Original Article

Development and validation of a clinical diagnostic model for surgical site infection after surgery in patients with gastric cancer

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Background: Surgical site infection (SSI) is a common and serious complication following gastric cancer surgery, often linked to patient age, surgery duration, and the surgical approach taken. Accurate prediction and personalized mitigation of SSI risk are crucial for improving surgical outcomes. While prior studies have focused on SSI rates after open and laparoscopic gastric cancer surgeries, it is important to also consider robot-assisted procedures. This study aims to develop a predictive model for SSI after radical gastric cancer surgery, validate it through external testing, and provide a reliable tool for clinical use.

Methods: Data from 763 postoperative gastric cancer patients were analyzed, with 601 in the training set from Gansu Provincial People's Hospital and 162 in the validation set from The First Hospital of Lanzhou University. All available variables were considered as potential predictors, and factors influencing SSI post-surgery were identified using logistic regression. A nomogram model was then created for precise SSI risk prediction.

Results: Among the 763 gastric cancer patients, 10.9% experienced postoperative SSI. Significant differences were noted in the American Society of Anesthesiologists (ASA) physical status classification system classification, preoperative albumin levels, surgical approach, and reconstruction techniques between groups. Age, surgery duration, surgical approach, total gastrectomy, and tumor diameter were identified as significant predictors of SSI. The nomogram model showed high predictive accuracy, with concordance index (C-index) values of 0.834 in the training set and 0.798 in the validation set. Calibration plots and decision curve analysis (DCA) further validated the model's performance.

Conclusions: This study identified five key predictors of postoperative SSI in gastric cancer and developed a nomogram model to enhance SSI prediction. These findings have important implications for preventing SSI in gastric cancer surgeries.

Keywords: Logistic regression; gastric cancer; nomogram; predictive modeling; surgical site infection (SSI)

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Introduction

Gastric cancer is the most prevalent malignant tumor globally. According to the GLOBOCAN 2020 report, there were over one million new cases of gastric cancer worldwide in 2020, with over 760,000 deaths. The incidence ranks fifth globally, while the mortality rate stands at fourth (1). Surgery is the primary means of treating gastric cancer (2,3). Currently, surgical site infection (SSI) is a significant clinical concern following gastric cancer surgery, with approximately 10% of post-gastric cancer surgery patients globally facing the risk of SSI (4). This risk is closely associated with factors such as patient age, surgery duration, and surgical technique (5-7).

In recent years, there has been a growing emphasis on reducing SSIs following gastric cancer surgeries (8,9). Researchers from both domestic and international backgrounds have dedicated efforts to investigate potential factors contributing to postoperative SSIs in gastric cancer and developing relevant prediction models. Kosuga *et al.* employed logistic regression to validate that factors such as gender, chronic liver disease, and total gastrectomy were linked to the risk of SSI (10). Conversely, Mao *et al.* examined 682 postoperative gastric cancer patients and identified myasthenia gravis as a significant factor for abdominal infections, subsequently creating a relevant prediction model (11). Kim *et al.* demonstrated that the visceral-to-subcutaneous-fat ratio served as an independent predictor of SSIs following gastric resection using logistic regression analysis (12). With the continuous development of artificial intelligence, robotics is expected to replace traditional surgery as the mainstream way to treat gastric cancer (13-15). However, despite the promising future, there are still some challenges and knowledge gaps in comprehensively considering the impact of robotic surgery on SSIs after gastric cancer surgery and in constructing a sound prediction scheme. At the current stage, an exhaustive assessment of existing SSI prediction models, highlighting their predictive accuracy, methodological strengths and weaknesses, limitations, and future research directions, will help to promote the further development of the field.

This study considered comprehensive risk factors for the occurrence of SSI post-gastric cancer surgery and established a nomogram with excellent discriminatory characteristics. Clinicians can utilize this nomogram as a decision-making tool for customizing individualized treatment for gastric cancer patients. It also serves as a valuable reference for the prevention and treatment of SSI after gastric cancer surgery. We present this article in accordance with the TRIPOD reporting checklist (available at https://tcr.amegroups.com/article/view/10.21037/tcr-24-79/rc).

