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Construction and validation of nomogram to predict surgical site infection after hysterectomy: a retrospective study

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This study aimed to develop a predictive tool for surgical site infections (SSI) following hysterectomy and propose strategies for their prevention and control. We conducted a retrospective analysis at a tertiary maternity and child specialist hospital in Zhejiang Province, focusing on patients who underwent hysterectomy between January 2018 and December 2023 for gynecological malignancies or benign reproductive system diseases resistant to medical treatment. Risk factors associated with surgical site infections (SSI) following hysterectomy were identified using LASSO regression analysis on data from 2018 to 2022 as the training set. Independent risk factors were then used to develop a nomogram. The model was validated using data from 2023 as the validation set. Model performance was assessed using the area under the receiver operating characteristic curve (ROC), while calibration curves were employed to gauge model accuracy. Furthermore, clinical utility was evaluated through clinical decision curve analysis (DCA) and clinical impact curve analysis (CIC), providing insights into the practical application of the nomogram. Multivariate analysis identified six independent risk factors associated with SSI development after hysterectomy: BMI ≥ 24 kg/m^2 (OR: 2.58; 95% CI 1.14–6.19; $P < 0.05$), hypoproteinaemia diagnosis (OR: 4.99; 95% CI 1.95–13.02; $P < 0.05$), postoperative antibiotic use for ≥ 3 days (OR: 49.53; 95% CI 9.73–91.01; $P < 0.05$), history of previous abdominal surgery (OR: 7.46; 95% CI 2.93–20.01; $P < 0.05$), hospital stay ≥ 10 days (OR: 9.67; 95% CI 2.06–76.46; $P < 0.05$), and malignant pathological type (OR: 4.62; 95% CI 1.78–12.76; $P < 0.05$). A nomogram model was constructed using these variables. ROC and calibration curves demonstrated good model calibration and discrimination in both training and validation sets. Analysis with DCA and CIC confirmed the clinical utility of the nomogram. Personalized nomogram mapping for SSI after hysterectomy enables early identification of high-risk patients, facilitating timely interventions to reduce SSI incidence post-surgery.

Keywords Hysterectomy, Surgical site infection, Hospital-acquired infection, LASSO regression

Surgical site infections (SSI) are prevalent among healthcare-associated infections[1], contributing significantly to morbidity, prolonged hospital stays, and increased healthcare costs[2,3]. Hysterectomy is one of the most common gynecological surgeries, involving the removal of the uterine corpus, cervix, both fallopian tubes, and both ovaries. This procedure can be performed abdominally, laparoscopically, or vaginally, categorized clinically as laparoscopic-assisted hysterectomy (LH), transabdominal hysterectomy (TAH), or vaginal hysterectomy (VH). Currently, laparoscopic hysterectomy is the predominant approach, with varying incidence rates of postoperative SSI observed globally[4–6].

It is crucial to note that all types of hysterectomy carry inherent risks of SSI, regardless of the surgical method chosen. These infections stem from factors such as postoperative pain and psychological stress, contributing to extended hospital stays and heightened healthcare expenditures. Previous studies[23,24] have identified multiple independent risk factors associated with SSI post-hysterectomy; however, translating these findings into clinical practice remains challenging. Developing a straightforward predictive tool could enhance the identification of these risk factors, thereby facilitating better clinical decision-making in SSI prevention and management.

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The nomogram, a graphical representation simplifying statistical equations, has emerged as a reliable method for assessing SSI risk. Despite its utility, its application in predicting SSI among hysterectomy patients remains relatively unexplored. Hence, our study sought to develop and validate a nomogram using readily available hospital data, encompassing admission details, laboratory results, pathology type, blood transfusion status, surgical specifics, and antibiotic usage. This nomogram aims to swiftly screen patients suspected to be at high risk of SSI, providing a valuable resource for clinical assessment and early intervention. This research represents a pioneering effort in China to advance the understanding and management of SSI risks in hysterectomy patients.

Methods

Type and medium of study

This retrospective observational study was conducted at the Shaoxing Women's and Children's Hospital, a tertiary specialist hospital affiliated to the Shaoxing Academy of Arts and Sciencesin eastern China, which has a bed capacity of 600, including four gynaecology wards with a total of 160 beds.

