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A Predictive Nomogram for the Occurrence of Gastroesophageal Reflux Disease After Sleeve Gastrectomy: A Study Based on Preoperative HERM

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Purpose: Gastroesophageal reflux disease (GERD) is a common complication after laparoscopic sleeve gastrectomy (LSG); This study aimed to construct a model that can predict the incidence of GERD after LSG by exploring the correlation between the results of high-resolution esophageal manometry (HREM) and the incidence of GERD after LSG.

Patients and Methods: We collected the clinical data of patients who had undergone HREM before bariatric surgery from September 2013 to September 2019 at the bariatric center of our hospital. The Gerd-Q scores during the postoperative follow-up were collected to determine the incidence of GERD. A logistic regression analysis was performed to explore the correlation of the HREM results and general clinical data with the incidence of GERD after LSG.

Results: The percentage of synchronous contractions, lower esophageal sphincter (LES) resting pressure, and history of smoking were correlated with the development of GERD after LSG, with the history of smoking and percentage of synchronous contractions as risk factors and LES resting pressure as a protective factor. The training set showed an area under the ROC curve (AUC) of the nomogram model of 0.847. The validation set showed an AUC of 0.761. The decision and clinical impact curves showed a high clinical value for the prediction model.

Conclusion: The HREM results correlated with the development of GERD after LSG, with the percentage of synchronous contractions and LES resting pressure showing predictive value. Combined with the history of smoking, the predictive model showed a high confidence and clinical value.

Keywords: gastroesophageal reflux disease, laparoscopic sleeve gastrectomy, high-resolution esophageal manometry, complications

Introduction

Obesity has a high global epidemiological prevalence, with rates increasing consistently in recent years. Approximately 25% of adults were estimated to be overweight in 2022.[1,2] With the development of society and changes in lifestyle habits, the incidence of obesity has been increasing every year.[3] In recent years, bariatric surgery has become increasingly popular among people with obesity.[4] Bariatric surgery includes laparoscopic sleeve gastrectomy (LSG) and laparoscopic Roux-en-Y gastric bypass (LRYGB). LSG has become the most widely performed type of bariatric surgery owing to its safety, effectiveness, ease of operation, and short learning curve.[5]

Common postoperative complications of bariatric surgery include postoperative bleeding, stenosis, malnutrition, and unstable blood sugar levels.[6–9] Compared to Bypass procedures, LSG may be more likely to lead to gastroesophageal

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reflux disease (GERD).[10–12] This complication has become a popular research topic. GERD is defined as a series of clinical syndromes including acid reflux and belching caused by the reflux of gastroduodenal contents into and outside the esophagus.[13] Complicated GERD in patients after LSG often reduces the patients' quality of life. Some patients require revision surgery in cases where long-term medication does not bring about a controlling effect.[14]

Aili et al revealed that the prevalence of GERD after LSG was as high as 35%, possibly because LSG changes the anatomy of the gastroesophageal junction, which leads to abnormal gastroesophageal motility, thus causing GERD.[15] In addition to the anatomical alterations caused by the surgery, a history of smoking, and combined hiatal hernia of the esophagus are associated with a higher incidence of postoperative GERD.[16] Men and older age groups are more likely to develop GERD after LSG.[17] However, no predictive model that can quantitatively predict the probability of developing GERD after LSG has been established. Therefore, it is crucial to establish a model that can predict the incidence of GERD after LSG preoperatively.[14,18]

In addition to the routine preoperative examination before LSG in patients with obesity, high-resolution esophageal manometry (HREM) is performed at our center. HREM can directly reflect the esophageal dynamics and help diagnose related disorders.[19] Compared to conventional esophageal manometry, HREM uses esophageal pressure mapping, which offers the advantages of efficient and detailed data collection and a simple and intuitive data display method.[20,21]

HREM results in patients with GERD usually include lower esophageal sphincter (LES) and upper esophageal sphincter (UES) lower than the respective normal levels, reflecting a series of indicators of esophageal motility.[14]

Therefore, this retrospective study aimed to explore the relationship between preoperative HREM-related index scores and the incidence of postoperative GERD after LSG and establish a prediction model for the GERD risk after LSG by combining the clinicopathological features. The null hypothesis was that the model can assess the GERD risk after LSG based on preoperative HREM findings.

Materials and Methods

Selection and Description of Participants

We retrospectively analyzed the clinical data of all patients who had undergone HREM from September 2013 to September 2019 before bariatric surgery at our bariatric center.

The inclusion criteria were: (1) a history of LSG (based on Chinese obesity and type 2 diabetes surgical treatment guidelines (2014)); (2) no history of abdominal surgery; (3) Patients with complete preoperative HREM results; (4) availability of Gerd-Q scores ≥3 years postoperatively; and (5) Patients excluded from the diagnosis of GERD through Upper Gastrointestinal Endoscopy examination (Upper Gastrointestinal Endoscopy shows that the esophageal mucosa is intact with no evidence of erosion, ulcers, or inflammation. The lower esophageal sphincter is tightly closed, showing no signs of dysfunction. Based on these findings, a diagnosis of GERD can be excluded).[22,23]

The exclusion criteria were: (1) incomplete preoperative and postoperative follow-up clinical data; (2) perioperative fistula/bleeding or other serious complications leading to a second operation; and (3) other esophageal or gastrointestinal operations during the postoperative follow-up period.

