Development and validation of a nomogram to predict perioperative blood transfusion for gastric cancer surgery

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Abstract

Background

This study aimed to construct and validate a nomogram composed of preoperative variables to predict perioperative blood transfusion for gastric cancer surgery.

Methods

600 gastric cancer patients undergoing gastrectomy between January 2010 and December 2015 were selected as primary cohort. 399 patients from January 2016 to June 2019 were collected as validation cohort. In the primary cohort, univariate and multivariate analyses were performed to identify independent risk factors for blood transfusion. Using Akaike information criterion, selected variables were incorporated to construct a nomogram. Validations of the nomogram were performed in the primary and validation cohort. Discrimination of the nomogram was assessed by the concordance index (C-index) and calibration of the nomogram was assessed by calibration curve and Hosmer–Lemeshow goodness-of-fit test.

Results

The following independent risk factors for transfusion were identified: Charlson comorbidity index score over 3 (odds ratio (OR) 2.15), tumor location (diffuse vs upper: OR 1.50), pTNM stage (III vs I: OR 3.17), type of gastrectomy (subtotal vs total gastrectomy: OR 0.58), extragastric organ resection (OR 2.03) and preoperative hemoglobin less than 80 g/l (vs over 120 g/l: OR 66.03). C-index was 0.863 and 0.901 in the primary and validation cohort, respectively, indicating good discrimination of the nomogram. Both calibration curves and Hosmer–Lemeshow goodness-of-fit tests (P-value 0.716 and 0.935) demonstrated high agreement between prediction and actual outcome.

Conclusion

A nomogram composed of preoperative variables to predict blood transfusion for gastric cancer surgery was developed and validated. This nomogram could be used to improve utilization of packed red blood cells.

Background

Gastric cancer is the fifth most common cancer and the third leading cause of cancer death around the world [1]. Surgery is the only curative treatment for gastric cancer [2]. A large proportion of patients with gastric cancer suffer from anemia. In addition, perioperative bleeding remains a significant challenge for gastrectomy. Thus, perioperative transfusion of packed red blood cells (PRBCs) is a common medical

procedure. Although blood transfusion has advantages of increasing oxygen supply to tissues and maintaining hemodynamic stability, studies have increasingly revealed that perioperative transfusion exerts negative effects on the prognosis of patients with gastric cancer [3–5]. Blood transfusion was associated with increased mortality [3], surgical-site infection [6], pneumonia [7], and sepsis [8]. In addition, a liberal transfusion strategy could increase transfusion-related risk and costs without improving outcomes [9]. Thus, doctors should be cautious about transfusing PRBCs perioperatively to patients with gastric cancer.

Optimizing the utilization of blood in surgical patients has been emphasized in recent guidelines [10–13]. Preoperative assessment of the patient and the risk for transfusion is a task of high priority for perioperative blood management [12]. Unlike other situations where doctors could use hemoglobin level alone to assess transfusion risk and trigger blood transfusion [11, 13], it is strongly recommended to include patient characteristics, laboratory test results and operation factors for preoperative evaluation [12]. A comprehensive and accurate preoperative assessment for perioperative transfusion could optimize the use of PRBCs, which having great impacts on enhancing patient safety, reducing costs and saving the limited resources produced by healthy volunteers. In addition, accurately predicting the risk of perioperative transfusion could be of benefit to plan necessary procedure including central venous access, invasive hemodynamic monitoring. Recently, various predictive models have been developed to predict the likelihood of blood transfusion for different surgical types, such as spinal surgery [14], cardiac surgery [15], hepatopancreaticobiliary and colorectal surgery [16]. To date, however, a predictive model regarding the risk of perioperative blood transfusion for gastrectomy has not been proposed.

A nomogram is a statistical tool used to predict an individual's particular outcome and it has been broadly implemented in clinical practice [17–19]. The aim of this study was to identify preoperative risk factors associated with perioperative blood transfusion for patients with gastric cancer surgery by using the database from a tertiary-care center in China. These identified preoperative variables were subsequently incorporated to construct a nomogram to predict the likelihood of receiving a blood transfusion for gastric cancer surgery.