The study population

The study encompassed a population of 635 patients, including both those who developed surgical site infections (SSI) following hysterectomy and those who did not, within the period from January 2018 to December 2023. Patient inclusion criteria were defined as follows: (1) SSI diagnosis adhering to the Technical Guidelines for Prevention and Control of Surgical Site Infections and Diagnosis of Hospital Infections issued by the National Health and Wellness Commission[7], which encompassed infections in the subcutaneous tissue, incisional skin, fascia, and muscle layers occurring within 30 days post-surgery; (2) Absence of severe cardiac, pulmonary, hepatic, or renal dysfunction; (3) Patients undergoing total hysterectomy. Patient exclusion criteria entailed: (1) Incomplete hysterectomy procedures; (2) Insufficient clinical information available; (3) Patients with infections of the vaginal vault.

Data collection

We conducted a retrospective collection of clinical and laboratory data obtained at admission from our electronic medical records system. The variables included age at admission, menopausal status, BMI at admission, presence of indwelling drains for lymphatic tissue drainage, preoperative hypertension status, preoperative anemia status, and preoperative hypo-proteinemia defined as total plasma protein less than 60 g/L with albumin less than 30 g/L. Additional variables collected were preoperative white blood cell count, duration of postoperative antimicrobial treatment, use of additional intraoperative antibiotics, surgical mode and duration, American Society of Anesthesiologists (ASA) classification, intraoperative blood loss, history of previous abdominal surgeries, total hospitalization days, pathology type (benign or malignant), adnexal resection (ovary or tubal), pelvic or aortic lymph node resection, and intraoperative blood transfusion status (including autologous or allogeneic transfusion). Also includes type of incision (whether midline or not). Patients were monitored for surgical site infections (SSI) through our hospital's infection surveillance system.

Statistical analysis

The data were initially assessed for normality using the Kolmogorov–Smirnov test and for homogeneity of variances using Bartlett's chi-square test. Categorical variables were presented as counts and percentages where appropriate. The training set underwent analysis using the Least Absolute Shrinkage and Selection Operator (LASSO) regression model to identify predictive risk factors with non-zero coefficients. Subsequently, based on these selected risk factors, multivariate logistic regression analyses were conducted to identify independent predictors. This led to the development of a nomogram model aimed at predicting the likelihood of surgical site infections (SSI) following hysterectomy. Validation of the model was performed using an independent dataset from 2023. The discriminative ability and calibration of the model were evaluated using receiver operating characteristic (ROC) curves and calibration plots, respectively. Additionally, Decision Curve Analysis (DCA) and Clinical Impact Curve (CIC) were employed to assess the clinical utility and net benefit of the predictive model. Statistical significance was set at a two-sided P-value of less than 0.05. All analyses were carried out using R software version 4.2.2, with relevant packages including "readr", "compareGroups", "tableone", "glmnet", "foreign", "rms", "rmda", "pROC", and "ggplot2".

Results

Population baseline characteristics

A total of 635 patients who underwent trans-hysterectomy met the inclusion criteria. Table 1 presents thebasic characteristics of these patients, among whom the incidence of surgical site infection was 9.45% (60/635). Continuous variables such as age, BMI, preoperative leukocyte count, duration of postoperative antibiotics, surgery duration, blood loss, and total hospital days were categorized using median or near-median values as thresholds. Among the patients included in the study, 360 individuals (56.7%, 360/635) were aged 52 years or older. Menopausal status was noted in 45.0% (286/635) of patients, while 52.9% (336/635) had a BMI $\geq$ 24 kg/m^2. Other notable percentages included 18.6% (118/635) with an indwelling drain, 18.3% (167/635) with hypertension, 19.5% (124/635) with anaemia, and 9.13% (58/635) with hypoproteinaemia. Furthermore, 40.8% (259/635) of patients received $\geq$ 3 days of postoperative antibiotics, and 6.61% (42/635) received additional intraoperative antibiotics. Laparoscopic surgery was performed in 60.2% (382/635) of cases. Operations lasting $\geq$ 105 min accounted for 52.6% (334/635), and 70.6% (448/635) of patients were classified as ASA II-III. Operative blood loss exceeded 50 ml in 33.1% (210/635) of patients, and 15.1% (96/635) had a history of previous abdominal surgery.Regarding hospital stay, 61.6% (391/635) of patients remained hospitalized for $\geq$ 10 days. Pathologically