All patients signed informed consent forms. The study adhered to the Declaration of Helsinki. The Ethics Review Board of Capital Medical University Affiliated Beijing Shijitan Hospital approved the study protocol [approval number: sjtkyll-lx-2022(076)]. All the participants provided informed consent for participation in the study.

Technical Information

HREM: The solid-state ManoScan™ HREM instrument, containing 36 solid-state capacitive column pressure transducers and 432 pressure points, was applied to collect and analyze patient data. One week before HREM, medications affecting esophageal dynamics were discontinued, and fasting and of water intake were prohibited for 12 and 6 h, respectively. The catheter was inserted into the nasal cavity through the nostril until it entered the stomach. The stomach was confirmed to contain three to five pressure channels across the UES, esophageal body, and LES.

After successful catheter insertion, the patient was placed in the supine position, and the catheter was fixed. The patient was instructed to adapt for a few minutes. Subsequently, the patient was instructed to rest and breathe steadily for 30s, without swallowing movements, and the pressure was recorded. The patient swallowed 5 mL of water every 30s and repeated it 10 times. The patient could not continue to swallow after a swallowing movement. The catheter was withdrawn after acquiring all pressure measurements. The Chicago Classification of Esophageal Motility Disorders was applied.[24]

Gerd-Q: The GERD-Q is used as a tool for diagnosing GERD during follow-up periods. The Gerd-Q contains six main questions, including the presence/absence of heartburn or retrosternal pain in the past 7 days, gastric content reflux, epigastric pain, nausea, sleep disturbance because of heartburn and retrosternal pain, and recent medication use for symptomatic relief. For each question, the respondents were asked to rate the frequency of symptoms over the past 7 days, and the total score was calculated. The total score ranged from 0 to 18, with higher scores indicating more severe symptoms.[25,26] A Gerd-Q score >8 was diagnostic of GERD and ≤8 ruled out GERD.[27]

Clinical Data

The patients' preoperative age, sex, height, weight, BMI, abdominal circumference, smoking history, and alcohol consumption history were retrospectively collected.

Definition of Relevant Indicators

A history of smoking was defined as smoking more than one cigarette daily for more than 6 months, or was defined as non-smokers' exposure to the tobacco smoke for an average of at least 10 min per day.[28,29]

A history of alcohol consumption was defined as consuming at least one standard alcoholic drink weekly, averaging more than 20 g of alcohol/day for over 1 year.[30]

The LES resting pressure, calculated during calm breathing, reflected the LES function, with normal values ranging from 10 to 35 mmHg.[31]

A percentage of synchronous contractions (synchronous contraction speed of the esophageal body >6.25 cm/s) >20% was considered to indicate an abnormal performance of the esophagus.[32]

Logistic Regression Analysis for Model Construction and Evaluation

Univariate logistic regression analysis was performed with the occurrence of postoperative reflux as the dependent variable and the HREM and general clinical data as the independent variables. Significant independent variables were then included in the Multivariate logistic regression analysis to obtain independent predictors (statistical significance at $p < 0.1$). The independent predictors were used to construct nomogram plots, and the accuracy of this predictive model was assessed using the receiver operating characteristic (ROC) curves. The actual probabilities were compared with the predicted probabilities using calibration curves, thus validating the predictive effect of the model. The decision curve analysis (DCA) and clinical impact curve (CIC) were used to assess the clinical effect of the nomogram.

Statistical Analysis

Categorical data, expressed as number (percentage), were compared using the chi-square or Fisher's exact test. Normally distributed quantitative data, expressed as mean ± standard deviation, were compared using the Shapiro–Wilk test. The independent-samples *t*-test was used for between-group comparisons. Non-normally distributed quantitative data, expressed as median (25th percentile, 75th percentile), were compared using non-parametric tests. A two-sided *p-value* < 0.05 was considered to indicate statistical significance. All analyses were completed using R version 4.3.1.

Results

The same surgeon at our center performed all procedures. In addition, to investigate the relationship between the HREM results and the incidence of GERD after LSG, HREM had been rendered free and voluntary. HREM did not increase patient burden, and its results did not influence the treatment plan of the patients.

Patient Demographics and Baseline Characteristics

According to the inclusion and exclusion criteria, a total of 64 patients were enrolled in the study. These patients had been undergoing LSG for more than 5 years, with a maximum of 11 years. Table 1 shows the baseline characteristics of all patients.

Table 1 The Baseline Characteristics of All Patients

Clinical Characteristics	Value
Age(years)	31.422±9.046
Gender	
Men	32 (50.000%)
Height(cm)	171.172±7.523
Weight(kg)	121.200 (100.500, 136.375)
BMI (kg/m^2)	41.629±8.036
Abdominal circumference (cm)	125.314±18.193
A history of smoking	
Yes	32 (50.000%)
A history of alcohol consumption	
Yes	36 (56.250%)
Postoperative year (years)	6 (5, 8)
Postoperative GERD	
Yes	32 (50.000%)
The lengths of LES(cm)	4.400 (4.000, 4.975)
LES resting pressure(mmHg)	14.650 (11.025, 25.825)
Residual pressure (mmHg)	10.550 (6.550, 14.975)
Percentage of synchronous contractions (≥6.25cm/s)	0.000 (0.000, 20.000)
Percentage of bimodal waves	0.000 (0.000, 20.000)
Distal contraction integral (mmHg*cm*s)	2063.950 (1329.650, 2960.425)
Velocity of the contraction front (cm/s)	3.500 (2.725, 4.500)
Intra-esophageal doughnut pressure (mmHg)	3.500 (0.350, 7.025)
Distal contraction delay (second)	6.550 (5.800, 7.900)
Percentage of ineffective swallows	0.000 (0.000, 0.000)
Peak USE pressures (mmHg)	15.172±9.544

Abbreviations: BMI, Body Mass Index; GERD, Gastroesophageal Reflux Disease; LES, Lower Esophageal Sphincter; USE, Upper Esophageal Sphincter.