Methods

Patients

This study was approved by the Sun Yat-sen Memorial Hospital Institutional Review Board. The informed consent was waived because it was a retrospective study. All consecutive patients who underwent gastrectomy for pathological diagnosed gastric adenocarcinoma between January 2010 and June 2019 in our hospital were screened for included in the study. Exclusion criteria included: age below 18 years, previous history of gastrectomy, received PRBCs before surgery, received neoadjuvant chemotherapy, emergency surgery, palliative gastrectomy, other synchronous malignancies and missing data. The detailed selection process is displayed in Fig. 1. Emergency surgery was defined as an emergency procedure performed within 12 h after admission or after the onset of related symptoms. Missing data

was defined as any unknown variables for demographic characteristics, preoperative laboratory tests, surgical variables and postoperative variables. Eligible patients underwent gastrectomy between January 2010 and December 2015 were selected into the primary cohort, those who underwent gastrectomy between January 2016 and June 2019 were selected into the validation cohort.

Data collection

Patient demographic characteristics including sex, age, weight, American Society of Anesthesiologists (ASA) status, Charlson comorbidity index (CCI) score and comorbidities were obtained. Preoperative laboratory tests including hemoglobin, international normalized ratio (INR), platelet and albumin were also collected. Tumor characteristics, such as tumor location and pTNM (pathological Tumor-Lymph Node-Metastasis) stage, were included in this study. Surgical variables including LN (lymph node) dissection, type of gastrectomy, approach method, extragastric organ resection, estimated blood loss, total crystalloid, total colloid and operation time were recorded. Postoperative variables included intensive care unit (ICU) admission, postoperative length of stay, complications, Clavien–Dindo severity classification of complications and in-hospital mortality. Definitions of variables are listed in Supplementary Table S1.

Primary outcome

The primary outcome of this study was blood transfusion, which was defined as transfusing PRBCs intraoperatively or postoperatively. Generally, blood transfusions were required when hemoglobin level were lower than 70 g/L. For patients having symptoms of anemia, blood transfusion was also administered.

Statistical analyses

Continuous variables were reported as median and interquartile range (IQR). Categorical variables were reported as whole numbers and percentages. In descriptive analysis, the association of patient demographic characteristics, preoperative laboratory tests, surgical variables and postoperative variables were assessed between the primary and validation cohorts. The differences between patients with and without blood transfusion were compared in the primary cohort. Mann-Whitney U-tests were used to assess all continuous variables, which were abnormal distributed in this study. Categorical variables were analyzed by chi-square test or Fisher exact test according to the frequencies of variables.

Univariate and multivariate logistical regressions were employed to identify the risk factors for blood transfusion. The linearity of the association between continuous variables and the probability of transfusion was assessed using restricted cubic splines and categorized if significant non-linearity ($P < 0.05$) was found. Variance inflation factor (VIF) was used to detect multicollinearity in regression analysis, with a reference value of 10. VIF of each variable included in the full multivariable regression model was ≤ 10 , indicating no multicollinearity. The plausible interaction terms between the preoperative hemoglobin, preoperative INR and preoperative platelet were also evaluated. No significant interaction was found and therefore no interaction term was included in the multivariate analysis.

To build the predictive model, the Akaike information criterion (AIC) was employed to select predictors through a backward step-down process from the full regression model. Selected variables were incorporated into the nomogram to predict the probability of blood transfusion for gastrectomy.

Both internal and external validations of the nomogram were performed based on the primary and validated groups, respectively. The concordance index (C-index) was used to assess the discrimination of nomogram. A calibration curve was employed to determine the calibration. The curve was corroborated with 1000 resamples conducted for validation, reducing the overfit bias, which would overstate the accuracy of the nomogram. In addition, the Hosmer–Lemeshow goodness-of-fit test was also used to assess the calibration.

All statistical analyses were performed through R software version 3.4.2 (Institute for Statistics and Mathematics, Vienna, Austria; <https://www.r-project.org/>), and a two-tailed *P*-value < 0.05 was considered to be statistically significant.

Results

Patients’ baseline characteristics

Figure 1 shows the flow diagram of this study. 1240 patients who underwent gastrectomy for gastric cancer between January 2010 and June 2019 were extracted from the database. After selection, 999 patients were included for analysis. 600 patients were assigned to the primary cohort and 399 patients were assigned to the validation cohort.

