0556 in both models), meaning the transfusion risk decreased more steadily as GNRI increased. Across all models, patients with lower GNRI scores had a higher probability of transfusion, with the strongest association seen in patients with the lowest GNRI values.

Subgroup and interaction analysis

As shown in Fig. 3, the association between GNRI and transfusion risk was consistent across most subgroups, with no significant interactions observed in terms of age (p for interaction = 0.114), smoking status (p for interaction = 0.939), drinking status (p for interaction = 0.806), hypertension (p for interaction = 0.426), and other clinical factors.

However, a significant interaction was observed based on gender (p for interaction = 0.031), indicating that the association between GNRI and blood transfusion risk

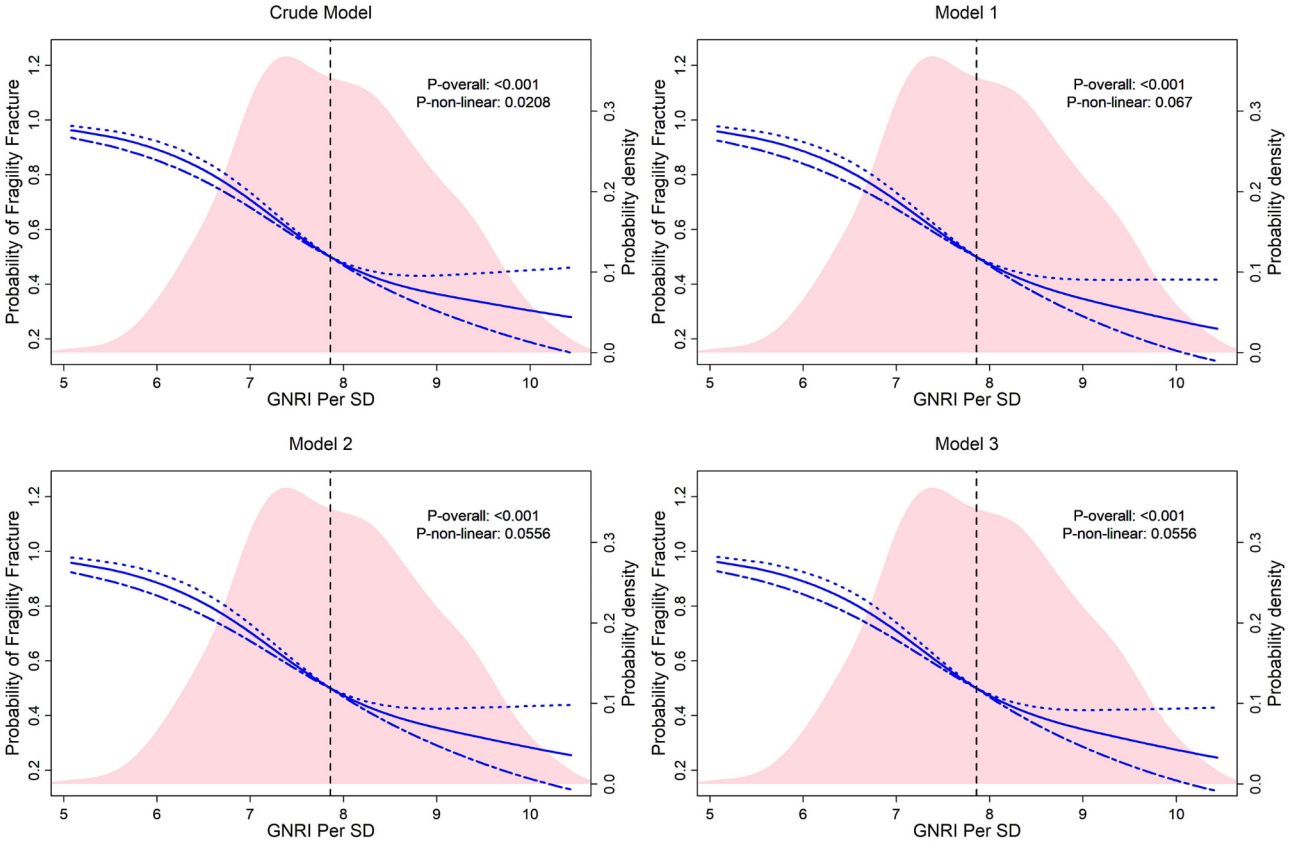

Fig. 2 Restricted Cubic Spline (RCS) Curves Showing the Association Between GNRI and Perioperative Blood Transfusion Risk in Elderly Patients Undergoing PLIF. RCS curves depict the probability of perioperative blood transfusion according to GNRI per SD across four models: crude model, Model 1 (adjusted for demographic and comorbidity factors), Model 2 (further adjusted for surgical factors), and Model 3 (fully adjusted for laboratory variables). The solid blue line represents the estimated probability, while the dashed lines indicate 95% confidence intervals. The red shaded area represents the density distribution of GNRI. Across all models, lower GNRI scores were associated with a higher probability of blood transfusion. P-overall values indicate the significance of the association, and P-nonlinear values assess the presence of nonlinearity