Methods

Patients

A retrospective analysis was conducted on patients who underwent radical gastric cancer surgery at Gansu Provincial People's Hospital from June 2021 to March 2023 (677 cases) and at The First Hospital of Lanzhou University from January 2021 to June 2021 (187 cases). Inclusion criteria comprised: (I) age greater than 18 years; and (II) patients diagnosed with primary gastric adenocarcinoma through histology. Exclusion criteria were as follows: (I) non-primary gastric cancer; (II) history of previous gastric resection; (III) plan to switch from laparoscopic or robot-assisted surgery to open surgery; (IV) T4b or palliative resection; and (V) incomplete clinical or pathological data. Finally, 763 patients were included in the final analysis. Patients from the hospital with a larger sample size (training set) were used to derive the nomogram (601 cases), while patients from the other hospital constituted the validation set (162 cases). Pathological diagnosis and staging were performed according to the eighth edition of the American Joint Committee on Cancer (AJCC) tumor-node-metastasis (TNM) classification system for gastric cancer (16). This study adhered to the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Gansu Provincial People's Hospital (No. 2023-535) and the Ethics Committee of The First Hospital of Lanzhou University (No. LDYYLL2024-305). The study was a retrospective case-control study and was approved by the institutional review boards of the participating institutions; therefore, informed consent was not required.

Definition of SSI

According to the guidelines of the Centers for Disease Control and Prevention (CDC), SSIs are defined as follows: the definition includes organ/space SSI and incisional SSI (17). In essence, superficial incisional SSI is confined to the skin and subcutaneous tissue, while deep incisional SSI refers to infections involving the fascial and muscle layers. Organ/space infection involves any organ or space beyond the abdominal wall incision layer.

Data collection

The following variables were extracted from medical records in two central databases: age, gender, body mass index (BMI), American Society of Anesthesiologists (ASA) grade, chronic diseases (hypertension, diabetes, cardiovascular diseases, pulmonary diseases), abdominal surgery history, hemoglobin concentration, albumin concentration, lymphocyte count, white blood cell count, perioperative blood transfusion (BTF), operation time, intraoperative blood loss, operation method (robotic-assisted surgery, laparoscopic surgery, open surgery), total gastrectomy, reconstruction method, combined resection, lymphadenectomy, tumor location, tumor diameter, tumor stage, duration of prophylactic antibiotic use.

Research design

In this clinical diagnostic prediction study, a dataset of gastric cancer patients obtained from Gansu Provincial People's Hospital was utilized as the training set, while data from postoperative gastric cancer patients from The First Hospital of Lanzhou University served as the external validation set. The study design encompassed a univariate analysis of all collected variables as independent variables, with the presence or absence of SSI serving as the dependent variable. Subsequently, multiple statistically significant factors were incorporated into a multifactorial logistic regression analysis. The predictive performance of the model were assessed through the area under the receiver operating characteristic (ROC) curve (AUC), calibration curve, and decision curve analysis (DCA).

Statistical analysis

Continuous data were expressed as mean ± standard deviation or median (interquartile range) based on the data distribution. Data comparison was conducted using *t*-tests or Mann-Whitney *U* tests. Categorical variables were represented as frequencies (percentage values) and compared using the χ^2 test or Fisher's exact test.

After screening for independent predictors of SSI through univariate analysis, a predictive model for the probability of developing an SSI after gastric cancer surgery was created by incorporating all variables with P values of less than 0.05 in a multivariate logistic regression model. Prediction probabilities and odds ratios (ORs) with a 95% confidence interval (CI) were calculated. The model's predictive performance was evaluated based on its discrimination and calibration. Discrimination was assessed using the AUC, while calibration was evaluated using calibration curves to reflect the agreement between observed and predicted results (18). DCA was performed to measure the net benefits at corresponding threshold probabilities (19). In two-sided statistical tests, a P value of 0.05 or lower was considered statistically significant. All statistical analyses were performed with R v4.3.0 and SPSS 25.0.