Table 1 shows the demographic and clinicopathological characteristics of patients in the primary and validation cohorts. The transfusion rate for gastrectomy was 28.0% in the primary cohort and 32.6% in the validation cohort. Except for the approach method, there was no significant difference among other variables between the two cohorts.

Surgical and medical complications stratified by transfusion in the overall cohort are displayed in Table 2. Compared to those without transfusion, the rate of surgical complications (12.5% vs 6.0%; *P* < 0.001) and the rate of medical complications (5.9% vs 3.0%; *P* = 0.046) were significantly higher in patients with transfusion. Wound infection was the most common complication in patients with or without transfusion (3.6% and 1.9%, respectively).

Table 3 shows patients’ demographic characteristics, preoperative laboratory tests, surgical variables and postoperative variables stratified by the transfusion status in the primary cohort. Patients who received a blood transfusion for gastrectomy were more likely to be older (median age in patients with transfusion 62.0 [54.0–70.0] years vs 58.0 [50.0–65.0] years in those without; *P* < 0.001), to present with higher ASA status (ASA III–IV: 50% vs 30.3%; *P* < 0.001) and higher CCI scores (CCI ≥ 4: 66.7% vs 45.4%; *P* < 0.001). In addition, patients receiving a blood transfusion were more prone to have total gastrectomy (36.3% vs 23.1%; *P* = 0.002) and higher pTNM stage (stage III: 68.5% vs 50.7%; *P* < 0.001). With respect to tumor

characteristics, tumor was prone to be located in the upper area (12.5% vs 10.2%), middle area (36.3% vs 22.9%) and diffuse area (6.0% vs 3.0%) of stomach in patients with blood transfusion ($P < 0.001$). Regarding preoperative laboratory tests, patients receiving a blood transfusion had lower hemoglobin level (91.0 [79.8–117] g/l vs 130 [117–141] g/l; $P < 0.001$), higher platelet level (286 [227–341] $\times 10^9$ /l vs 253 [206–303] $\times 10^9$ /l; $P < 0.001$) and lower albumin level (38.8 [35.3–41.7] g/l vs 41.2 [38.3–44.1] g/l; $P < 0.001$). As for surgical and postoperative variables, patients receiving a blood transfusion had larger amount of estimated blood loss (200 [100–400] ml vs 100 [100–200] ml; $P < 0.001$). Compared to those without transfusion, the amount of total crystalloid was lower (1000 [1000–1500] ml vs 1250 [1000–1500] ml; $P = 0.002$) and the amount of total colloid was similar (1000 [688–1250] ml vs 1000 [500–1250] ml; $P = 0.293$) in patients with transfusion. In addition, patients with transfusion had longer operation time (255 [202–304] min vs 230 [188–285] min; $P < 0.001$) and longer postoperative length of stay (13.0 [11.0–19.0] days vs 11.0 [9.0–15.0] days; $P < 0.001$). Compared to those without transfusion, the ICU admission rate (8.3% vs 3.9%; $P = 0.048$), the complications rate (19.6% vs 10.0%; $P = 0.002$) and the hospital mortality rate (2.4% vs 0.5%; $P < 0.001$) were higher among patients with transfusion. With regard to the severity classification of complications, patients receiving a blood transfusion were more prone to have severer complications (grade III or greater: 9.5% vs 4.6%, $P = 0.032$) compared to those without transfusion.

Univariate and multivariate analysis of the primary cohort

Table 4 shows the univariate and multivariate analyses among patients with and without blood transfusion in the primary cohort. Age and preoperative hemoglobin were categorized based on the result of cubic spline function analysis (Supplementary **Figure S1, S3**). Weight, preoperative platelet, preoperative INR and preoperative albumin were not categorized as no significant nonlinearity was found (Supplementary **Figure S2, S4-S6**). In univariate analyses, age, ASA status, CCI score, tumor location, pTNM stage, type of gastrectomy, preoperative hemoglobin level, preoperative platelet level and preoperative albumin level were significantly associated with blood transfusion in patients undergoing gastrectomy. In multivariate analysis, CCI score, tumor location, pTNM stage, type of gastrectomy, extragastric organ resection, and preoperative hemoglobin level were identified as independent risk factors for blood transfusion for gastrectomy.

