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Development and validation of a clinical nomogram prediction model for surgical site infection following lumbar disc herniation surgery

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Surgical site infection (SSI) following lumbar disc herniation (LDH) surgery leads to prolonged hospital stays, increased costs and reoperations. Therefore, we aim to develop and validate a nomogram to predict the risk of SSI following LDH surgery, thereby helping spine surgeons design personalized prevention strategies and promote early recovery. Data from 647 patients with SSI who underwent LDH surgery at the First Affiliated Hospital of Air Force Medical University (AFMU) from 2020 to 2023 were collected. Ultimately, 241 patients with SSI were selected based on inclusion and exclusion criteria. Patients were randomly divided into training and validation sets with a ratio of 7:3. LASSO regression, univariate, and multivariate logistic regression were utilized to identify target variables and establish the prediction model, which was subsequently validated. Six factors—Age, Body Mass Index (BMI), Postoperative Suction Drainage (PSD), Gelatin Sponge (GS), None-Preoperative Antibiotic (NPTA), and Thrombin Time (TT)—were selected to construct the nomogram model. In the training set, the area under the curve (AUC) for the nomogram was 0.818 (95% CI 0.779–0.857). In the validation set, the AUC was 0.782 (95% CI 0.717–0.846). Calibration curves for both sets showed satisfactory agreement between predicted and actual SSI probabilities. Decision curve analysis indicated that the nomogram is clinically useful with a threshold range of 1–90%. The Clinical Impact Curve (CIC) demonstrated an acceptable cost-benefit ratio. The developed nomogram model effectively predicts the risk of SSI following LDH surgery, enabling spine surgeons to formulate more professional and rational clinical prevention strategies.

Keywords Lumbar disc herniation, Surgical site infection, Prediction model, Nomogram, Risk factor

Abbreviations

SSI	Surgical site infection
HBP	High blood pressure
DM	Diabetes mellitus
BMI	Body mass index
MS	Multistage surgery
OT	Operation time
IBL	Intraoperative blood loss
PSD	Postoperative suction drainagen
GS	Gelatin sponge
PTAG	Postoperative anticoagulation

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NPTA	None preoperative antibiotic
PTHB	Postoperative hemoglobin
PTSA	Postoperative serum albumin
LKF	Liver and kidney function
TT	Thrombin time

The number of surgeries for spinal diseases has been rising globally in recent years[1]. Lumbar disc herniation (LDH) is a prevalent issue in spinal surgery, with an incidence of 2–4%[2]. LDH frequently affects men aged 30 to 50, with an increasing trend in younger patients[3]. Non-surgical treatment is the first-line approach for LDH, while surgery is essential for patients unresponsive to conservative methods. Primary surgical procedures, including lumbar discectomy and lumbar fusion, can offer long-term symptom relief. However, these operations often carry risks. These procedures may result in various postoperative complications, such as infection, recurrence, and symptomatic epidural hematoma[4].

Surgical site infection (SSI) is a serious postoperative complication, defined as an infection occurring within 30 days after surgery if no implant is present, or within one year if an implant is involved and the infection is surgery-related[5]. SSI not only increases patient readmission and mortality rates but also significantly escalates healthcare costs, by two to four times, imposing a substantial burden on both patients and healthcare systems[6]. Despite advances in infection control measures, including enhanced operating room ventilation, barrier implementation, and antibacterial prophylaxis, the incidence of SSI remains high; for instance, the reported incidence after lumbar surgery is 0.81%[7]. Effective management of SSI following LDH surgery is crucial for optimal postoperative outcomes and patient satisfaction.

Numerous studies have sought to identify risk factors for SSI following spinal surgery to develop preventive strategies[8–10]. Common risk factors include age, diabetes, obesity, smoking, alcohol, long-term steroid use, implants, prolonged surgical time, excessive blood loss, number of fusion segments, revision status, and surgical method[8–12]. However, the results of these studies have been inconsistent, preventing reliable conclusions about these risk factors and perpetuating debate on the optimal SSI management strategies[13]. Nonetheless, the importance of prevention has been consistently underscored, highlighting the critical need to identify factors linked to an elevated SSI risk[14].

This study aimed to identify risk factors for SSI following LDH surgery, establish a predictive model, and provide evidence-based insights for SSI identification, assessment, and prevention. The overarching goals were to enhance patient satisfaction and treatment outcomes, reduce morbidity, and control healthcare costs.

Materials and methods

Ethics statement

The present study was approved by the Ethics Committee of the First Affiliated Hospital of the Air Force Medical University (AFMU) (Approval NO. KY20232117-C-1). Research involving human subjects complied with all relevant national regulations, institutional policies and was conducted in accordance with the tenets of the 1964 Helsinki Declaration. All participants provided written informed consent.

Patients and study design

Participants diagnosed with LDH and undergoing surgery at the First Affiliated Hospital of the AFMU between January 2020 and December 2023 were included in this population-based retrospective study. We included 241 patients with SSI following LDH surgery and screened two other patients without SSI who had undergone surgery performed by the same surgeon within a similar timeframe as a control group.

Patients meeting all the following criteria were included:

(1) Patients who had surgery of LDH and completed the entire procedure.
(2) Patients with complete medical records.
(3) Patients with SSI after the initial surgery.
(4) Patients who have signed informed consent.

Exclusion criteria encompassed:

(1) SSI causes unrelated to the initial surgery (pressure sores, secondary trauma, etc.).
(2) Patients with infectious spinal diseases (spinal tuberculosis, suppurative, spondylitis and brucellosis, etc.).
(3) Patients with lumbar surgery due to other diseases (trauma, tumour, fracture, cyst, etc.).
(4) Patients with other serious diseases (malignant tumors, heart failure, chronic kidney disease, neurological diseases, COPD, coagulation dysfunction, etc.).
(5) Patients with incomplete data (missing > 20%).

Data collection

Data were obtained from the hospital's electronic medical record system (EMRS). Patient information was identified using ID numbers. By combining literature review and clinical experience, we identified 21 potential risk factors for SSI. These factors include: (1) demographic indicators: gender, age, smoking status, drinking status, high blood pressure (HBP), diabetes mellitus (DM), and body mass index (BMI); (2) perioperative indicators: multi-stage surgery (MS), implant, operation time (OT), intraoperative blood loss (IBL), postoperative suction drainage (PSD), gelatin sponge (GS), postoperative anticoagulation (PTAG), and None-preoperative antibiotic (NPTA); (3) laboratory indicators: postoperative hemoglobin (PTHB), postoperative serum albumin (PTSA), liver and kidney function (LKF), K+, Ca+, and thrombin time (TT). Since the datasets used in this study

contained missing values, removing all incomplete data might reduce the amount and quality of data analyzed, thereby compromising the predictive results. Therefore, we excluded data with more than 20% missing values.