Comparison of Baseline Characteristics Between the Training and Validation Sets

A random grouping method was used to divide the patients into a training set (*N = 45, 70%*) and a validation set (*N = 19, 30%*) at a ratio of 7:3. We enrolled 45 participants in the training set and 19 participants in the validation set. After randomization, sex was the only baseline characteristic significantly different between the two groups. Table 2 shows the baseline characteristics of the patients in the two groups.

Comparison of Baseline Characteristics with and without Postoperative Occurrence of Reflux in the Training Set

The training set included 21 patients with GERD and 24 patients without GERD, with differences in smoking history, residual pressure, and percentage of synchronous contractions between the two groups. None of the other variables showed significant differences. Table 3 shows the baseline characteristics of the patients in the two groups.

Logistical Regression Analysis of HREM Results

The results of univariate logistic regression analysis showed that the history of smoking, LES resting pressure, and percentage of synchronous contractions were significant independent variables ($p < 0.1$). The results of multivariate logistic regression analyses showed that the history of smoking, LES resting pressure, and percentage of synchronous contractions were significant independent predictors. Table 4 shows the results of the univariate and multivariate logistic regression analysis.

Table 2 Comparison of Baseline Characteristics Between the Training and Validation Sets

	Training Set (n=45)	Validation Set (n=19)	X^2/t/Z	p-value
Age(years)	30.244±1.288	34.211±2.203	−1.623[b]	0.110
Gender			6.063[a]	0.014
Men	18(40%)	14(73.684%)		
Height(cm)	171.022±1.053	171.526±1.998	−0.243 [b]	0.809
Weight(kg)	119.847±3.576	129.184±8.335	−1.030 [b]	0.313
BMI(kg/m^2)	40.864±1.076	43.441±2.222	−1.176 [b]	0.244
Abdominal circumference (cm)	124.091±2.501	122.000 (114.000, 136.000)	−0.375[c]	0.708
A history of smoking			0.075 [a]	0.784
Yes	22(48.889%)	10(52.632%)		
A history of alcohol consumption			0.144 [a]	0.705
Yes	26(57.778%)	10(52.632%)		
Postoperative year (years)	6.000(5.000, 7.500)	6.000(5.000, 8.000)	−0.579[c]	0.563
Postoperative GERD			0.674 [a]	0.412
Yes	21(46.7%)	11(57.9%)		
The lengths of LES(cm)	4.400(4.000, 4.950)	4.505±0.206	−0.996[c]	0.334
LES resting pressure(mmHg)	14.500(10.500, 20.850)	21.995±2.774	−1.683[c]	0.092
Residual pressure (mmHg)	9.800(5.800, 14.550)	14.647±3.054	−1.881[c]	0.604
Percentage of synchronous contractions (≥6.25cm/s)	0.000(0.000, 20.000)	0.000(0.000, 40.000)	−0.604[c]	0.546
Percentage of bimodal waves	0.000(0.000, 18.500)	10.000(0.000, 30.000)	−1.384[c]	0.166
Distal contraction integral (mmHg*cm*s)	2058.600 (1337.500, 2925.550)	2155.100 (1235.000, 3909.100)	−0.536[c]	0.592
Velocity of the contraction front (cm/s)	3.500(2.750, 4.500)	3.600±0.231	−0.029[c]	0.977
Intra-esophageal doughnut pressure (mmHg)	3.000(0.000, 6.050)	6.800(2.200, 11.700)	−1.903[c]	0.057
Distal contraction delay (second)	6.400(5.650, 7.750)	7.100(6.200, 8.600)	−1.176[c]	0.240
Percentage of ineffective swallows	0.000(0.000, 0.000)	0.000(0.000, 9.000)	−0.356[c]	0.722
Peak USE pressures (mmHg)	14.300(8.600, 12.050)	15.584±1.986	−0.404[c]	0.686

Note: [a] x^2-value; [b] t-value; [c] Z-value;
Abbreviations: BMI, Body Mass Index; GERD, Gastroesophageal Reflux Disease; LES, Lower Esophageal Sphincter; USE, Upper Esophageal Sphincter.