Results

Clinical characteristics of patients

Table 1 presents the clinical and pathological characteristics of patients in the training and validation sets. In the training set, a total of 601 patients meeting the inclusion criteria were included in the study, among whom 64 individuals (10.6%) experienced postoperative SSI. In the validation set, there were 162 patients, with 19 individuals (11.7%) developing postoperative SSI. The majority of patients were male, comprising 453 males (75.4%) in the training set and 125 males (77.2%) in the validation set. Regarding surgical procedures, there were 155 cases (25.8%) and 9 cases (5.6%) of Da Vinci robot-assisted surgery, 275 cases (45.8%) and 86 cases (53.1%) of laparoscopic surgery, and 171 cases (28.5%) and 67 cases (41.4%) of open surgery in the training and validation sets, respectively. Statistically significant differences were observed between the two groups in ASA grade (P=0.047), preoperative albumin (P<0.001), operation method (P<0.001), and reconstruction (P=0.01).

Risk factor in the training set

Univariate and multivariate analyses were conducted on the training set to further construct the nomogram. Eight variables were found to be closely associated with SSI through univariate analysis. Subsequently, multivariate logistic regression analysis on this basis identified age (≥65 years: OR =2.53, 95% CI: 1.40–4.58, P=0.002), operation time (≥280 minutes: OR =9.12, 95% CI: 4.59–18.12, P<0.001), operation method (laparoscopic surgery: OR =1.71, 95% CI: 0.78–3.73, P=0.18; open surgery: OR =6.07, 95% CI: 2.53–14.55, P<0.001), total gastrectomy (OR =2.18, 95% CI: 1.18–4.03, P=0.01), and tumor diameter (≥5 cm: OR =2.05, 95% CI: 1.14–3.68, P=0.02) as independent risk factors for SSI (*Table 2*).

Table 1 Characteristics of patients with SSI in training and validation set

Variables	Training cohort (n=601)	Validation cohort (n=162)	P value
Gender			0.64
Male	453 (75.4)	125 (77.2)	
Female	148 (24.6)	37 (22.8)	
Age (years)	61 [55–68]	60 [52–67]	0.08
BMI (kg/m^2)	22.1 [19.8–24.5]	22.1 [20.1–24.6]	0.76
Hypertension			0.58
No	508 (84.5)	134 (82.7)	
Yes	93 (15.5)	28 (17.3)	
Diabetes mellitus			0.39
No	560 (93.2)	154 (95.1)	
Yes	41 (6.8)	8 (4.9)	
Cardiovascular disease			0.68
No	555 (92.3)	148 (91.4)	
Yes	46 (7.7)	14 (8.6)	
Pulmonary disease			0.83
No	561 (93.3)	152 (93.8)	
Yes	40 (6.7)	10 (6.2)	
Abdominal surgery history			0.32
No	526 (87.5)	137 (84.6)	
Yes	75 (12.5)	35 (15.4)	
ASA			0.047
1	8 (1.3)	7 (4.3)	
2	528 (87.9)	136 (84.0)	
3	65 (10.8)	19 (11.7)	
Preoperative laboratory tests			
White blood cell count (×10^9/L)	5.3 [4.2–6.5]	5.4 [4.4–6.5]	0.71
Lymphocyte count (×10^9/L)	1.3 [1.0–1.7]	1.3 [1.1–1.6]	0.65
Hemoglobin (g/L)	129.00 [99.00–147.00]	132.00 [110.75–146.25]	0.18
Albumin (g/L)	38.6 [35.5–41.5]	42.0 [39.5–45.6]	<0.001
Operation time (min)	240 [200–290]	247 [210–300]	0.31
Blood loss (mL)	100 [50–200]	100 [95–200]	0.09
Operation method			<0.001
Robotic-assisted surgery	155 (25.8)	9 (5.6)	
Laparoscopic surgery	275 (45.8)	86 (53.1)	
Open surgery	171 (28.5)	67 (41.4)	

Table 1 (*continued*)

Table 1 (*continued*)