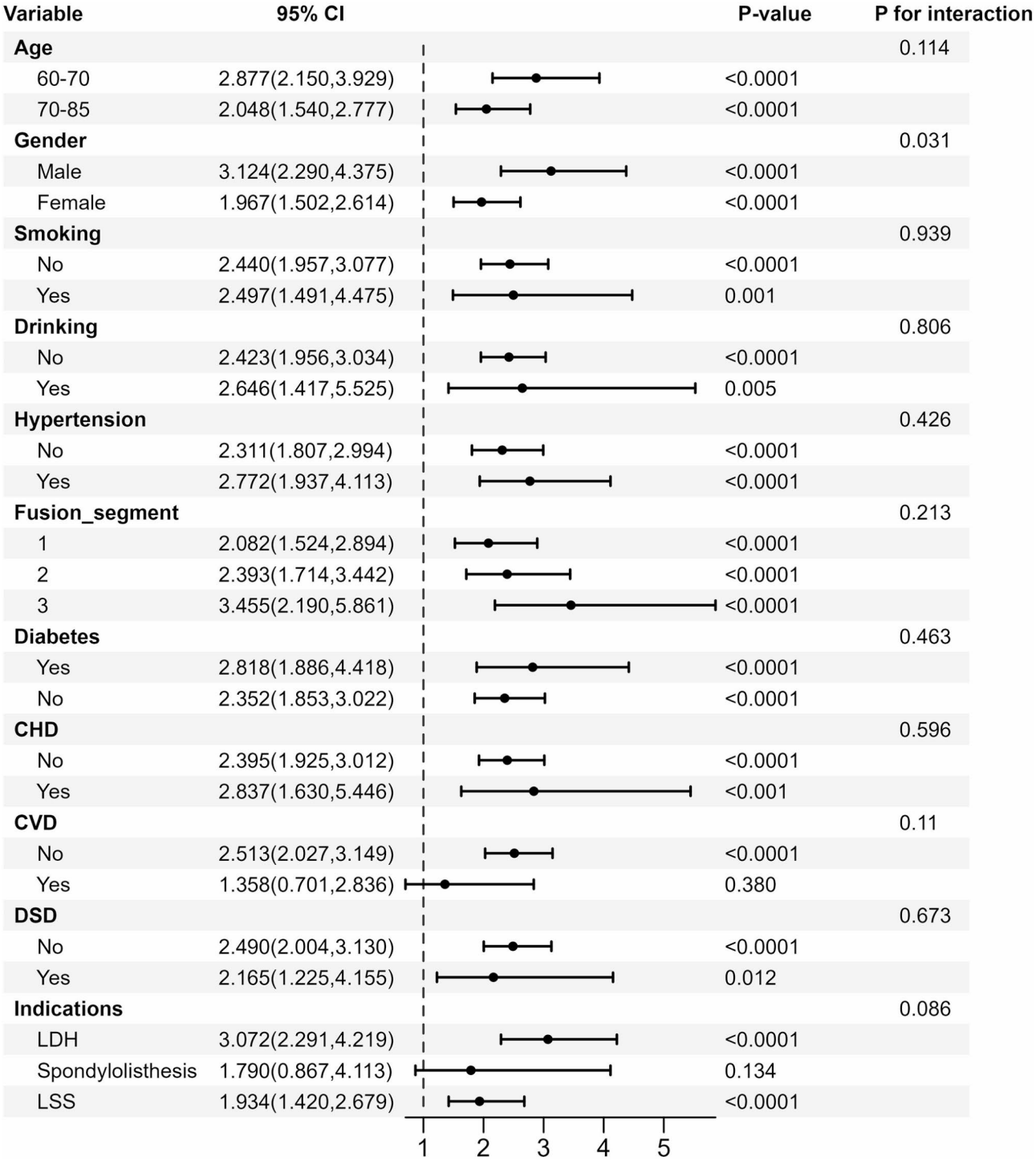

Fig. 3 Forest Plot of Subgroup and Interaction Analysis for the Association Between GNRI and Perioperative Blood Transfusion Risk in Elderly Patients Undergoing PLIF. Subgroups include age, gender, smoking and drinking status, hypertension, diabetes, coronary heart disease (CHD), cerebrovascular disease (CVD), digestive system disease (DSD), surgical indications, and the number of fusion segments

may vary between males and females, with males showing a stronger association. Additionally, the number of fusion segments also showed a suggestive trend toward interaction (p for interaction = 0.213), with patients undergoing multiple fusion segments having a slightly higher transfusion risk.

Across all subgroups, lower GNRI scores were generally associated with a higher risk of blood transfusion, and this trend was most pronounced in patients with

diabetes (OR = 2.81, 95% CI: 1.89–4.42) and those undergoing multiple fusion segments (OR = 3.46, 95% CI: 2.19–5.86 for three segments, $p < 0.001$). The consistency of the findings across subgroups highlights the robustness of GNRI as a predictor of transfusion risk.

Discussion

This retrospective study investigated the association between the GNRI and the risk of perioperative blood transfusion in elderly patients undergoing PLIF. The primary finding was that a lower preoperative GNRI score was significantly associated with an increased risk of requiring blood transfusion during or after PLIF surgery. After adjusting for potential confounders, such as demographic characteristics, comorbidities, surgical factors, and laboratory tests, patients with a GNRI score below 92 had a nearly six-fold higher risk of blood transfusion compared to those with normal GNRI scores. The restricted cubic spline analysis revealed a linear, negative relationship between GNRI and transfusion risk, suggesting that the risk of transfusion progressively increases as the GNRI score decreases. This finding was consistent across various patient subgroups, as demonstrated by the stratified analyses, highlighting the robustness of the association between GNRI and transfusion risk in the elderly population undergoing PLIF. These findings underscore the importance of preoperative nutritional assessment using the GNRI in elderly patients scheduled for PLIF surgery. Identifying patients at high risk for malnutrition and subsequent increased transfusion requirements can inform preoperative interventions and perioperative management strategies aimed at optimizing outcomes and reducing the need for blood transfusions in this vulnerable population.