Table 3 Comparison of Baseline Characteristics with and without Postoperative Occurrence of Reflux in the Training Set

	Training Set		X^2/t/Z	p-value
	With Postoperative Occurrence of Reflux (n=24)	Without Postoperative Occurrence of Reflux (n=21)		
Age(years)	28.875±7.898	31.810±9.368	−1.140 [b]	0.260
Gender			0.060[a]	0.807
Men	10(41.667%)	8(38.095%)		
Height(cm)	171.750±7.520	170.190±6.593	0.735 [b]	0.466
Weight(kg)	123.546±27.346	115.619±19.264	1.109 [b]	0.274
BMI(kg/m^2)	41.741±8.190	39.861±5.951	0.869 [b]	0.389
Abdominal circumference (cm)	127.125±16.246	120.624±17.090	1.307 [b]	0.198
A history of smoking			11.745[a]	0.001
Yes	16(76.19%)	6(25%)		
A history of alcohol consumption			0.275[a]	0.600
Yes	13(54.167%)	13(61.905%)		
Postoperative year (years)	6.00(5.00, 6.75)	6.00(5.50, 8.50)	−1.350[c]	0.177
The lengths of LES(cm)	4.150(4.000, 4.850)	4.533±0.791	−1.044[c]	0.297
LES resting pressure(mmHg)	18.825±9.475	13.300(9.100, 15.150)	−1.064[c]	0.109

(*Continued*)

Table 3 (Continued).

	Training Set		X^2/t/Z	p-value
	With Postoperative Occurrence of Reflux (n=24)	Without Postoperative Occurrence of Reflux (n=21)		
Residual pressure (mmHg)	11.592±4.713	7.900(3.700, 11.950)	−2.332[c]	0.020
Percentage of synchronous contractions (≥6.25cm/s)	0.000(0.000, 10.000)	10.000(0.000, 35.000)	−2.492[c]	0.013
Percentage of bimodal waves	0.000(0.000, 20.000)	0.000(0.000, 14.500)	−0.386[c]	0.700
Distal contraction integral (mmHg*cm*s)	2550.175±1221.406	1869.100(954.600, 2380.600)	−1.866[c]	0.062
Velocity of the contraction front (cm/s)	3.300(2.725, 4.050)	3.900(2.800, 4.750)	−1.138[c]	0.255
Intra-esophageal doughnut pressure (mmHg)	4.100(1.825, 6.525)	0.700(−1.800, 5.100)	−1.809[c]	0.070
Distal contraction delay (second)	6.867±1.526	6.200(5.150, 7.600)	−0.831[c]	0.406
Percentage of ineffective swallows	0.000(0.000, 0.000)	0.000(0.000, 5.500)	−0.782[c]	0.434
Peak USE pressures (mmHg)	13.467±10.883	16.748±8.777	−1.103 [b]	0.276

Note: [a]x^2-value; [b] t-value; [c] Z-value;
Abbreviations: BMI, Body Mass Index; GERD, Gastroesophageal Reflux Disease; LES, Lower Esophageal Sphincter; USE, Upper Esophageal Sphincter.

Table 4 Univariate and Multivariate Logistical Regression Analysis of HREM and Clinical Results

	Univariate		Multivariate	
	OR(95% CI)	p-value	OR(95% CI)	p-value
Age(years)	1.042(0.970, 1.120)	0.259		
Gender				
Men	Ref			
Women	1.161(0.350, 3.844)	0.807		
Height(cm)	0.968(0.889, 1.054)	0.457		
Weight(kg)	0.986(0.960, 1.011)	0.270		
BMI(kg/m^2)	0.963(0.885, 1.048)	0.382		
Abdominal circumference (cm)	0.976(0.941, 1.013)	0.196		
A history of smoking				
Yes	Ref		Ref	
No	9.600(2.454, 37.575)	0.001	4.766(1.046, 21.716)	0.044
A history of alcohol consumption				
Yes	Ref			
No	1.375(0.418, 4.528)	0.600		
The lengths of LES(cm)	1.316(0.712, 2.432)	0.381		
LES resting pressure(mmHg)	0.923(0.851, 1.000)	0.051	0.906(0.817, 1.006)	0.065
Residual pressure (mmHg)	0.914(0.815, 1.025)	0.123		
Percentage of synchronous contractions (≥6.25cm/s)	1.061(1.009, 1.115)	0.022	1.058(0.998, 1.122)	0.058
Percentage of bimodal waves	0.983(0.935, 1.034)	0.516		
Distal contraction integral (mmHg*cm*s)	1.000(0.999, 1.000)	0.216		
Velocity of the contraction front (cm/s)	1.166(0.766, 1.774)	0.474		
Intra-esophageal doughnut pressure (mmHg)	0.975(0.916, 1.038)	0.432		
Distal contraction delay (second)	1.043(0.792, 1.374)	0.765		
Percentage of ineffective swallows	1.032(0.978, 1.089)	0.247		
Peak USE pressures (mmHg)	1.035(0.973, 1.101)	0.274		

Abbreviations: HREM, High-Resolution Esophageal Manometry; BMI, Body Mass Index; GERD, Gastroesophageal Reflux Disease; LES, Lower Esophageal Sphincter; USE, Upper Esophageal Sphincter.

Nomogram

Based on the results of multivariate logistic regression analysis, the independent predictive factors were constructed into a nomogram (Figure 1). Combining three independent predictive factors in the nomogram, the probability of developing GERD after LSG can be calculated for patients.