Variables	Training cohort (n=601)	Validation cohort (n=162)	P value
Total gastrectomy			0.96
No	325 (54.1)	88 (54.3)	
Yes	276 (45.9)	74 (45.7)	
Reconstruction			0.01
B-I	76 (12.6)	7 (4.3)	
B-II	227 (37.8)	77 (47.5)	
Roux-en-Y	278 (46.3)	72 (44.4)	
Other	20 (3.3)	6 (3.7)	
Combined resection			0.18
No	539 (89.7)	151 (93.2)	
Yes	62 (10.3)	11 (6.8)	
Lymphadenectomy			0.20
D1	38 (6.3)	6 (3.7)	
D2	563 (93.7)	156 (96.3)	
Tumor location			0.92
Lower	306 (50.9)	85 (52.5)	
Middle	184 (30.6)	47 (29.0)	
Upper	111 (18.5)	30 (18.5)	
Tumor diameter (cm)	4.0 [3.0–6.0]	4.0 [2.5–5.5]	0.08
Tumor stage			0.31
1	137 (22.8)	35 (21.6)	
2	143 (23.8)	48 (29.6)	
3	321 (53.4)	79 (48.8)	
Perioperative BTF			0.07
No	457 (76.0)	134 (82.7)	
Yes	144 (24.0)	28 (17.3)	

Data are presented as n (%) or median [IQR]. SSI, surgical site infection; BMI, body mass index; ASA, American Society of Anesthesiologist; BTF, blood transfusion; IQR, interquartile range.

Development and validation of the nomogram

Based on the independent features identified in the multivariate analysis, a nomogram was created to predict the incidence of SSI in gastric cancer patients. By summing the results of the five predictive factors, the nomogram can calculate the likelihood of SSI. The score of each variable was transformed linearly to a 100-point scale. The higher the total score, the higher the estimated incidence of SSI (*Figure 1*).

Performances of the nomogram

Following the ROC analysis of the training set, the AUC was determined to be 0.834 (95% CI: 0.790–0.878), exhibiting a specificity of 65.4% and a sensitivity of 89.1%

Table 2 Univariate and multivariate logistic regression analysis of SSI in training set

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Gender		0.25		
Male	1			
Female	0.68 (0.35–1.31)			
Age (years)		<0.001		0.002
<65	1		1	
≥65	2.93 (1.70–5.05)		2.53 (1.40–4.58)	
BMI (kg/m^2)		0.53		
<25	1			
≥25	1.22 (0.66–2.25)			
Hypertension		0.44		
No	1			
Yes	1.30 (0.66–2.54)			
Diabetes mellitus		0.11		
No	1			
Yes	0.20 (0.03–1.46)			
Cardiovascular disease		0.96		
No	1			
Yes	1.03 (0.39–2.69)			
Pulmonary disease		0.12		
No	1			
Yes	0.20 (0.03–1.50)			
Abdominal surgery history				
No	1			
Yes	0.70 (0.29–1.69)	0.43		
ASA	0.59 (0.25–1.40)	0.23		
1				
2				
3				
White blood cell count (×10^9/L)		0.51		
<4	1			
≥4	1.28 (0.61–2.68)			
Lymphocyte count (×10^9/L)		0.21		
<0.8	1			
≥0.8	0.59 (0.27–1.33)			

Table 2 (*continued*)

Table 2 (*continued*)

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Hemoglobin (g/L)		0.36		
<110	1			
≥110	0.78 (0.46–1.33)			
Albumin (g/L)		0.18		
<30	1			
≥30	0.53 (0.21–1.34)			
Operation time (min)		<0.001		<0.001
<280	1		1	
≥280	5.70 (3.26–9.94)		9.12 (4.59–18.12)	
Blood loss (mL)		0.63		
<100	1			
≥100	1.15 (0.65–2.05)			
Operation method		0.02		
Robotic-assisted surgery	1		1	
Laparoscopic surgery	1.19 (0.58–2.45)	0.63	1.71 (0.78–3.73)	0.18
Open surgery	2.23 (1.09–4.58)	0.03	6.07 (2.53–14.55)	<0.001
Total gastrectomy		<0.001		0.01
No	1		1	
Yes	3.41 (1.93–6.03)		2.18 (1.18–4.03)	
Reconstruction		0.003		
B-I	1			
B-II	0.59 (0.21–1.67)	0.32		
Roux-en-Y	2.25 (0.92–5.50)	0.08		
Other	1.30 (0.24–6.97)	0.76		
Combined resection		0.02		
No	1			
Yes	2.25 (1.13–4.49)			
Lymphadenectomy		0.28		
D1	1			
D2	2.23 (0.52–9.48)			
Tumor location		0.25		
Lower	1			
Middle	0.84 (0.45–1.59)	0.60		
Upper	1.60 (0.85–3.03)	0.15		