Construction of nomogram

The AIC-based multivariate analysis identified CCI score, tumor location, pTNM stage, type of gastrectomy, extragastric organ resection and preoperative hemoglobin level as independent predictors for blood transfusion. These identified risk factors were used to develop the nomogram to predict the likelihood of receiving a blood transfusion for gastric cancer surgery (Fig. 2).

Validation of the nomogram

The C-indexes were 0.863 and 0.901 in the primary and validation cohorts, respectively. Both of the C-indexes indicated good discrimination ability of the nomogram. To assess the calibration, calibration curves were employed in the primary and validation cohorts, respectively (Fig. 3). Additionally, P -values

for the Hosmer–Lemeshow goodness-of-fit test were 0.716 and 0.935 in the primary and validation cohorts, respectively. Both the calibration curves and the Hosmer–Lemeshow goodness-of-fit tests demonstrated high agreement between the nomogram prediction and actual outcomes.

Discussion

Surgery is the only curative treatment for gastric cancer. Blood transfusion is a frequent medical procedure for gastric cancer surgery. Previous studies have shown perioperative blood transfusion had negative impacts on postoperative outcomes for gastric cancer patients undergoing gastrectomy, included increasing the risk of surgical-site infection, complications and mortality [3–7]. Similarly, this study also showed that transfusion was significantly associated with higher incidence of surgical and medical complications. In addition, allogeneic blood transfusion has a risk of complications, including hemolysis, which can be life-threatening. Moreover, PRBCs are special and limited medical resources which are produced by healthy volunteers. Although many methods are used to assess the volunteers' health status, there are still some safety concerns. To avoid transfusion-related negative impacts and optimize the utilization of blood products, preoperative assessment of the risk of perioperative transfusion has been highlighted in guidelines for perioperative blood management [10–13]. To date, however, there is no study to focus on assessing the likelihood of perioperative blood transfusion for gastric cancer surgery.

In this study, using the database from a tertiary-care center in China, CCI score, tumor location, pTNM stage, type of gastrectomy, extragastric organ resection and preoperative hemoglobin were found to be independent risk factors for blood transfusion for gastric cancer patients undergoing gastrectomy. Subsequently, these identified risk factors were employed to develop a nomogram to predict the need for blood transfusion. The nomogram was constructed by demographic characteristics, preoperative laboratory tests, and surgical variables, all of which are obtainable preoperatively. The advantage that all information is obtainable before the surgery ensures the practical and convenient application of this predictive tool. More importantly, the validation of the nomogram demonstrated good discrimination ability and calibration in the primary and validation cohorts, respectively. These results indicated that this predictive model was highly accurate in determining a gastric cancer patient's risk of blood transfusion for gastrectomy.

Generally, serum hemoglobin level is the main indicator to direct doctors to transfuse PRBCs. The trigger threshold for blood transfusion varies in different institutions and remains a matter of debate [10]. Moreover, it was recently reported that nadir hemoglobin affected the relationship between red cell transfusion and outcomes [20], which indicated that the optimal hemoglobin level might vary in different patients. Thus, merely using hemoglobin level to direct blood transfusion is imprecise and incomprehensive. Regarding preoperative assessment of the risk for transfusion, guidelines recommended reviewing available laboratory test results including hemoglobin and coagulation profiles (i.e., INR, platelet), all of which were assessed in this study. As expected, preoperative hemoglobin level was the most powerful predictor in this predictive model, which was similar to other predictive models for

hepatopancreaticobiliary surgery [16] and hepatectomy [17]. In this study, using preoperative hemoglobin level greater than or equal to 120 g/L as a reference, hemoglobin level less than 80 g/l contributed 100 points to the nomogram. However, neither preoperative INR nor preoperative platelet level were found to be independent risk factors for blood transfusion for gastrectomy. In addition, CCI score, a factor reflecting a patient's state of health, was also included in the nomogram. Those who had a higher CCI score were prone to have more comorbidities, indicating that they were more susceptible to blood loss and more at-risk for transfusion for gastrectomy.

With respect to tumor characteristics, both tumor location and pTNM stage were identified as independent variables for blood transfusion for gastrectomy. Patients with higher pTNM stage are more likely to receive blood transfusion. It was possibly because tumor with advanced stage was prone to invade into adjacent tissues, increasing the complexity of surgery and the likelihood of bleeding.