Conduct test

Research subjects were randomly divided into training and validation sets at a ratio of 7:3 using the R package. The training set comprised 506 participants, with 165 patients diagnosed with SSI and 341 without. The validation set, meanwhile, consisted of 217 patients, of which 76 had SSI and 141 did not. The data from the training set were utilized to discern the characteristics and patterns inherent in the sample, enabling the development of a predictive model. Conversely, the validation set served to assess the model's performance, specifically through validation and tuning processes, whilst also evaluating its generalization capability to novel samples. A comparative analysis of indices was conducted between the SSI and non-SSI groups within both the training and validation sets. The study flow chart is shown in Fig. 1.

Statistical analysis

Statistical analysis was primarily conducted using R software (version 4.2.1) and SPSS software (IBM, version 26.0). GraphPad Prism V9.2.0.332 was used to analyze correlation between variables. Categorical variables were shown as number and percentages, which were compared using the Chi-square (χ^2) test or Fishers' exact test. The least absolute shrinkage and selection operator (LASSO), along with univariate and multivariate logistic regression analyses, were conducted to investigate risk factors for SSI following LDH surgery. The rms package was used to construct the nomogram. The clinical prediction model underwent internal validation in validation set using the Bootstrap resampling method with B = 1000 repetitions. The ROC curve, calibration curve, Decision Curve Analysis (DCA), clinical impact curve (CIC) and reasonable analysis were used to evaluate the discrimination and predictive capability of the nomogram model. The model's performance was graded as follows: (1) $0.5 < AUC \leq 0.7$, indicating low predictive value; (2) $0.7 < AUC \leq 0.9$, indicating moderate predictive value; and (3) $0.9 < AUC < 1$, indicating high predictive value. In this study, statistical significance was defined as $p < 0.05$.

Results

Patient characteristics

Table 1 shows variations in demographic, perioperative, and laboratory indicators between SSI and Non-SSI patients in both the training and validation sets. In the training set, there were no significant differences between SSI and Non-SSI patients in terms of gender, smoking and drinking status, HBP, and other demographic indicators. For perioperative indexes, SSI patients exhibited significantly higher ratios of OT, PSD, and GS compared to Non-SSI patients perioperative indexes such as MS, Implant, IBL, and PTAG showed no significant differences. Additionally, laboratory indicators indicated no significant differences in THB, LKF, and Ca+. The heat map shows no significant strong correlations between the variables (Fig. 2) .

Univariate logistic regression of surgical site infection following lumbar disc herniation surgery

Univariate logistic regression analysis was conducted on 21 independent variables to assess the impact of each variable on the occurrence of SSI. The results indicated that the following variables were statistically significant: Age, DM, BMI, OT, IBL, PSD, GS, NPTA, K+, PTSA, TT, as shown in Table 2. A p-value of less than 0.1 was considered statistically significant.

LASSO regression

LASSO regression was employed to reduce the number of independent variables, and ten-fold cross-validation was conducted to select variables with the highest correlation based on lambda.1-SE. From the 21 variables, we identified seven with nonzero coefficients (Fig. 3A,B).

Subsequently, seven significant variables were identified, combining meaningful indicators from univariate logistic regression and those screened by LASSO regression, including age, BMI, PSD, GS, NPTA, K+, and TT.

Multivariate logistic regression analysis

The seven identified variables were subsequently included in a multivariate logistic regression analysis. The results indicated that the following variables were statistically significant: age (OR 1.80, 95% CI 1.13–2.88, $p = 0.014$), PSD (OR 5.27, 95% CI 3.11–9.31, $p < 0.001$), GS (OR 2.62, 95% CI 1.33–5.53, $p = 0.007$), NPTA (OR 1.86, 95% CI 1.14–3.06, $p = 0.013$), TT (OR 3.64, 95% CI 2.34–5.69, $p < 0.001$), BMI (OR 1.82, 95% CI 1.16–2.87, $p = 0.009$) (Fig. 3C).

Creation of a nomogram for predicting the risk of SSI following LDH surgery

Based on the multivariate logistic regression results, we developed a nomogram model utilizing six indicators to predict the probability of postoperative SSI in LDH patients. In personalized medicine, nomogram points can be determined based on specific values for age, BMI, PSD, GS, NPTA and TT. (Fig. 3D).

Validation of the nomogram

ROC curves were generated to evaluate the model's predictive efficacy in both the training and validation sets (Fig. 4A,B). Figure 4A shows the strong predictive ability of the nomogram model in the training sets, with an AUC of 0.818 (95% CI 0.779–0.857, cutoff value 0.376, sensitivity 0.721, specificity 0.804). The validation set also exhibited high predictive performance, with an AUC of 0.782 (95% CI 0.717–0.846, cutoff 0.412, sensitivity