Our study's findings are consistent with growing evidence supporting the role of preoperative nutritional status in predicting postoperative outcomes, particularly in elderly patients undergoing spine surgery. Numerous studies have demonstrated a strong association between preoperative nutritional deficiencies and adverse postoperative outcomes in elderly spinal surgery patients. The utilization of nutritional screening tools, such as the Geriatric Nutritional Risk Index (GNRI), Prognostic Nutritional Index (PNI), and Controlling Nutritional Status (CONUT) score, has been shown to predict the risk of postoperative complications following spinal procedures. Recent studies highlight the value of these additional nutritional markers in predicting surgical outcomes. For example, the PNI—calculated using serum albumin and total lymphocyte count—has been demonstrated to independently predict postoperative complications and 2-year mortality in patients undergoing hip fracture surgery [15]. Patients with higher PNI scores exhibited significantly lower risks of complications and mortality, underscoring its potential utility as a prognostic tool across various surgical populations. Similarly, the CONUT score, which incorporates serum albumin, total cholesterol, and lymphocyte count, has been associated with postoperative recovery outcomes. In hip fracture patients, a higher CONUT score, indicative of moderate-to-severe malnutrition, was independently linked to a greater likelihood of losing walking independence at 180 days postoperatively [19]. These findings suggest that combining GNRI with tools like PNI and CONUT may enhance the ability to predict postoperative risks in elderly patients, allowing for more comprehensive preoperative assessments. Furthermore, a systematic review and meta-analysis by Huang et al. [20] revealed that decreased PNI and GNRI scores were significantly associated with an increased overall risk of adverse events after spinal surgeries, while an elevated CONUT score also demonstrated a non-significant association with adverse event risk. Specifically, lower GNRI values have been linked to an increased risk of surgical site infections (SSIs) in spinal surgery patients [21]. Furthermore, malnutrition in elderly individuals has been associated with various postoperative complications, including hyponatremia [22], osteoporosis, and reduced muscle mass [23, 24]. Consequently, preoperative GNRI assessment holds significant value in identifying high-risk elderly patients undergoing spinal surgery.

Researchers have also proposed utilizing routinely collected clinical data in conjunction with the Global Leadership Initiative on Malnutrition diagnostic criteria to derive malnutrition risk scores and diagnoses, thereby improving the prediction of surgical outcomes [25]. Cho et al. [26] demonstrated the predictive ability of preoperative nutritional status, assessed using electronic health records, on postoperative health outcomes in elderly spinal surgery patients. Moreover, studies have investigated the associations between nutritional parameters, such as the GNRI, and other clinical factors, including postoperative delirium, immune function, and functional status [24, 27, 28]. These findings underscore the importance of preoperative nutritional assessment in guiding individualized perioperative management and prognostic evaluation for elderly spinal surgery patients. A study investigating risk factors for surgical site infections (SSI) after soft-tissue sarcoma resection found that 18.4% of the 152 patients developed SSIs. Key factors contributing to SSI risk included male sex, larger incisions, larger tumor size, open wounds, and lower GNRI. The study concluded that malnutrition, indicated by a lower GNRI, was a significant predictor of SSI, suggesting that addressing malnutrition preoperatively could reduce infection risk [29]. In summary, the existing literature strongly supports the incorporation of nutritional screening tools, particularly the GNRI, into the preoperative evaluation

of elderly patients undergoing spinal surgery to identify high-risk individuals, guide targeted interventions, and improve postoperative outcomes.

Malnutrition, as reflected by a low GNRI score, is often accompanied by impairments in wound healing capacity. Deficiencies in key nutrients like protein, zinc, and vitamin C can negatively affect various phases of the wound healing process, including the inflammatory response, angiogenesis, collagen synthesis, and epithelialization. As a result, malnourished surgical patients may also experience delayed wound healing and higher susceptibility to wound complications, potentially increasing intraoperative blood loss. Furthermore, malnutrition is linked to compromised immune function, rendering patients more vulnerable to surgical site infections (SSIs). A weakened immune response due to nutritional deficits can impair the body's ability to combat bacterial infections, which may necessitate additional invasive procedures or lead to prolonged hospital stays, thereby increasing overall transfusion needs.

Notably, the GNRI incorporates serum albumin levels, a sensitive marker of nutritional status and an independent predictor of postoperative complications. Hypoalbuminemia, commonly observed in malnourished patients, is linked to increased capillary leakage and reduced oncotic pressure, leading to significant intraoperative fluid shifts and blood loss, especially during major surgeries such as spinal fusions. A recent study on elderly patients undergoing hemiarthroplasty for femoral neck fractures identified hypoalbuminemia and chronic kidney disease (CKD) as key risk factors for perioperative blood transfusion [30]. Similarly, research on patients undergoing radical nephrectomy for renal cell carcinoma highlighted preoperative hypoalbuminemia and anemia as strong predictors of transfusion, with transfused patients experiencing poorer postoperative outcomes, including longer ICU stays [31]. These findings reinforce the critical role of serum albumin in maintaining tissue integrity and wound healing, further supporting its involvement in increased transfusion risk among malnourished surgical patients.