Type of gastrectomy and extragastric organ resection were also included in the construction the nomogram. Compared with patients undergoing subtotal gastrectomy, those who underwent total gastrectomy have a higher risk of transfusion. One possible explanation was that in patients undergoing total gastrectomy, the extent of the disease is more comprehensive, which increases the difficulty of operation and the risk of blood loss. Patients with extragastric organ resection are at greater risk for transfusion compared with those without. Similarly, extrahepatic organ resection was selected to predict the risk of transfusion following hepatectomy [17, 21].

There are some limitations in this study. First, the nomogram was based on a retrospective study of a database from a single institution, thus having inherent limitations. At this point, a multicenter prospective cohort study to verify the results in this study is needed. Secondly, to maximize its clinical application, only preoperative variables were included. In future studies, nomograms including intraoperative and postoperative variables will be built, which may increase the predictive ability for the probability of blood transfusion for gastrectomy. Thirdly, the nomogram was validated internally and externally in the same database, which necessitates future validation in independent databases.

Conclusion

In the present study, a nomogram was constructed and validated to predict the probability of blood transfusion for gastric cancer surgery. Clinicians could use the nomogram to evaluate the likelihood of an individual receiving PRBCs to improve effective utilization of PRBCs.

Abbreviations

PRBCs: packed red blood cells; ASA status, the American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; pTNM stage, Pathological Tumor-Lymph Node-Metastasis; LN dissection, lymph node dissection; INR, international normalized ratio; ICU, intensive care unit.

Declarations

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Availability of data and materials

The datasets during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

HQH and ZXH wrote the manuscript; XL, ZQL and SH reviewed the medical records and collected data; MHC proofread and revised the manuscript; all authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Not applicable.

Ethics approval and consent to participate

This study was approved by the Sun Yat-sen Memorial Hospital Institutional Review Board. The informed consent was waived because it was a retrospective study.

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Tables

Table 1 Patient characteristics in the primary and validation cohorts.

	Primary cohort (n=600)	Validation cohort (n=399)	<i>P</i>
Transfusion			
No	432 (72.0%)	269 (67.4%)	0.139*
Yes	168 (28.0%)	130 (32.6%)	
Sex			
Female	197 (32.8%)	140 (35.1%)	0.503*
Male	403 (67.2%)	259 (64.9%)	
Age (years)			
Median [Q1, Q3]	59.0 [51.0, 66.0]	60.0 [51.5, 68.0]	0.182†
Weight (kg)			
Median [Q1, Q3]	58.0 [51.0, 64.6]	57.0 [50.8, 65.0]	0.760†
ASA status			
I-II	385 (64.2%)	247 (61.9%)	0.510*
III-IV	215 (35.8%)	152 (38.1%)	
CCI score			
0-3	292 (48.7%)	188 (47.1%)	0.678*
≥4	308 (51.3%)	211 (52.9%)	
Comorbidities			
No	493 (82.2%)	309 (77.4%)	0.079*
Yes	107 (17.8%)	90 (22.6%)	
Tumor location			
Upper	65 (10.8%)	55 (13.8%)	0.155*
Middle	160 (26.7%)	123 (30.8%)	
Lower	352 (58.7%)	207 (51.9%)	
Diffuse	23 (3.8%)	14 (3.5%)	
pTNM stage			
I	124 (20.7%)	83 (20.8%)	0.552*
II	142 (23.7%)	83 (20.8%)	
III	334 (55.7%)	233 (58.4%)	
LN dissection			
D1/D1+	107 (17.8%)	54 (13.5%)	0.085*
D2/D2+	493 (82.2%)	345 (86.5%)	
Type of gastrectomy			
Total	161 (26.8%)	111 (27.8%)	0.787*
Subtotal	439 (73.2%)	288 (72.2%)	
Approach method			
Laparoscopy	170 (28.3%)	199 (49.9%)	<0.001*
Open	430 (71.7%)	200 (50.1%)	
Extragastric organ resection			
No	527 (87.8%)	333 (83.5%)	0.062*
Yes	73 (12.2%)	66 (16.5%)	
Preoperative hemoglobin (g/l)			
Median [Q1, Q3]	124 [104, 138]	123 [97.5, 139]	0.613†
Preoperative INR			
Median [Q1, Q3]	0.990 [0.940, 1.037]	1.001 [0.950, 1.042]	0.115†
Preoperative platelet (× 10 ⁹ /l)			
Median [Q1, Q3]	259 [211, 311]	263 [209, 320]	0.701†
Preoperative albumin (g/l)			
Median [Q1, Q3]	40.4 [37.5, 43.5]	39.8 [35.7, 42.7]	0.096†
Estimated blood loss (ml)			
Median [Q1, Q3]	100 [100, 200]	100 [65.0, 200]	0.099†