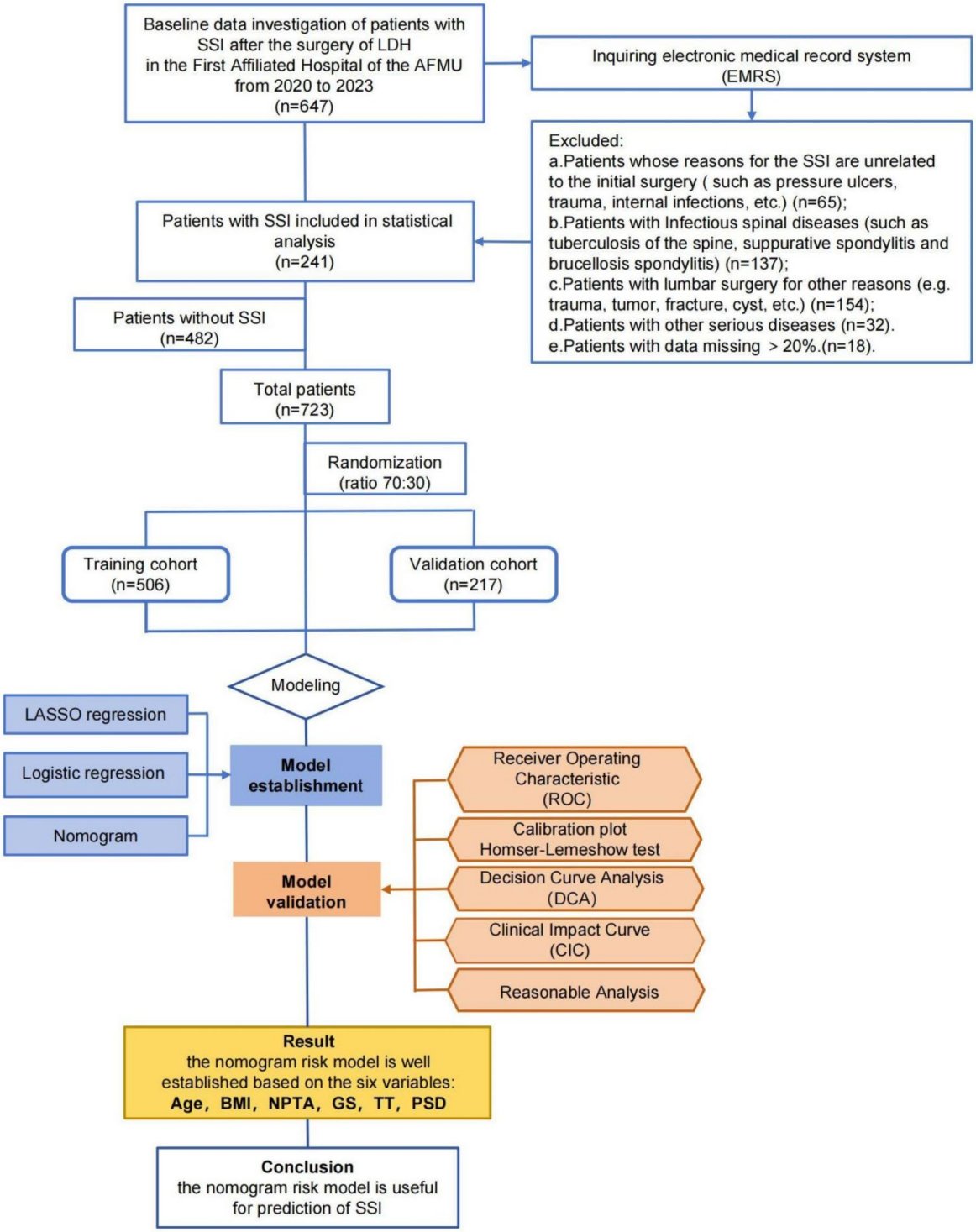

Fig. 1. The workflow of the study. *LDH* Lumbar disc herniation, *AFMU* Air Force Medical University, *SSI* surgical site infection, *LASSO* least absolute shrinkage and selection operator, *BMI* body mass index, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *NPTA* none-preoperative antibiotic, *TT* thrombin time.

0.605, specificity 0.823) (Fig. 4B). These findings indicate that the clinical prediction model developed in this study demonstrated moderate predictive value (AUC > 0.7).

Figure 4C.D presents the calibration curves for the training and validation sets respectively, created using the Bootstrap recalibration method (repeated 1000 times). The apparent and deviation-corrected lines indicate that in the training set, the Brier score is 0.156, the slope is 1.000, and $P = 0.839$ (Fig. 4C). In the validation sets, the

Variables	Training set			Validation set		
	SSI (*N* = 165)	Non-SSI (*N* = 341)	P-value	SSI (*N* = 76)	Non-SSI (*N* = 141)	P-value
Demographic Indicators						
Gender			0.20			1.00
Female	79 (47.88%)	141 (41.35%)		34 (44.74%)	64 (45.39%)	
Male	86 (52.12%)	200 (58.65%)		42 (55.26%)	77 (54.61%)	
Age			**0.001**			0.21
<60 years	98 (59.39%)	253 (74.19%)		52 (68.42%)	109 (77.30%)	
≥ 60 years	67 (40.61%)	88 (25.81%)		24 (31.58%)	32 (22.70%)	
Smoke status			0.72			**0.03**
Never	107 (64.85%)	214 (62.76%)		41 (53.95%)	99 (70.21%)	
Ever/current	58 (35.15%)	127 (37.24%)		35 (46.05%)	42 (29.79%)	
Drink status			0.35			0.72
Never	134 (81.21%)	263 (77.13%)		58 (76.32%)	103 (73.05%)	
Ever/current	31 (18.79%)	78 (22.87%)		18 (23.68%)	38 (26.95%)	
HBP			0.63			**0.03**
No	109 (66.06%)	234 (68.62%)		47 (61.84%)	108 (76.60%)	
Yes	56 (33.94%)	107 (31.38%)		29 (38.16%)	33 (23.40%)	
DM			**0.001**			**0.001**
No	97 (58.79%)	251 (73.61%)		40 (52.63%)	106 (75.18%)	
Yes	68 (41.21%)	90 (26.39%)		36 (47.37%)	35 (24.82%)	
BMI			**<0.001**			**0.004**
<28 kg/m^2	51 (30.91%)	185 (54.25%)		25 (32.89%)	77 (54.61%)	
≥ 28 kg/m^2	114 (69.09%)	156 (45.75%)		51 (67.11%)	64 (45.39%)	
Perioperative indicators						
MS:			0.96			0.10
No	115 (69.70%)	240 (70.38%)		47 (61.84%)	104 (73.76%)	
Yes	50 (30.30%)	101 (29.62%)		29 (38.16%)	37 (26.24%)	
Implant			0.15			0.10
No	18 (10.91%)	55 (16.13%)		9 (11.84%)	31 (21.99%)	
Yes	147 (89.09%)	286 (83.87%)		67 (88.16%)	110 (78.01%)	
OT:			**0.03**			0.56
< 3 h	78 (47.27%)	197 (57.77%)		47 (61.84%)	80 (56.74%)	
≥ 3 h	87 (52.73%)	144 (42.23%)		29 (38.16%)	61 (43.26%)	
IBL			0.09			1.00
< 200 ml	144 (87.27%)	315 (92.38%)		68 (89.47%)	127 (90.07%)	
≥ 200 ml	21 (12.73%)	26 (7.62%)		8 (10.53%)	14 (9.93%)	
PSD			**<0.001**			**<0.001**
< 300 ml	21 (12.73%)	165 (48.39%)		12 (15.79%)	70 (49.65%)	
≥ 300 ml	144 (87.27%)	176 (51.61%)		64 (84.21%)	71 (50.35%)	
GS			**<0.001**			**0.005**
No	12 (7.27%)	84 (24.63%)		4 (5.26%)	29 (20.57%)	
Yes	153 (92.73%)	257 (75.37%)		72 (94.74%)	112 (79.43%)	
PTAG			0.60			0.37
No	43 (26.06%)	98 (28.74%)		18 (23.68%)	43 (30.50%)	
Yes	122 (73.94%)	243 (71.26%)		58 (76.32%)	98 (69.50%)	
NPTA			**0.009**			**0.02**
No	110 (66.67%)	266 (78.01%)		45 (59.21%)	106 (75.18%)	
Yes	55 (33.33%)	75 (21.99%)		31 (40.79%)	35 (24.82%)	
Laboratory indicators						
PTHB			0.32			0.09
Normal	57 (34.55%)	135 (39.59%)		32 (42.11%)	42 (29.79%)	
Continued						