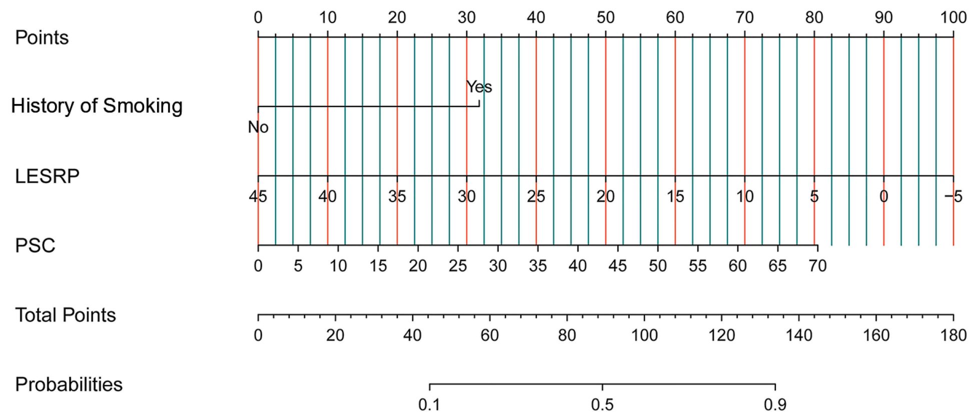

Figure 1 The Nomogram of this model.

Validation and Evaluation of the Model

The training set showed an area under the ROC curve (AUC) of the nomogram model of 0.847 (Figure 2A). The validation set showed an AUC of 0.761 (Figure 2B). The calibration curves showed that the nomogram-predicted risks of occurrence in the training and validation sets were in good agreement with the actual risk of occurrence (Figure 2C and D). The DCAs of the training and validation sets showed that the nomogram model predicted a good net clinical benefit for GERD at a threshold probability of 0.00–0.93 (Figure 3A and B). The CIC nomogram further confirmed that the net benefit of the model was higher compared to that of the extreme value curves in the farthest threshold ranges (Figure 3C and D).

The Web-Based Nomogram

We further visualized the nomogram and created web versions. The probability of GERD after LSG can be displayed by selecting the corresponding clinical features on the left side of the web interface (Figure 4A). Additionally, a specific numerical summary was produced to increase prediction accuracy (Figure 4B).

Discussion

LSG has become the most popular procedure of bariatric surgery, and its safety and efficacy have been confirmed in many studies.[33–37] GERD after LSG is a major complication that affects the quality of life of patients undergoing LSG.[38] Therefore, we focused on concomitant GERD after LSG and developed a prediction model based on a correlation analysis with the clinical data of patients, aimed at guiding surgeons to formulate individual treatment plans for patients.

Abdominal obesity, smoking, alcohol consumption, and regular intake of fried foods are high risk factors for the development of GERD.[39–42] In addition, the removal of two-thirds of the gastric body with LSG reduces the gastric content volume and compliance, thereby increasing the intragastric pressure and altering the gastroesophageal pressure gradient, leading to the development of GERD.[14] During LSG, when the fundus is cut, the angle of His, a component of the LES, may decrease the anti-reflux function of the LES, which increases the possibility of developing GERD.[42,43] GERD after LSG results from alterations in the anatomical structure of the stomach, such as destruction of the LES structure, changes in the gastroesophageal pressure gradient, and reduced gastric compliance, which further cause abnormalities of gastroesophageal dynamics and triggering of GERD. Considering the differences in the gastroesophageal dynamics of the patients' preoperative period, which may be intrinsically related to the occurrence of GERD after LSG, this study was conducted to elucidate the independent predictors of GERD after LSG among HREM parameters using a logistic regression analysis. A prediction model was established to assess the GERD risk after LSG using preoperative HREM-related index scores and finding independent predictors among HREM parameters using a logistic regression analysis.