Total crystalloid (ml)			
Median [Q1, Q3]	1200 [1000, 1500]	1250 [1000, 1500]	0.198 [†]
Total colloid (ml)			
Median [Q1, Q3]	1000 [500, 1250]	1000 [500, 1250]	0.254 [†]
Operation time (min)			
Median [Q1, Q3]	240 [192, 293]	240 [205, 290]	0.086 [†]
ICU admission			
No	569 (94.8%)	371 (93.0%)	0.281 [*]
Yes	31 (5.2%)	28 (7.0%)	
Postoperative length of stay (days)			
Median [Q1, Q3]	12.0 [9.00, 16.0]	11.0 [9.00, 15.0]	0.229 [†]
Complications			
No	524 (87.3%)	356 (89.2%)	0.422 [*]
Yes	76 (12.7%)	43 (10.8%)	
Clavien-Dindo severity classification of complications			
None	524 (87.3%)	356 (89.2%)	0.078 [*]
Grade II	40 (6.7%)	14 (3.5%)	
Grade III or greater	36 (6.0%)	29 (7.3%)	
In hospital mortality			
No	593(98.8%)	396(99.2%)	0.749 [*]
Yes	7(1.2%)	3(0.8%)	

* chi-squared test or Fisher exact test; [†] Mann-Whitney U test. Abbreviation: ASA status, the American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; pTNM stage, Pathological Tumor-Lymph Node-Metastasis; LN dissection, lymph node dissection; INR, international normalized ratio; ICU, intensive care unit.

Table 2 Complications stratified by transfusion in the overall cohort.

	No transfusion (n=695)	Transfusion (n=304)	<i>P</i>
Surgical complication	42 (6.0%)	38 (12.5%)	0.001
Wound infection	13 (1.9%)	11 (3.6%)	
Stenosis	8 (1.2%)	10 (3.3%)	
Abscess	9 (1.3%)	7 (2.3%)	
Ileus	4 (0.6%)	3 (1.0%)	
Anastomotic leakage	1 (0.1%)	2 (0.7%)	
Intestinal obstruction	1 (0.1%)	2 (0.7%)	
Pancreatitis	1 (0.1%)	1 (0.3%)	
Intraabdominal bleeding	5 (0.7%)	2 (0.7%)	
Medical complication	21 (3.0%)	18 (5.9%)	0.046
Pulmonary infection	7 (0.1%)	8 (2.6%)	
Pleural effusion	3 (0.4%)	2 (0.7%)	
Pulmonary failure	4 (0.6%)	1 (0.3%)	
Cardiac failure	0 (0%)	2 (0.7%)	
Renal failure	1 (0.1%)	2 (0.7%)	
Urinary retention	1 (0.1%)	0 (0%)	
Stroke	2 (0.3%)	1 (0.3%)	
Others	3 (0.4%)	2 (0.7%)	
Total	63(9.1%)	56(18.4%)	0.001

Table 3 Characteristics of patients stratified by transfusion in the primary cohort.