Vriable	ALL	SSI	Non- SSI	p
	N = 635	N = 60	N = 575	
Age(years)				0.336
< 52	275 (43.3%)	30 (50.0%)	245 (42.6%)	
≥ 52	360 (56.7%)	30 (50.0%)	330 (57.4%)	
Menopause				0.132
Yes	286 (45.0%)	21 (35.0%)	265 (46.1%)	
No	349 (55.0%)	39 (65.0%)	310 (53.9%)	
BMI(kg/m^2)				0.008
< 24	299 (47.1%)	18 (30.0%)	281 (48.9%)	
≥ 24	336 (52.9%)	42 (70.0%)	294 (51.1%)	
Abdominal drainage tube				< 0.001
Yes	118 (18.6%)	27 (45.0%)	91 (15.8%)	
No	517 (81.4%)	33 (55.0%)	484 (84.2%)	
Hypertension				0.482
Yes	167 (26.3%)	13 (21.7%)	154 (26.8%)	
No	468 (73.7%)	47 (78.3%)	421 (73.2%)	
Anaemia				0.102
Yes	124 (19.5%)	17 (28.3%)	107 (18.6%)	
No	511 (80.5%)	43 (71.7%)	468 (81.4%)	
Hypoproteinemia				< 0.001
Yes	58 (9.1%)	26 (43.3%)	32 (5.6%)	
No	577 (90.9%)	34 (56.7%)	543 (94.4%)	
Pre-operative WBC(10^9/L)				
				0.549
< 5.4	325 (51.2%)	28 (46.7%)	297 (51.7%)	
≥ 5.4	310 (48.8%)	32 (53.3%)	278 (48.3%)	
Timing of postoperativeantimicrobial use(days)				< 0.001
< 3	376 (59.2%)	6 (10.0%)	370 (64.3%)	
≥ 3	259 (40.8%)	54 (90.0%)	205 (35.7%)	
Additional intraoperative antibiotics				0.004
Yes	42 (6.6%)	10 (16.7%)	32 (5.6%)	
No				
No	593 (93.4%)	50 (83.3%)	543 (94.4%)	
Surgical approach				< 0.001
LH	382 (60.2%)	34 (56.7%)	348 (60.5%)	
VH	187 (29.4%)	11 (18.3%)	176 (30.6%)	
TAH	66 (10.4%)	15 (25.0%)	51 (8.9%)	
Duration of surgery(min)				0.106
< 105	301 (47.4%)	22 (36.7%)	279 (48.5%)	
≥ 105	334 (52.6%)	38 (63.3%)	296 (51.5%)	
ASA				0.805
I	187 (29.4%)	19 (31.7%)	168 (29.2%)	
II-III	448 (70.6%)	41 (68.3%)	407 (70.8%)	
Surgical blood loss (ml)				0.179
≤ 50	425 (66.9%)	35 (58.3%)	390 (67.8%)	
> 50	210 (33.1%)	25 (41.7%)	185 (32.2%)	
Previous abdominal surgery				< 0.001
Yes	96 (15.1%)	26 (43.3%)	70 (12.2%)	
No	539 (84.9%)	34 (56.7%)	505 (87.8%)	
Total hospital days				< 0.001
< 10	244 (38.4%)	5 (8.3%)	239 (41.6%)	
≥ 10	391 (61.6%)	55 (91.7%)	336 (58.4%)	
Type of pathology				< 0.001
Benign disease	451 (71.0%)	18 (30.0%)	433 (75.3%)	
Malignant disease	184 (29.0%)	42 (70.0%)	142 (24.7%)	
Adnexectomy				0.194
Continued				

Vriable	ALL	SSI	Non- SSI	p
	N = 635	N = 60	N = 575	
Yes	566 (89.1%)	50 (83.3%)	516 (89.7%)	
No	69 (10.9%)	10 (16.7%)	59 (10.3%)	
Pelvic or aortic lymphadenectomy				< 0.001
Yes	103 (16.2%)	21 (35.0%)	82 (14.3%)	
No	532 (83.8%)	39 (65.0%)	493 (85.7%)	
Intraoperative blood transfusion				0.524
Yes	74 (11.7%)	9 (15.0%)	65 (11.3%)	
No	561 (88.3%)	51 (85.0%)	510 (88.7%)	
Midline incision				
Yes	66 (10.4%)	15 (25.0%)	51 (8.9%)	< 0.001
No	569(89.6%)	45 (75.0%)	524(91.1%)	