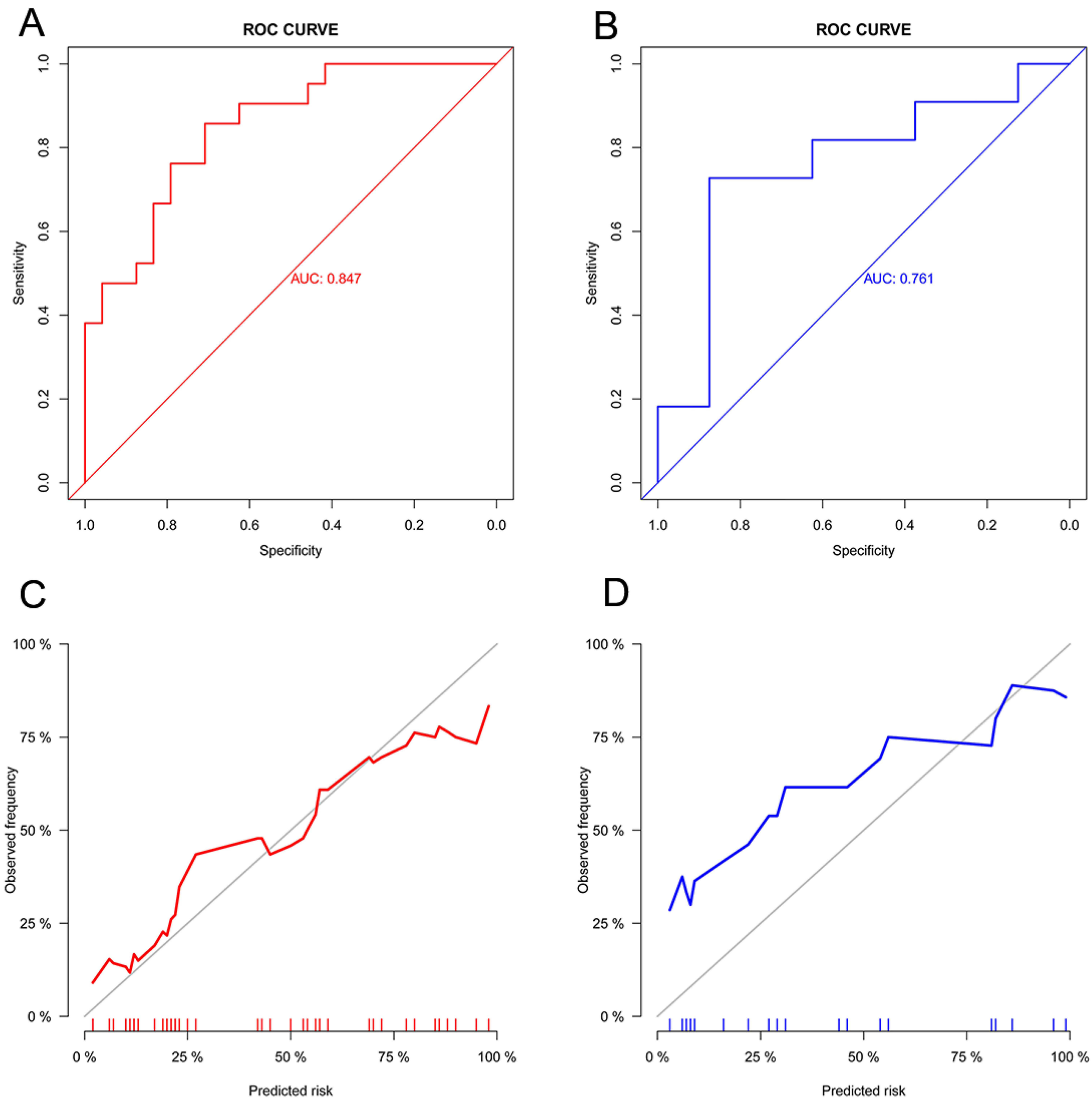

Figure 2 The ROC curves and calibration curve of the training and validation sets. (**A**) ROC curve for predicting GERD after LSG in the training set. (**B**) ROC curve for predicting GERD after LSG in the Validation set. (**C**) Calibration curve for predicting GERD after LSG in the training set. (**D**) Calibration curve for predicting GERD after LSG in the Validation set.

HREM-related indicators and clinicopathological characteristics were subjected to univariate and multivariate logistic regression analyses. The results showed that the history of smoking, LES resting pressure, and percentage of synchronous contractions were independent predictors.

A decrease in the LES resting pressure usually represents a structural and functional abnormality of the LES, which is the main anti-reflux barrier in the gastroesophageal structure.[44,45] Structural and functional abnormalities of the LES are major risk factors for the development of GERD.[46] During LSG, damage to the LES usually results from the impact on the angle of His, which usually manifests as a decrease in the LES resting pressure. In patients with a low preoperative LES resting pressure, the already low LES resting pressure further decreases after LSG, resulting in a more pronounced impact on the anti-reflux barrier, which makes them more susceptible to GERD.