	No transfusion (n=432)	Transfusion (n=168)	<i>P</i>
Sex			
Female	141 (32.6%)	56 (33.3%)	0.948*
Male	291 (67.4%)	112 (66.7%)	
Age (years)			
Median [Q1, Q3]	58.0 [50.0, 65.0]	62.0 [54.0, 70.0]	<0.001 [†]
Weight (kg)			
Median [Q1, Q3]	58.0 [51.4, 65.0]	58.0 [51.0, 63.1]	0.354 [†]
ASA status			
I-II	301 (69.7%)	84 (50.0%)	<0.001*
III-IV	131 (30.3%)	84 (50.0%)	
CCI score			
0-3	236 (54.6%)	56 (33.3%)	<0.001*
≥4	196 (45.4%)	112 (66.7%)	
Comorbidities			
No	356 (82.4%)	137 (81.5%)	0.898*
Yes	76 (17.6%)	31 (18.5%)	
Tumor location			
Upper	44 (10.2%)	21 (12.5%)	<0.001*
Middle	99 (22.9%)	61 (36.3%)	
Lower	276 (63.9%)	76 (45.2%)	
Diffuse	13 (3.0%)	10 (6.0%)	
pTNM stage			
I	106 (24.5%)	18 (10.7%)	<0.001*
II	107 (24.8%)	35 (20.8%)	
III	219 (50.7%)	115 (68.5%)	
LN dissection			
D1/D1+	49 (10.5%)	15 (8.9%)	0.674*
D2/D2+	419 (89.5%)	153 (91.1%)	
Type of gastrectomy			
Total	100 (23.1%)	61 (36.3%)	0.002*
Subtotal	332 (76.9%)	107 (63.7%)	
Approach method			
Laparoscopy	126 (29.2%)	44 (26.2%)	0.532*
Open	306 (70.8%)	124 (73.8%)	
Extragastric organ resection			
No	385 (89.1%)	142 (84.5%)	0.159*
Yes	47 (10.9%)	26 (15.5%)	
Preoperative hemoglobin (g/l)			
Median [Q1, Q3]	130 [117, 141]	91.0 [78.8, 117]	<0.001 [†]
Preoperative INR			
Median [Q1, Q3]	0.990 [0.940, 1.04]	0.990 [0.948, 1.04]	0.848 [†]
Preoperative platelet (× 10⁹/l)			
Median [Q1, Q3]	253 [206, 303]	286 [227, 341]	<0.001 [†]
Preoperative albumin (g/l)			
Median [Q1, Q3]	41.2 [38.3, 44.1]	38.8 [35.3, 41.7]	<0.001 [†]
Estimated blood loss (ml)			
Median [Q1, Q3]	100 [100, 200]	200 [100, 400]	<0.001 [†]
Total crystalloid (ml)			
Median [Q1, Q3]	1250 [1000, 1500]	1000 [1000, 1500]	0.002 [†]
Total colloid (ml)			

Median [Q1, Q3]	1000 [500, 1250]	1000 [688, 1250]	0.293 [†]
Operation time (min)			
Median [Q1, Q3]	230 [188, 285]	255 [202, 304]	0.001 [†]
ICU admission			
No	415 (96.1%)	154 (91.7%)	0.048*
Yes	17 (3.9%)	14 (8.3%)	
Postoperative length of stay (days)			
Median [Q1, Q3]	11.0 [9.00, 15.0]	13.0 [11.0, 19.0]	<0.001 [†]
Complications			
No	389 (90.0%)	135 (80.4%)	0.002*
Yes	43 (10.0%)	33 (19.6%)	
Clavien-Dindo severity classification of complications			
None	389 (90.0%)	135 (80.4%)	0.006*
Grade II	23 (5.3%)	17 (10.1%)	
Grade III or greater	20 (4.6%)	16 (9.5%)	
In hospital mortality			
No	430 (99.5%)	164 (97.6%)	0.032*
Yes	2 (0.5%)	4 (2.4%)	

* chi-squared test or Fisher exact test; [†] Mann-Whitney U test. Abbreviation: ASA status, the American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; pTNM stage, Pathological Tumor-Lymph Node-Metastasis; LN dissection, lymph node dissection; INR, international normalized ratio; ICU, intensive care unit.

Table 4 Univariable and multivariable logistic regression analysis of factors associated with perioperative blood transfusion.