Variables	Training set			Validation set		
	SSI (*N* = 165)	Non-SSI (*N* = 341)	P-value	SSI (*N* = 76)	Non-SSI (*N* = 141)	P-value
Abnormal	108 (65.45%)	206 (60.41%)		44 (57.89%)	99 (70.21%)	
PTSA			**0.004**			**0.002**
Normal	91 (55.15%)	234 (68.62%)		36 (47.37%)	98 (69.50%)	
Abnormal	74 (44.85%)	107 (31.38%)		40 (52.63%)	43 (30.50%)	
LKF			0.71			0.09
Normal	67 (40.61%)	146 (42.82%)		40 (52.63%)	56 (39.72%)	
Abnormal	98 (59.39%)	195 (57.18%)		36 (47.37%)	85 (60.28%)	
K+			**0.001**			0.65
Normal	43 (26.06%)	141 (41.35%)		27 (35.53%)	56 (39.72%)	
Abnormal	122 (73.94%)	200 (58.65%)		49 (64.47%)	85 (60.28%)	
Ca+			0.18			0.37
Normal	96 (58.18%)	221 (64.81%)		43 (56.58%)	90 (63.83%)	
Abnormal	69 (41.82%)	120 (35.19%)		33 (43.42%)	51 (36.17%)	
TT			**<0.001**			**<0.001**
Normal	56 (33.94%)	251 (73.61%)		39 (51.32%)	108 (76.60%)	
Abnormal	109 (66.06%)	90 (26.39%)		37 (48.68%)	33 (23.40%)	

Table 1. Comparisons of demographic, perioperative and laboratory indicators between SSI and Non-SSI patients in the training and validation set. *SSI* surgical site infection, *HBP* high blood pressure, *DM* diabetes mellitus, *BMI* body mass index, *MS* multi-stage surgery, *OT* operation time, *IBL* intraoperative blood loss, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *PTAG* postoperative anticoagulation, *NPTA* none-preoperative antibiotic, *PTHB* postoperative hemoglobin, *PTSA* postoperative serum albumin, *LKF* liver and kidney function, *TT* thrombin time. Categorical variables were presented as number and percentage (n, %). The bold text means that the P value was < 0.05.

Brier score was 0.174, the slope was 0.956, and $P = 0.280$ (Fig. 4D). These results demonstrate strong concordance between the predicted and actual probabilities. The P-value of the Homser-Lemeshow test is 0.318 (validation set is 0.583), indicating that the clinical prediction model for SSI is well-calibrated. DCA was performed to assess the clinical utility of the model. The results show that in the training set, when the threshold of the model is set between 1% and 90%, the decision curve is above the NONE and ALL lines, indicating clinical practicability within this range (Fig. 4E). Similarly, the validation set demonstrated reasonable clinical practicability with the model threshold set between 1% and 90% (Fig. 4F).

Additionally, the clinical impact curve (CIC) demonstrated that within the most favorable threshold probability range, the number of expected high-risk patients consistently exceeded the number of actual patients, accompanied by an acceptable cost-benefit ratio (Fig. 4G,H).

Reasonable analysis

ROC curves of reasonable analysis of the training and validation sets showed that the nomogram model had superior predictive ability compared to individual variables (Fig. 5A,B). Furthermore, Decision Curve Analysis (DCA) showed that the nomogram had greater clinical practicality than any single variables (Fig. 5C,D). Analysis of nomogram scores revealed statistically significant differences between SSI and Non-SSI groups in both the training and validation sets (Fig. 5E,F).

Discussion

Postoperative SSI following spinal surgery presents significant challenges, often requiring repeated irrigation and debridement procedures, while prolonged antibiotic use elevates the risk of resistance. Severe cases might necessitate the removal of internal fixation devices, potentially resulting in postoperative nonunion, which has serious implications for both patients and surgeons[15]. Furthermore, SSI imposes a substantial medical burden, encompassing prolonged care, additional surgeries, unplanned readmissions, and delayed return to work. Our study found an overall SSI incidence of 4.46% following LDH surgery, consistent with previous research[6]. Identifying associated factors is crucial for SSI prevention. Previous studies have reported numerous potential risk factors without reaching a consensus[16,17].

Integrating a nomogram into clinical practice enhances the conversation with patients. This visual tool, derived from a multivariate logistic regression model, assigns scores to each risk factor based on its impact on outcomes, enabling bedside calculations during routine clinical care. Previous researchers have successfully utilized this tool across diverse medical fields. Our study focused on LDH patients, thereby making our model more specific to this population[18,19].

- Our study demonstrates that logistic regression modeling effectively evaluates factors influencing SSI risk in LDH patients by using demographic, perioperative, and laboratory indicators. After rigorous statistical