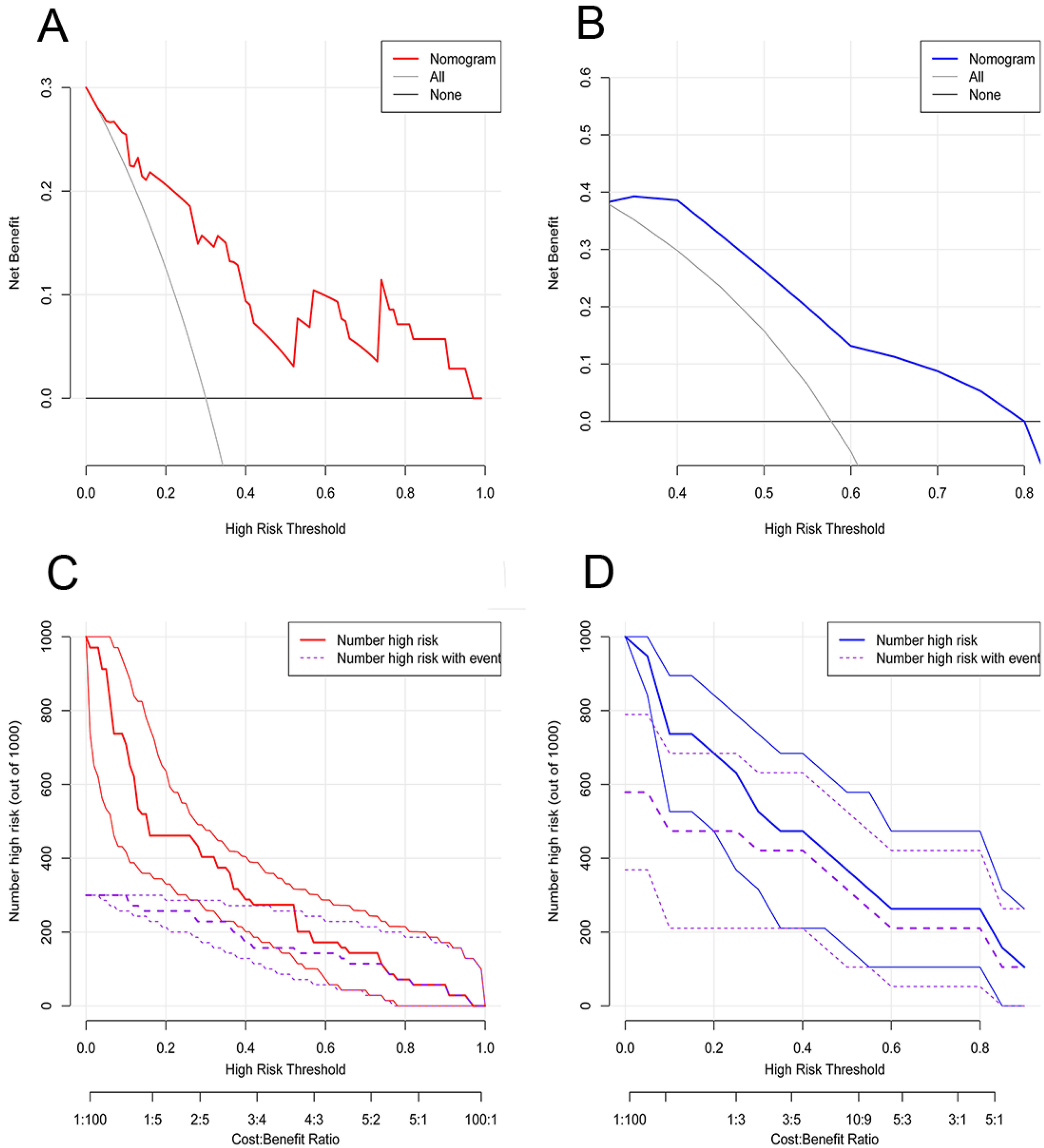

Figure 3 The DCAs and CICs of the training and validation sets. (**A**) the DCA of training set. (**B**) the DCA of validation set. (**C**) the CIC of training set. (**D**) the CIC of validation set.

An increase in the percentage of synchronous contractions of the esophagus indicates that the esophagus may have abnormal motility or even spastic synchronous contractions, which may decrease esophageal clearance with impaired esophageal emptying, and ultimately lead to the development of reflux.[47] Therefore, patients with a higher percentage of preoperative synchronous contractions may be more likely to develop GERD after LSG.

Compared to healthy people, patients who have smoked and consumed alcohol are more likely to develop GERD, which may be closely related to the stimulation of nicotine and alcohol in tobacco.[48,49] The univariate regression analysis showed that the correlation between alcohol consumption and the development of GERD postoperatively was insignificant, possibly because of