	Univariable logistic regression		Multivariable logistic regression		AIC based multivariable logistic regression	
	OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
Sex						
Female	Reference		Reference		-	
Male	0.97 (0.67-1.42)	0.871	0.95 (0.56-1.62)	0.841	-	-
Age (years)						
≤60	Reference		Reference		-	
≥60	2.00 (1.39-2.90)	<0.001	0.81 (0.39-1.66)	0.567	-	-
Weight (kg)	0.99 (0.97-1.01)	0.216	0.99 (0.97-1.01)	0.422	-	-
ASA status						
I-II	Reference		Reference		-	
III-IV	2.30 (1.60-3.32)	<0.001	1.21 (0.73-2.00)	0.463	-	-
CCI score						
0-3	Reference		Reference		Reference	
≥4	2.41 (1.67-3.51)	<0.001	2.56 (1.23-5.40)	0.012	2.15 (1.34-3.49)	0.002
Comorbidities						
No	Reference		Reference		-	
Yes	1.06 (0.66-1.67)	0.805	0.72 (0.38-1.36)	0.324	-	-
Tumor location						
Upper	Reference	0.025	Reference	0.038	Reference	0.052
Middle	1.29 (0.71-2.41)	0.412	1.31 (0.57-3.13)	0.197	1.29 (0.57-2.98)	0.545
Lower	0.58 (0.33-1.04)	0.062	0.56 (0.25-1.29)	0.162	0.58 (0.27-1.29)	0.173
Diffuse	1.61 (0.60-4.28)	0.337	1.36 (0.32-5.55)	0.672	1.50 (0.36-5.90)	0.569
pTNM stage						
I	Reference	<0.001	Reference	<0.001	Reference	<0.001
II	1.93 (1.04-3.68)	0.041	1.69 (0.77-3.81)	0.197	1.70 (0.78-3.76)	0.182
III	3.09 (1.83-5.50)	<0.001	3.15 (1.62-6.48)	0.001	3.17 (1.65-6.40)	0.001
LN dissection						
D1/D1+	Reference		Reference		-	
D2/D2+	1.34 (0.83-2.22)	0.240	1.49 (0.78-2.95)	0.237	-	-
Type of gastrectomy						
Total	Reference		Reference		Reference	
Subtotal	0.53 (0.36-0.78)	0.001	0.55 (0.33-0.90)	0.018	0.58 (0.35-0.96)	0.026
Approach method						
Laparoscopy	Reference		Reference		-	
Open	1.16 (0.78-1.75)	0.468	0.82 (0.48-1.39)	0.455	-	-
Extragastric organ resection						
No	Reference		Reference		Reference	
Yes	1.50 (0.89-2.50)	0.124	2.01 (1.01-3.93)	0.043	2.03 (1.02-3.95)	0.041
Preoperative hemoglobin (g/l)						
≥120	Reference	<0.001	Reference	<0.001	Reference	<0.001
110-119	1.34 (0.58-2.81)	0.464	1.19 (0.48-2.67)	0.690	1.37 (0.58-2.94)	0.187
100-109	3.29 (1.73-6.13)	<0.001	2.73 (1.33-5.50)	0.005	2.96 (1.50-5.76)	<0.001
90-99	7.44 (3.64-15.30)	<0.001	7.29 (3.22-16.72)	<0.001	8.50 (3.90-17.79)	<0.001
80-89	23.06 (10.88-52.85)	<0.001	23.91 (9.81-62.99)	<0.001	26.52 (11.68-65.08)	<0.001
≤80	72.90 (29.97-219.30)	<0.001	59.85 (22.12-195.65)	<0.001	66.03 (26.20-204.42)	<0.001
Preoperative INR	1.38 (0.15-12.67)	0.777	0.31 (0.01-7.17)	0.472	-	-
Preoperative platelet (×	1.004 (1.002-1.006)	<0.001	1.0004 (0.9978-1.0030)	0.782		

109/l)						
Preoperative albumin (g/l)	0.88 (0.85-0.92)	<0.001	0.98 (0.93-1.04)	0.526	-	-

Abbreviation: ASA status, the American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; pTNM stage, Pathological Tumor-Lymph Node-Metastasis; LN dissection, lymph node dissection; INR, international normalized ratio; ICU, intensive care unit.

Figures

Figure 1

Flow chart of study inclusion and exclusions.

Figure 2

Nomogram predicting the probability of perioperative transfusion following gastric cancer surgery. Abbreviation: ASA status, the American Society of Anesthesiologists physical status; CCI, Charlson comorbidity index; pTNM stage, Pathological Tumor-Lymph Node-Metastasis.

Figure 3

Calibration curves of the nomogram in the primary (A) and validation cohort (B).

Supplementary Files

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