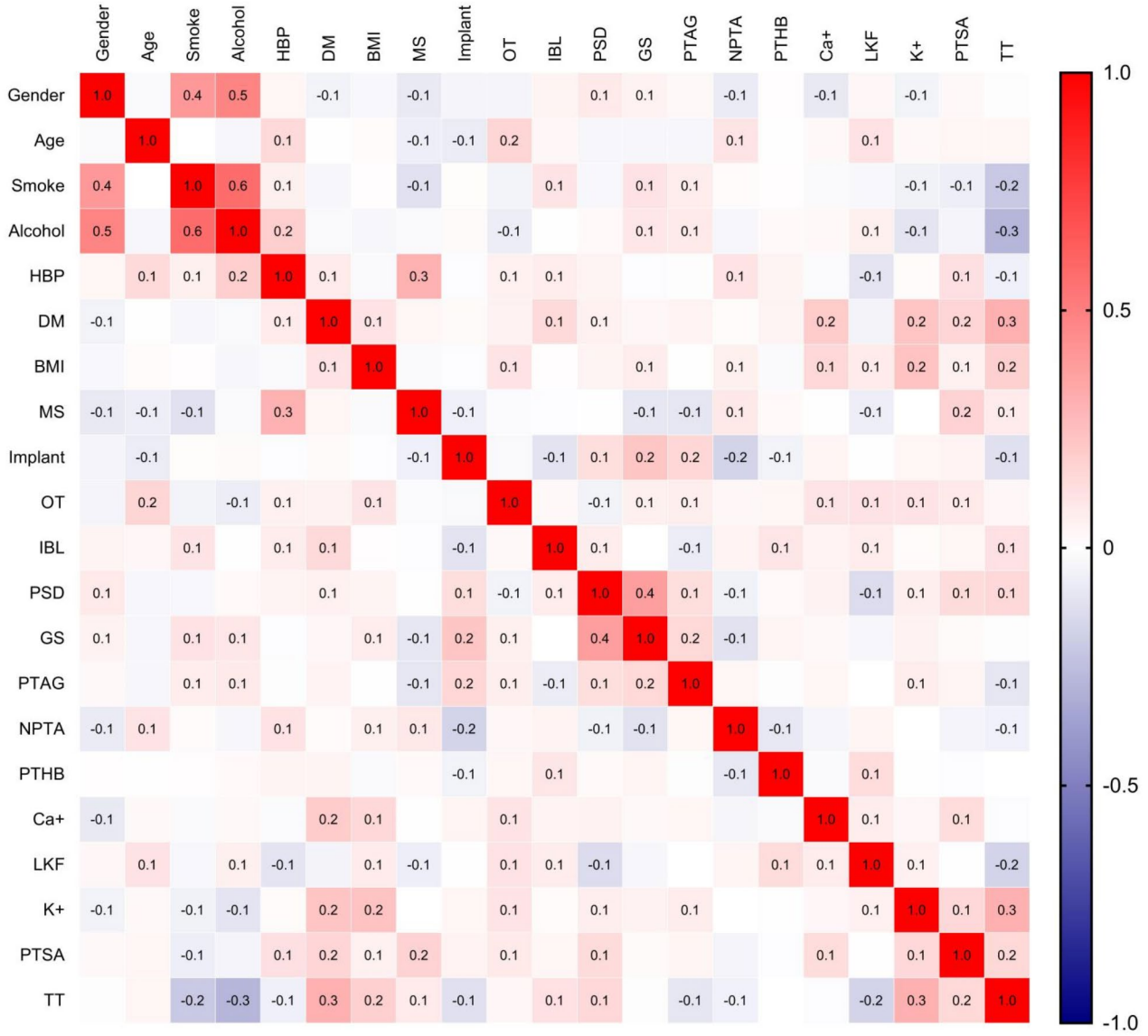

Fig. 2. Heat map of the correlations between all the variables. The illustration reveals that there are no strong correlations among the variables (correlation coefficient < 0.7). *HBP* high blood pressure, *DM* diabetes mellitus, *BMI* body mass index, *MS* multi-stage surgery, *OT* operation time, *IBL* intraoperative blood loss, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *PTAG* postoperative anticoagulation, *NPTA* none-preoperative antibiotic, *PTHB* postoperative hemoglobin, *PTSA* postoperative serum albumin, *LKF* liver and kidney function, *TT* thrombin time.

analysis, including univariate, multivariate logistic regression, and LASSO regression, age, BMI, PSD, GS, NPTA and TT emerged as significant predictors of SSI. Utilizing these variables, we constructed a nomogram to predict SSI risk, which exhibited robust predictive performance, with AUCs of 0.818 (95% CI 0.779–0.857) and 0.782 (95% CI 0.718–0.846) in the training and validation sets, respectively. Furthermore, our model effectively discriminated between regular and SSI patients, as evidenced by significant score differences in both sets.

- Elderly individuals are often predisposed to postoperative spinal infections due to diminished physiological resilience, increased comorbidities, and impaired tissue healing capacity[20,21]. Studies by Fei et al. and Dubory et al. have highlighted ages > 60 and > 65 years, respectively, as significant risk factors for postoperative SSI in spinal surgery[22,23]. Given that China categorizes individuals aged over 60 as elderly, our study compared this age group with non-elderly individuals, offering valuable insights for SSI management. Our findings revealed a 1.8-fold increased SSI risk in individuals aged ≥ 60 years, underscoring the need for enhanced perioperative care and infection prevention strategies for elderly patients.

Variable	B	SE	OR	95% CI	*P*
Gender	− 0.265	0.19073	0.767	0.767 (0.528–1.116)	0.17
Age	0.676	0.20111	1.966	1.966 (1.325–2.916)	**0.001**
Smoke status	− 0.091	0.19782	0.913	0.913 (0.618–1.343)	0.65
Drink status	− 0.248	0.23737	0.78	0.78 (0.485–1.232)	0.30
HBP	0.116	0.20162	1.124	1.124 (0.754–1.665)	0.56
DM	0.67	0.20028	1.955	1.955 (1.32–2.896)	**0.001**
BMI	0.975	0.20049	2.651	2.651 (1.798–3.949)	< **0.001**
MS	0.033	0.20679	1.033	1.033 (0.686–1.545)	0.88
Implant	0.451	0.28989	1.571	1.571 (0.906–2.839)	0.12
OT	0.423	0.19062	1.526	1.526 (1.051–2.22)	**0.03**
IBL	0.569	0.31016	1.767	1.767 (0.954–3.24)	**0.07**
PSD	1.861	0.2575	6.429	6.429 (3.957–10.90)	< **0.001**
GS	1.427	0.32506	4.167	4.167 (2.285–8.259)	< **0.001**
PTAG	0.135	0.21394	1.144	1.144 (0.756–1.751)	0.53
NPTA	0.573	0.21063	1.773	1.773 (1.171–2.678)	**0.007**
PTHB	0.216	0.19765	1.242	1.242 (0.845–1.836)	0.27
Ca+	0.28	0.19434	1.324	1.324 (0.903–1.936)	0.15
LKF	0.091	0.19263	1.095	1.095 (0.752–1.601)	0.64
K+	0.693	0.20867	2	2 (1.337–3.033)	**0.001**
PTSA	0.576	0.19525	1.778	1.778 (1.213–2.609)	**0.003**
TT	1.692	0.20525	5.428	5.428 (3.648–8.163)	< **0.001**

Table 2. Univariate logistic analysis based on training groups. *HBP* high blood pressure, *DM* diabetes mellitus, *BMI* body mass index, *MS* multi-stage surgery, *OT* operation time, *IBL* intraoperative blood loss, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *PTAG* postoperative anticoagulation, *NPTA* none-preoperative antibiotic, *PTHB* postoperative hemoglobin, *PTSA* postoperative serum albumin, *LKF* liver and kidney function, *TT* thrombin time. The bold text means that the P value was<0.05.

Global obesity rates are rising, with numerous studies linking obesity (or elevated BMI) to increased SSI risk post-spinal surgery[9,10]. Higher BMI has consistently correlated with increased SSI incidence in postoperative patients, as demonstrated by studies conducted by Ming, Piper, and others[24–27]. Obese individuals often present with comorbidities such as diabetes, metabolic disorders, and immune dysfunction, making them more susceptible to infections[12]. Consistent with prior research, our study defined obesity as a BMI ≥ 28 kg/m^2, reaffirming the heightened SSI risk in obese individuals compared to non-obese counterparts.