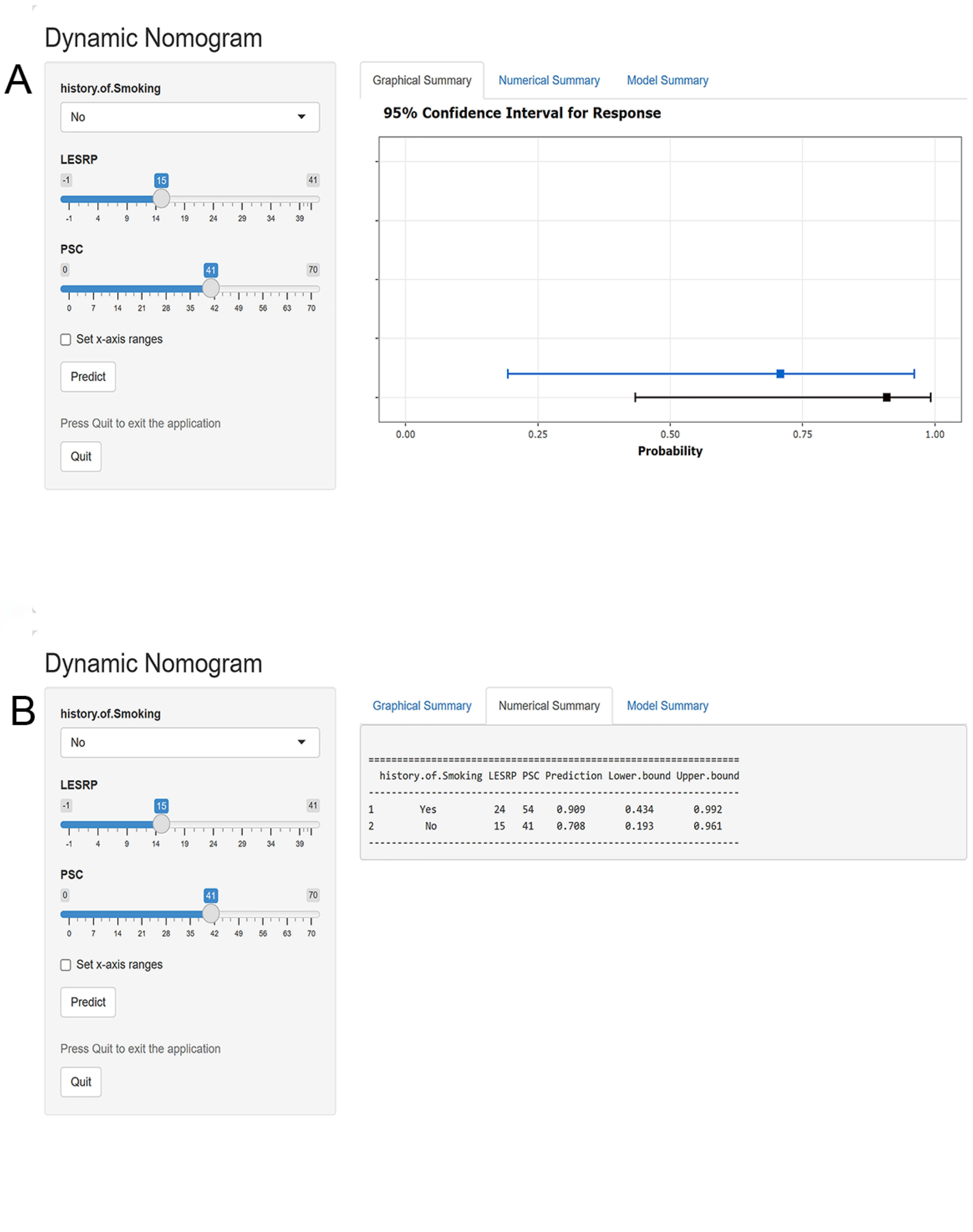

Figure 4 Operation interface of nomogram on web page. (**A**) After entering history of smoking, LESRP, and PSC on the web, a clinician can predict the possibility of GERD after LSG. (**B**) A numerical summary showing the actual values of probability and 95% CI.

the small sample size of this study. The history of alcohol consumption did not differ significantly between patients with and without GERD. These results should be validated using larger sample sizes. The univariate regression analysis showed that the correlation between the history of smoking and the development of GERD postoperatively was significant. Smoking can decrease the tone of the esophageal sphincter and esophageal clearance and prolong the esophageal clearance of acid, possibly because of smoking interfering with the gag and swallowing reflexes of the patient and tobacco interfering with the normal functioning of the esophageal mucosa, thereby decreasing the capacity to clear acid.[48,50–52] Therefore, patients who have smoked may be more likely to develop GERD after LSG compared to nonsmokers.

Thus, based on three independent predictors, we developed a prediction model to predict the occurrence of GERD after LSG, and the AUCs of the ROC curves in the training and validation sets reached 0.847 and 0.761 respectively. The calibration curves predicted the risk of occurrence with good agreement with the actual risk of occurrence, and the DCA and CIC results showed that the model had a good clinical value. Discrimination and calibration were high in both training and validation sets. Finally, the nomogram established by the three independent predictors (history of smoking, LES resting pressure, and percentage of synchronous contractions) showed high degrees of stability and reliability.

Currently, predictive models for the occurrence of GERD after LSG are few, and reliable predictive models for the long-term postoperative period are lacking. The patients included in this model had a mean follow-up of 6.6 years. Further, this was the first study to utilize HREM results in predicting the occurrence of GERD after LSG. When patients meet the criteria for bariatric surgery, we can utilize the nomogram to assess the risk of GERD after LSG. If the nomogram predicts a high risk of GERD, we will recommend that the patient consider other types of surgical procedure. Such a strategy can help the medical team to more accurately tailor personalized treatment plans for patients. In addition, HREM has low invasiveness and cost compared to conventional prediction models. It is performed before bariatric surgery and does not cause additional injury to the patient. The history of smoking can be obtained only at the time of history-taking. Thus, the predictive model is relatively simple, effective, and feasible. Finally, the CIC and DCA results indicated that the model had a high net clinical benefit rate and strong clinical applicability.

However, this study has some limitations. First, the postoperative follow-up period was too long, and the loss to follow-up rate was high. Second, the sample size of this study was small, potentially resulting in low reliability of the results. Despite the internal and external validations, further validation in large samples is required. Third, in this study, we used the GERD-Q as the diagnostic standard for GERD during postoperative follow-up, instead of gold standard examinations such as upper gastrointestinal endoscopy or 24-hour pH monitoring.[53,54] This may lead to overlooking asymptomatic GERD patients, thus affecting the reliability of the predictive model.[53,54] However, studies on long-term GERD after LSG are lacking. No prediction model that can predict the incidence of long-term GERD after LSG existed before this study. The novelty and simplicity of the present predictive model render it a clinically applicable model for preoperative prediction of the occurrence of GERD after LSG. In future studies, we aim to expand the sample size, and follow-up the patients closely to construct a more accurate prediction model with a higher clinical applicability for predicting the probability of developing GERD after LSG.

Conclusion

In conclusion, this study identified three independent predictors of GERD after LSG that have predictive value using a logistic regression analysis, established and visualized a prediction model that can effectively predict the incidence of GERD after LSG. The model showed high sensitivity and specificity.

Author Contributions

All authors made significant contributions to the reported work, including conception, study design, execution, data acquisition, analysis and interpretation, or in all these areas. They participated in drafting, revising, or critically reviewing the article, provided final approval for the version to be published, agreed on the journal to which the article was submitted, and are accountable for all aspects of the work.

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Disclosure

The author(s) report no conflicts of interest in this work.

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