One of the key strengths of this study is its large sample size, which included 1,246 elderly patients undergoing PLIF surgery. This substantial sample size enhances the statistical power and precision of the findings, reducing the likelihood of type II errors and increasing the generalizability of the results to similar surgical populations. Additionally, the study's comprehensive data collection process is a notable strength. The researchers meticulously gathered and analyzed a wide range of potential confounding variables, including demographic characteristics, comorbidities, surgical factors, and laboratory tests. This approach strengthens the robustness of the findings by accounting for various factors that could influence the association between GNRI and transfusion risk.

Despite its strengths, this study has several limitations that warrant consideration. Firstly, its retrospective design introduces inherent biases and limitations. The data were collected from existing medical records, which may be subject to incomplete or inconsistent documentation, potentially affecting the accuracy and completeness of the variables analyzed. Second, the study was conducted at a single institution, which may limit the generalizability of the results to other populations or healthcare settings. Future prospective studies involving diverse populations from multiple centers are necessary to validate our findings and ensure broader applicability across different healthcare systems and demographic groups. Furthermore, the retrospective nature of the study precludes the establishment of causality between GNRI and transfusion risk. While the observed association is robust, it does not necessarily imply a direct causal relationship, and the potential influence of unmeasured confounders cannot be entirely ruled out. Additionally, the study period overlapped with the COVID-19 pandemic, which may have influenced the implementation of preoperative screening protocols and the overall healthcare delivery system. During this time, medical services were disrupted, potentially affecting patient management and clinical decision-making. Although the specific impact of the pandemic on our findings is unclear, future studies should consider how healthcare disruptions may affect nutritional status assessments and surgical outcomes.

Conclusion

This retrospective cohort study demonstrated a significant association between lower preoperative GNRI scores and increased risk of perioperative blood transfusion in elderly patients undergoing PLIF. After adjusting for potential confounders, patients with a GNRI score below 92 had an approximately six-fold higher risk of receiving a blood transfusion compared to those with normal nutritional status. This finding highlights the value of preoperative GNRI assessment in identifying high-risk populations and provides a rationale for implementing targeted nutritional interventions to optimise surgical outcomes. Although limited by the retrospective study design, the results support incorporating GNRI into preoperative evaluation of elderly spinal surgery patients to guide individualised perioperative management. Future prospective studies are warranted to validate the predictive ability of GNRI across different populations, while interventional trials should assess the potential benefits of nutritional support in reducing transfusion requirements and improving outcomes, laying the groundwork for evidence-based guidelines.

Abbreviations

GNRI	Geriatric Nutritional Risk Index
SD	Standard Deviation
IQR	Interquartile Range
BMI	Body Mass Index
CHD	Coronary Heart Disease
CVD	Cerebrovascular Disease
DSD	Digestive System Disease
LDH	Lumbar Disc Herniation
LSS	Lumbar Spinal Stenosis
WBC	White Blood Cell count
PLT	Platelet count
RET	Reticulocyte count
MCHC	Mean Corpuscular Hemoglobin Concentration
Hb	Hemoglobin
ALB	Albumin
GLO	Globulin
ALT	Alanine Aminotransferase
AST	Aspartate Aminotransferase

Author contributions
Bo Liu wrote the manuscript and analyzed the data; Zhijie Wang and Xiuling Huang conceived and designed the study. All authors have read and approved the final version of the manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
This study was conducted in accordance with the ethical standards of the Helsinki Declaration and was approved by the Ethics Committee of Qingdao University Affiliated Hospital. Given the retrospective nature of the study, the requirement for informed patient consent was waived by the ethics committee. All patient data were anonymized and handled with strict confidentiality to ensure privacy and data protection.

Conflict of interest
Bo Liu, Zhijie Wang and Xiuling Huang declare that they have no conflict of interest.

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