Negative pressure wound therapy (NPWT) and closed suction irrigation systems (CSIS) have become widely accepted in spinal surgery for postoperative wound management. NPWT facilitates continuous antibiotic irrigation and pollutant absorption, providing anti-inflammatory effects. It also reduces hematoma and edema through negative pressure, enhances local blood circulation, and promotes neovascularization and granulation tissue formation for accelerated wound healing[28–31]. Although closed drainage systems have been implicated in retrograde infections, studies by Liu et al. found no significant difference in wound infection rates compared to open drainage[32,33]. Notably, postoperative drainage volume, indicative of tissue edema and wound healing, emerged as a significant risk factor for postoperative SSI, emphasizing the importance of managing drainage flow rather than just using negative pressure devices. Therefore, we believe that rather than focusing solely on the use of negative pressure drainage devices, it is more important to explore the impact of drainage volume on SSI. Our results showed that a total postoperative drainage volume > 300 ml was a significant risk factor for postoperative SSI after LDH (OR: 5.27, 95% CI 3.11–9.31). Therefore, perioperative strategies such as minimizing tissue exposure, optimizing surgical timing, and ensuring prompt hemostasis are crucial for controlling postoperative drainage.

Gelatin sponge, known for its biocompatibility, biodegradability, and cost-effectiveness, is widely used in biomedical and tissue engineering. Its porous structure facilitates cell migration and provides structural support for tissue regeneration[34–36]. Despite its liquid absorption and hemostatic properties, the gelatin sponge lacks intrinsic antibacterial effects[37]. However, its use in postoperative hemostasis may inadvertently disrupt local blood flow, impede wound healing and foster a microbial-friendly environment, thus increasing the risk of SSI. Our study found a 2.62-fold higher SSI risk associated with gelatin sponge usage, emphasizing the need for alternative hemostatic techniques such as electrotome and ligation to mitigate infection risk.

Guidelines for antibiotic use in spinal surgery remain debated among practitioners. While Trampu et al. advocate for antibiotic prophylaxis in both clean and contaminated incisions, concerns over antibiotic resistance have prompted some to question its preoperative use without comprehensive research on resistance patterns[38]. Despite evidence supporting preoperative antibiotic prophylaxis to reduce postoperative infection rates, there is no consensus on its optimal duration. Lai et al. observed a correlation between the omission of preoperative antibiotics and postoperative SSI in lumbar spine surgeries[39]. While prophylactic antibiotics reduce

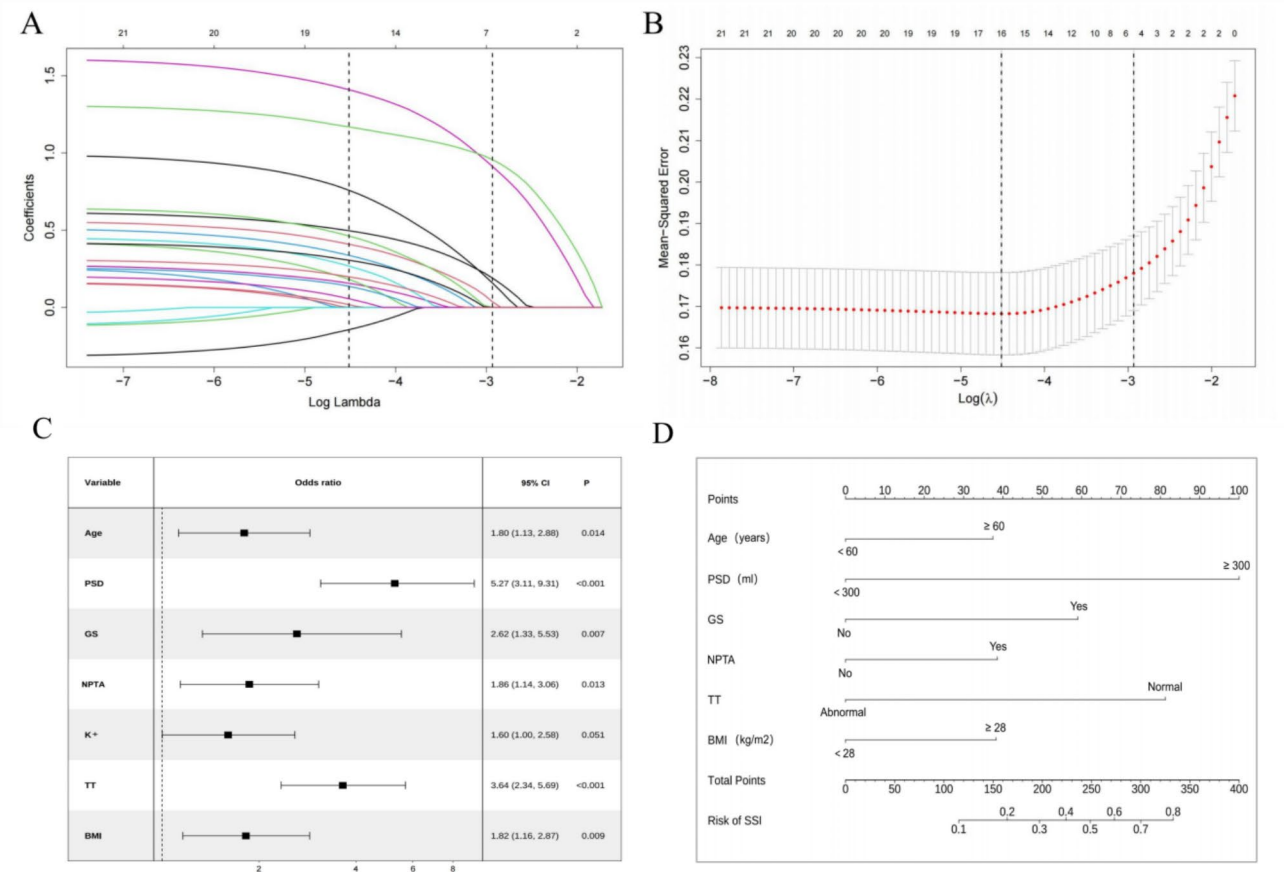

Fig. 3. Establishment of nomogram prediction model. (**A**) LASSO coefficient profiles of the factors were analyzed. The outcomes of cross-validation for the LASSO regression models are presented. A vertical line is drawn at the point of optimum with the minimum criterion, as well as at 1 standard error (1-SE) of the minimum criterion. At 1-SE, seven variables were selected for logistic regression analysis. (**B**) Employ cross-validation to determine the optimal penalty parameter lambda. The coefficient profile plot of predictors illustrates the seven factors that displayed significant differences between patients with SSI and those without SSI. (**C**) The forest plot of multivariate logistic regression. The results showed that the selection of six independent variables as significant risk factors for SSI following LDH surgery. (**D**) The six factors are used to construct a nomogram for predicting SSI. Each independent predictor is assigned a score on the upper scale, while the total score of the six factors for each case is represented on the lower scale. The total score at the bottom of the chart corresponds to the likelihood of postoperative SSI diagnosis, providing an assessment of the risk for patients with LDH. *SSI* surgical site infection, *LASSO* least absolute shrinkage and selection operator, *BMI* body mass index, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *NPTA* none-preoperative antibiotic, *TT* thrombin time.