Table 2 (*continued*)

Table 2 (*continued*)

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Tumor diameter (cm)		0.001		0.02
<5	1		1	
≥5	2.40 (1.41–4.10)		2.05 (1.14–3.68)	
Tumor stage	1.57 (1.09–2.26)	0.01		
1				
2				
3				
Perioperative BTF		0.61		
No	1			
Yes	1.17 (0.65–2.11)			
Duration of prophylactic antibiotics (days)		0.77		
≤2	1			
>2	1.09 (0.61–1.96)			

SSI, surgical site infection; OR, odds ratio; CI, confidence interval; BMI, body mass index; ASA, American Society of Anesthesiologists; BTF, blood transfusion.

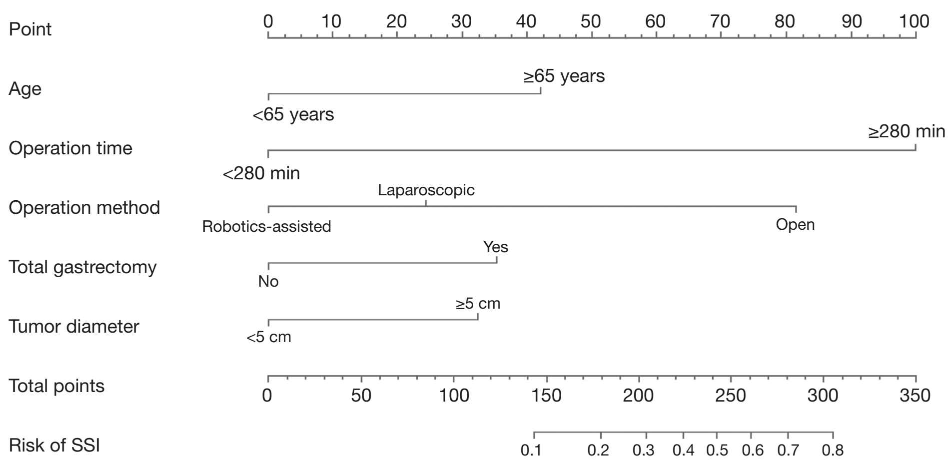

Figure 1 The nomogram for estimating the risk of SSI was constructed based on the 5 identified predictors. SSI, surgical site infection.

(*Figure 2A*). Within the validation set, the AUC was calculated as 0.798 (95% CI: 0.699–0.879), demonstrating a specificity of 72% and a sensitivity of 73.7% (*Figure 2B*). This indicates that the model has good discriminative ability and accuracy. In the calibration plots for the training and validation sets, the model shows good fit and calibration with the ideal curve (*Figure 3*). The Y-axis of the decision curve represents the net benefit. The predictive model is represented by the red line, the all-treatment strategy is shown as the gray line, and the no-treatment strategy is represented by the black line. In the threshold probability range of the DCA curve, the net benefit for patients is higher than the other two extreme curves. When the patient's threshold probability exceeds 5%, the treatment