Table 1. Demographic and clinical characteristics of hysterectomized patients.

confirmed malignant tumors were present in 29.0% (184/635), and adnexal resection was performed in 89.1% (566/635) of cases. Pelvic or aortic lymphadenectomy was performed in 16.2% (103/635) of patients, and 11.7% (74/635) received intraoperative blood transfusions. Additionally, 10.7%(66/635) of patients with an open abdomen underwent a midline incision type. Baseline comparisons across twelve variables showed significant differences ($p < 0.05$). Table 2 presents the patient demographics divided into training and validation sets. The training set included data from 544 patients (January 2018 to December 2022), with 48 cases of surgical site infections, while the validation set comprised 91 patients from 2023, with 12 infections reported.

LASSO regression and multivariate analysis

LASSO regression was employed to identify risk factors associated with surgical site infections (SSI) in transhysterectomy patients. Initially, 21 variables were subjected to LASSO regression, resulting in 12 potential predictors highlighted in the coefficient profiles (Fig. 1A). The model's performance was validated through a cross-validated error plot (Fig. 1B). Notably, the final LASSO model incorporated predictors such as menopausal status, BMI, presence of indwelling drains, hypoproteinaemia, duration of postoperative antimicrobial use, use of intraoperative antibiotics, surgical duration, ASA classification, history of previous abdominal surgery, total hospital days, and pathological diagnosis of malignant tumors or adnexectomy.Subsequent multifactorial logistic regression analysis, following the LASSO screening, revealed six independent predictors significantly associated with SSI (Table 3). These included BMI ≥ 24 kg/m^2 (OR: 2.58; 95% CI 1.14–6.19; $P < 0.05$), hypoproteinaemia (OR: 4.99; 95% CI 1.95–13.02; $P < 0.05$), postoperative antibiotic use for ≥ 3 days (OR: 49.53; 95% CI 9.73–91.01; $P < 0.05$), history of previous abdominal surgery (OR: 7.46; 95% CI 2.93–20.01; $P < 0.05$), total hospital stay of ≥ 10 days (OR: 9.67; 95% CI 2.06–76.46; $P < 0.05$), and pathological diagnosis of malignant tumors (OR: 4.62; 95% CI 1.78–12.76; $P < 0.05$).

Individualised predictive model construction nomogram

The final selection of six variables was incorporated into a nomogram to construct a predictive model forsurgical site infections (SSI) following total hysterectomy, using R 4.2.2 (Fig. 2). Each variable was assigned points by projecting upward along a straight line to the points axis. The total score was then plotted on the axis representing total points, and a line was drawn downward to the probability axis, indicating the likelihood of an SSI. Patients were scored based on the nomogram, with a maximum score of 450 points. In Fig. 3, red dots represent observed values for each variable in the patient from the second row of the study dataset. For instance, this patient had a BMI ≥ 24, hypoproteinemia, no history of abdominal surgery, a malignant tumor pathology, days of a hospital stay ≥ 10, days of postoperative antibiotics ≥ 3, and a total score of 392 points. According to the nomogram, this score corresponds to a probability of 0.672 for developing a surgical site infection.

Internal and external validation

The model's performance was assessed through ROC curves and calibration plots, yielding an area under the ROC curve (AUC) of 0.935 for the training set (Fig. 3A) and 0.877 for the validation set (Fig. 3B). Calibration curves in both sets (Fig. 4A,B) demonstrated close alignment between predicted and observed rates, indicating reliable predictive accuracy.

Clinical Use of the nomogram

To assess the model's performance beyond ROC curves, we analyzed clinical decision curves (DCA) for the training and validation sets, each based on 635 transhysterectomy patients. The DCA illustrated significant net gains across a broad spectrum of high-risk thresholds, affirming the nomogram's efficacy (Fig. 5A,C). Additionally, clinical impact curves (CIC) were plotted. The red curve depicts individuals classified as positive (high risk) by