postoperative infection rates by 3.4–6%, no study unequivocally favors prolonged postoperative antibiotic use over preoperative administration for SSI prevention[38,40]. Therefore, our study specifically investigated the impact of preoperative antibiotic use on SSI development, revealing a 1.86-fold increase SSI risk in patients without preoperative antibiotic coverage. Given the unique anatomical challenges of spinal surgery, short-term preoperative antibiotic prophylaxis is recommended.

TT is a crucial indicator of both intrinsic and extrinsic coagulation pathways, sensitively reflecting patients' coagulation status[41]. Management of antiplatelet and anticoagulant medications preoperatively and postoperatively adhered to guidelines, with no preoperative history of such drugs among patients[42]. Given TT's ability to reflect intrinsic coagulation dynamics, it is a superior risk indicator compared to other clotting parameters for assessing postoperative SSI risk. Therefore, we use TT as a risk indicator rather than other clotting parameters. Abnormal TT values conferred a 3.64-fold increased SSI risk, underscoring the importance of preoperative coagulation assessments to minimize bleeding-related complications.

Previous studies have suggested that internal implants may incite soft tissue inflammation, hematoma formation, and microbial proliferation[43]. Additionally, metal debris from implant fretting can foster granuloma formation, providing a conducive environment for bacterial colonization[44]. Contrary to expectations, our study did not identify internal implants as a significant risk factor for SSI. Notably, while DM is commonly implicated as a key SSI risk factor due to impaired immune responses and delayed wound healing, our findings did not confirm its independent association with SSI[22,45]. Hyperglycemia impairs neutrophil activity and chemotactic

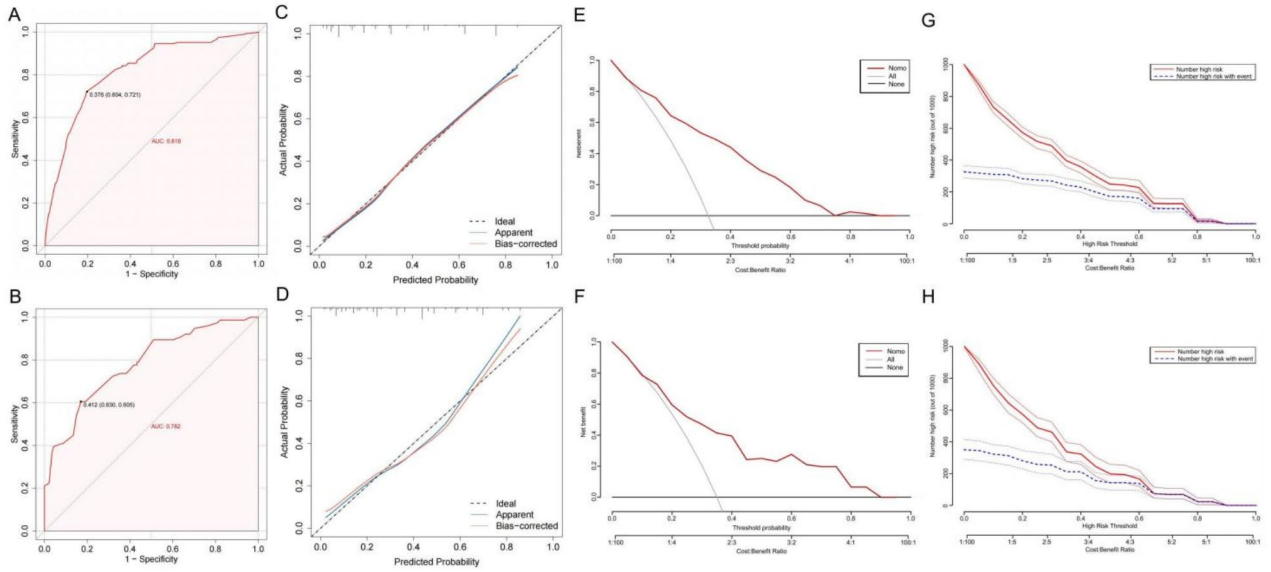

Fig. 4. Validation of nomogram prediction model. (**A**) Receiver operating characteristic (ROC) curves for distinguishing surgical site infection (SSI) from Non-SSI in the training set. (**B**) ROC curves for distinguishing SSI from Non-SSI in the validation set. The horizontal axis represents 1-specificity, and the vertical axis represents sensitivity, both with maximum values of 1. The dotted line is the reference line (AUC = 0.5), and the red curve is the ROC curve. The further the ROC curve is from the reference line, the greater the AUC value, indicating better model predictive performance. The results showed that the model had good predictive performance in both the training and validation sets (AUC > 0.75). (**C**) Calibration curve of the nomogram in the training set. (**D**) Calibration curve of the nomogram in the validation set. Calibration curves depict the calibration of each model in terms of agreement between predicted SSI risks and observed SSI outcomes. The Y-axis represents the actual incidence of SSI. The X-axis represents the predicted SSI risk. The diagonal dotted line represents a perfect prediction by an ideal model. The solid pink line represents the performance of the nomogram; a closer fit to the diagonal dotted line indicates better predictive accuracy. The Hosmer-Lemeshow goodness-of-fit test shows favorable results in both the training set and validation set. (**E**) Decision curve analysis (DCA) for the nomogram model in the training set. (**F**) DCA for the nomogram model in the validation set. The results indicated that both the training set and the validation set exhibit substantial net benefit across a specified range of SSI threshold probabilities (0–0.8). (**G**) Clinical impact curve (CIC) of the nomogram based on data from the training set. (**H**) CIC of the nomogram based on data from the validation set. The horizontal axis represents the probability threshold, while the vertical axis indicates the number of individuals. The solid red lines represent the number of individuals deemed by the model to be at high risk for SSI at different probability thresholds. The dashed blue line represents the number of individuals predicted by the model to be at high risk for SSI who actually experienced the outcome at different probability thresholds. The bottom axis indicates the benefit ratio, representing the ratio of loss to gain at different probability thresholds.

function, leading to prolonged wound healing and increased susceptibility to infection[46]. Although a statistical difference in DM prevalence existed between SSI and Non-SSI patients, the sample size of this study may have influenced the outcome. Future research should explore the impact of postoperative hyperglycemia on SSI beyond the status of DM.