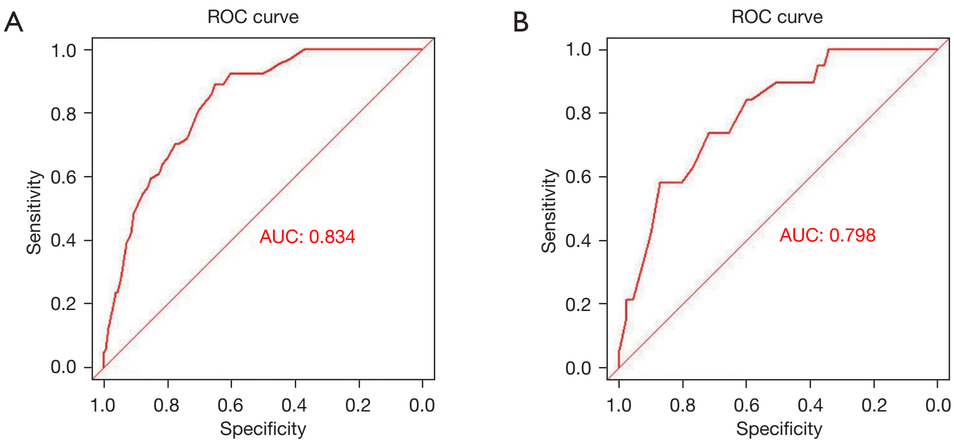

Figure 2 ROC curve for predictive models in the training and external validation sets. The ROC curves show good discrimination between the training (A) and validation (B) sets. ROC, receiver operating characteristic; AUC, area under the ROC curve.

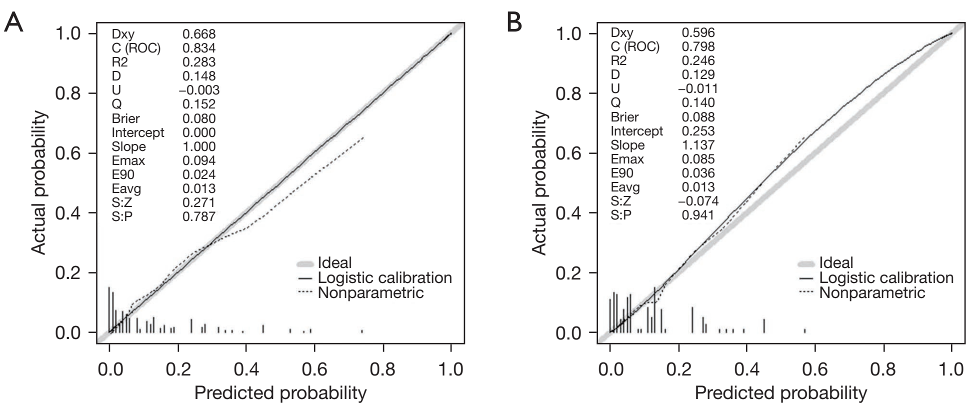

Figure 3 Calibration curves for the model in the training (A) and validation (B) set are shown. The X-axis shows the predicted probability and the Y-axis represents the actual probability of malignancy. The diagonal line represents an ideal prediction. The closer the calibration curves fit the diagonal line, the more accurate the prediction of the actual outcomes. ROC, receiver operating characteristic.

plan created by the nomogram model is more valuable than the "all or none" strategy (*Figure 4*).

Discussion

Current gastric cancer treatment primarily involves surgical resection, but SSI is a common complication and an important clinical outcome indicator for elective surgery (20,21). SSI can lead to prolonged hospital stays, septic shock, multi-organ failure, and even death (22,23). Although studies have been conducted on SSI after gastric cancer surgery, the numerous influencing factors make accurate prediction challenging. In this study, the incidence of SSI after gastric cancer surgery was 10.6%, comparable to a study in Japan (10).

The study analyzed data of 601 patients undergoing gastric cancer resection for 25 potential variables associated with SSI. The following independent risk factors were identified: age (≥65 years), operation time (≥280 minutes), operation method (laparoscopic surgery, open surgery) tumor size (≥5 cm), and total gastrectomy. The nomogram showed good diagnostic performance (AUC =0.834) and was externally validated with data from another hospital. Additionally, according to DCA, the predictive model demonstrated excellent performance in clinical application.

SSI is more common in the elderly, and many studies have investigated related risk factors. In this study, advanced age was also identified as a risk factor in multivariate analysis.

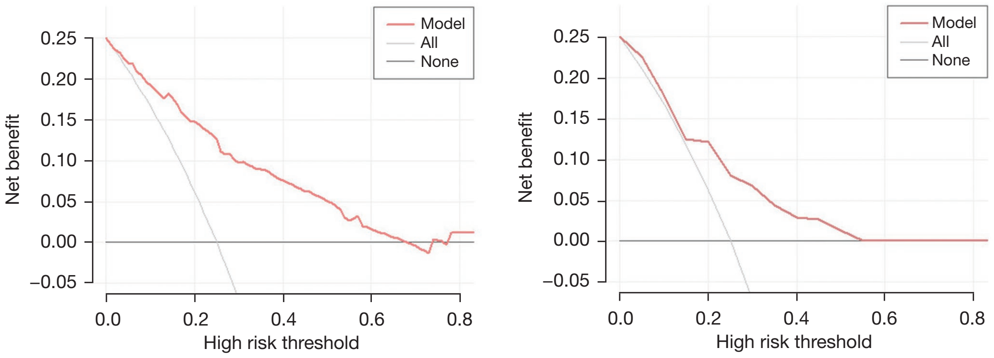

Figure 4 Decision curves for the predictive model show that treatment strategies created based on the nomogram model produce higher net benefits when the patient's predictive threshold probability is greater than 5%, compared to the 'treat all or treat none' strategy. The grey and black reference lines represent the assumptions for the 'treat all' and 'no treatment' strategies, respectively.

This suggests that healthcare professionals should pay more attention to these patients, who are more prone to infections and have longer postoperative recovery times (24-26). Furthermore, longer surgery duration (>280 minutes) was an independent risk factor for SSI, consistent with previous research. Kim *et al.* reported that the duration of surgery was a risk factor for SSI after gastrectomy (27). This has been demonstrated in patients undergoing gastrectomy. Surgeons need to make efforts to shorten the duration of surgery to prevent SSI Shortening the duration of surgery to prevent SSI infection.

Total gastrectomy and tumor size were identified as independent risk factors for SSI. The impact of these factors on infection is closely related to expanded surgical scope, prolonged surgery duration, and increased intraoperative bleeding (28-30). Moreover, multi-organ resection may be another independent risk factor for infection, as mentioned in previous research results (31).

While risk factors for SSI based on surgical approach have been studied, with the development of various surgical methods such as laparoscopic and robotic gastrectomy, the previous nomogram neglected factors affecting SSI in gastric cancer patients after robotic surgery (32-34). In this study, we considered robotic surgery as a factor, with an SSI incidence of 10.6% (64/601), where the SSI incidence for robotic surgery was 7.7% (12/155), laparoscopic surgery was 9.1% (25/275), and open surgery was 15.8% (27/171). These results indicate that the SSI incidence for minimally invasive surgery (e.g., laparoscopic or robotic) is significantly lower than that for open surgery (P=0.03), highlighting minimally invasive surgery as a dominant factor in SSI after gastric cancer surgery. It should be incorporated into the nomogram, and from a postoperative infection prevention perspective, patients are recommended to undergo such surgeries.

The study has several limitations. Firstly, it adopts a retrospective design, which may introduce selection bias. Secondly, differences in the proportion of inpatients and referral bias may be reasons for the distinct baseline characteristics between the two patient groups. Thirdly, the small sample size may impact the accuracy of the model. Hence, conducting more multicenter randomized controlled trials is warranted to enhance the model's effectiveness.

Conclusions

Herein, we constructed a nomogram model to predict postoperative SSI in gastric cancer using logistic regression analysis. The training group and validation group had AUC of 0.834 and 0.798, respectively, indicating excellent predictive capability. The nomogram model can serve as a reference for the selection of elective surgery and surgical methods, effectively reducing the risk of postoperative SSI in gastric cancer patients.

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Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at https://tcr.amegroups.com/article/view/10.21037/tcr-24-79/rc

Data Sharing Statement: Available at https://tcr.amegroups.com/article/view/10.21037/tcr-24-79/dss

Peer Review File: Available at https://tcr.amegroups.com/article/view/10.21037/tcr-24-79/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://tcr.amegroups.com/article/view/10.21037/tcr-24-79/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study adhered to the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Gansu Provincial People's Hospital (No. 2023-535) and the Ethics Committee of The First Hospital of Lanzhou University (No. LDYYLL2024-305), respectively, and was exempted from the requirement of informed consent because it was a retrospective case-control study and the study was approved by the institutional review boards of each participating site.

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