This study reveals that age, BMI, PSD, GS, NPTA, and TT constitute risk factors for postoperative infection in patients with LDH. Examination of the nomogram underscores PSD as the primary influencing factor, with TT and GS emerging as two additional significant contributors. This underscores the clinical importance of preoperative TT assessment; for patients with severe abnormalities, surgical intervention should be deferred or carefully considered. During surgery, minimizing the use of gelatin sponges is advisable, with electrocautery and ligation serving as viable alternatives to mitigate the risk of postoperative infection. Although negative pressure drainage is a common postsurgical practice, our findings indicate that a drainage volume exceeding 300 ml represents a crucial factor in the development of infection. Consequently, meticulous monitoring of patients' drainage volumes within the initial three postoperative days is imperative. For patients whose drainage volume surpasses 300 ml, prompt symptomatic treatment is essential. This includes cleaning the drainage site and timely removal of the drainage tube when the daily drainage volume drops below 50 ml. Furthermore, utilizing B-ultrasound to detect wound fluid accumulation is a pivotal preventive measure against infection.

The study has several limitations. Firstly, the study was conducted at a single center, and despite internal validation, no external validation was conducted. Secondly, the retrospective design may introduce subjective

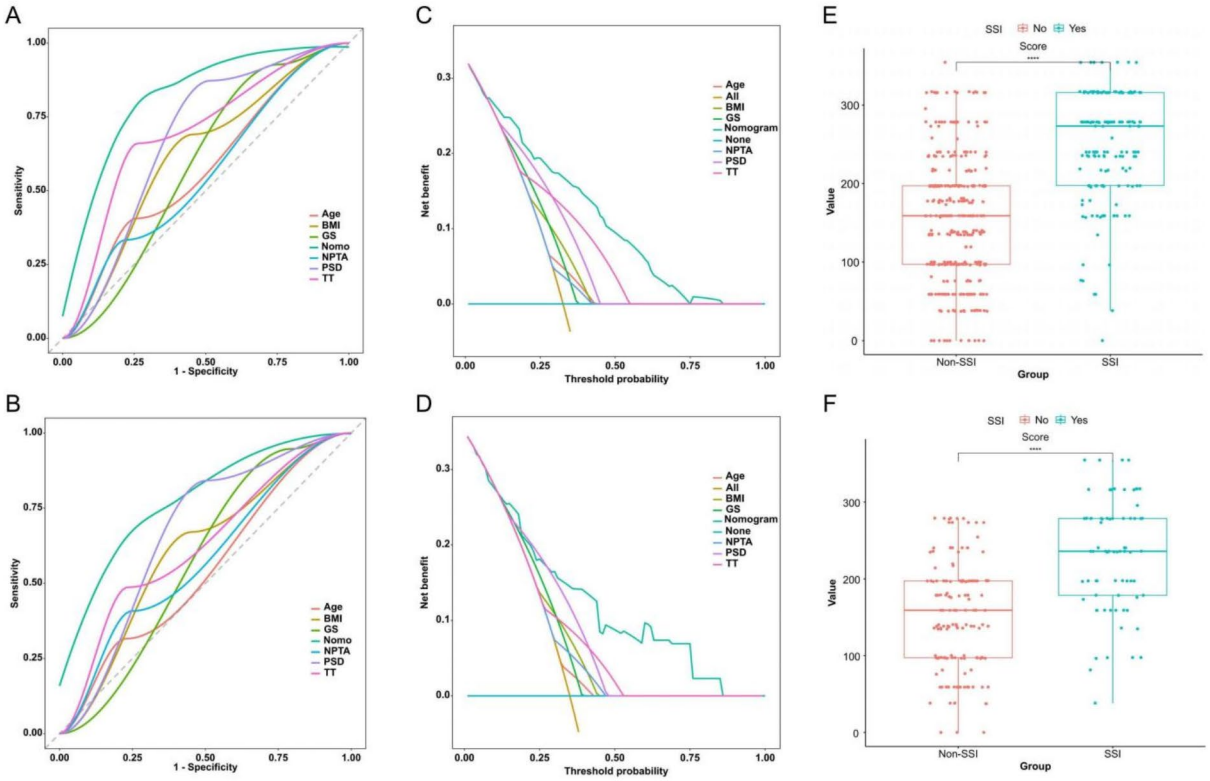

Fig. 5. The reasonable analysis of the established clinical prediction model. (**A**) Receiver Operating Characteristic (ROC) diagram of reasonable analysis in the training set. (**B**) ROC diagram of reasonable analysis in the validation set. The results showed that the Area Under the Curve (AUC) of the nomogram model is higher than that of single-variable models in both the training set and the validation set. This indicates that the predictive performance of the six-variable model is superior to that of any single-variable model. (**C**) Decision curve analysis (DCA) diagram of reasonable analysis in the training set. (**D**) DCA diagram of reasonable analysis in the validation set. The results of the DCA diagram of reasonable analysis showed that the net benefit rate of the nomogram model is higher than that of a simple model with thresholds ranging from 0.1 to 0.8 in the training set and from 0.3 to 0.8 in the validation set. This indicates that the net benefit of the six-variable model is superior to that of single-variable models in both the training and validation sets. (**E**) The results of the model score comparison the Significant differences in nomogram scores between the SSI and Non-SSI groups in the training set. (**F**) The results of the model score comparison the Significant differences in nomogram scores between the SSI and Non-SSI groups in the validation sets. The results of the model score comparison indicating the model's effectiveness. P values were calculated via two independent samples t-tests. *SSI* surgical site infection, *BMI* body mass index, *PSD* postoperative suction drainagen, *GS* gelatin sponge, *NPTA* none-preoperative antibiotic, *TT* thrombin time.

and selection biases. Lastly, although the nomogram achieved good calibration and optimal discrimination through internal validation, it requires external validation with additional datasets.

Conclusion

The nomogram model developed in this study enables early identification of SSI risk post-surgery for LDH, provides valuable references for clinical decision-making, and optimizes medical resource allocation. Furthermore, we constructed and validated a nomogram to predict SSI probability in patients following LDH surgery.

Data availability

The original contributions presented in the study are included in the article. Further inquiries can be directed to the corresponding authors.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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