Vriable	ALL	Training Cohort	Validation Cohort	P
	N = 635	N = 544	N = 91	
Age (years)				0.003
< 52	275 (43.3%)	249 (45.8%)	26 (28.6%)	
≥ 52	360 (56.7%)	295 (54.2%)	65 (71.4%)	
Menopause				0.209
Yes	286 (45.0%)	239 (43.9%)	47 (51.6%)	
NO	349 (55.0%)	305 (56.1%)	44 (48.4%)	
BMI(kg/m^2)				0.291
< 24	299 (47.1%)	251 (46.1%)	48 (52.7%)	
≥ 24	336 (52.9%)	293 (53.9%)	43 (47.3%)	
Abdominal drainage tube				0.181
Yes	118 (18.6%)	96 (17.6%)	22 (24.2%)	
No	517 (81.4%)	448 (82.4%)	69 (75.8%)	
Hypertension				0.162
Yes	167 (26.3%)	149 (27.4%)	18 (19.8%)	
No	468 (73.7%)	395 (72.6%)	73 (80.2%)	
Anaemia				0.621
Yes	124 (19.5%)	104 (19.1%)	20 (22.0%)	
No	511 (80.5%)	440 (80.9%)	71 (78.0%)	
Hypoproteinemia				0.100
Yes	58 (9.1%)	45 (8.3%)	13 (14.3%)	
No	577 (90.9%)	499 (91.7%)	78 (85.7%)	
Pre-operative WBC(10^9/L)				
				0.663
< 5.4	325 (51.2%)	276 (50.7%)	49 (53.8%)	
≥ 5.4	310 (48.8%)	268 (49.3%)	42 (46.2%)	
Timing of postoperativeantimicrobial use (days)				0.887
< 3	376 (59.2%)	321 (59.0%)	55 (60.4%)	
≥ 3	259 (40.8%)	223 (41.0%)	36 (39.6%)	
Additional intraoperative antibiotics				0.012
Yes	42 (6.6%)	30 (5.5%)	12 (13.2%)	
No	593 (93.4%)	514 (94.5%)	79 (86.8%)	
Surgical approach				0.001
LH	382 (60.2%)	343 (63.1%)	39 (42.9%)	
VH	187 (29.4%)	147 (27.0%)	40 (44.0%)	
TAH	66 (10.4%)	54 (9.9%)	12 (13.2%)	
Duration of surgery(min)				0.083
< 105	301 (47.4%)	266 (48.9%)	35 (38.5%)	
≥ 105	334 (52.6%)	278 (51.1%)	56 (61.5%)	
ASA				0.118
I	187 (29.4%)	167 (30.7%)	20 (22.0%)	
II-III	448 (70.6%)	377 (69.3%)	71 (78.0%)	
Surgical blood loss (ml)				1.000
≤ 50	425 (66.9%)	364 (66.9%)	61 (67.0%)	
> 50	210 (33.1%)	180 (33.1%)	30 (33.0%)	
Previous abdominal surgery				0.134
Yes	96 (15.1%)	77 (14.2%)	19 (20.9%)	
No	539 (84.9%)	467 (85.8%)	72 (79.1%)	
Total hospital days				0.026
< 10	244 (38.4%)	199 (36.6%)	45 (49.5%)	
≥ 10	391 (61.6%)	345 (63.4%)	46 (50.5%)	
Type of pathology				< 0.001
Benign disease	451 (71.0%)	402 (73.9%)	49 (53.8%)	
Malignant disease	184 (29.0%)	142 (26.1%)	42 (46.2%)	
Adnexectomy				0.189
Yes	566 (89.1%)	489 (89.9%)	77 (84.6%)	
Continued				

Vriable	ALL	Training Cohort	Validation Cohort	P
	N = 635	N = 544	N = 91	
No	69 (10.9%)	55 (10.1%)	14 (15.4%)	
Pelvic or aortic lymphadenectomy				1.000
Yes	103 (16.2%)	88 (16.2%)	15 (16.5%)	
No	532 (83.8%)	456 (83.8%)	76 (83.5%)	
Intraoperative blood transfusion				0.015
Yes	74 (11.7%)	56 (10.3%)	18 (19.8%)	
No	561 (88.3%)	488 (89.7%)	73 (80.2%)	
Midline incision				0.449
Yes	66 (10.4%)	54 (9.9%)	12 (13.2%)	
No	569 (89.6%)	490 (90.1%)	79 (86.8%)	
SSI				0.261
Yes	60 (9.4%)	48 (8.8%)	12 (13.2%)	
No	575 (90.6%)	496 (91.2%)	79 (86.8%)	

Table 2. Baseline information grouped by training and validation sets.

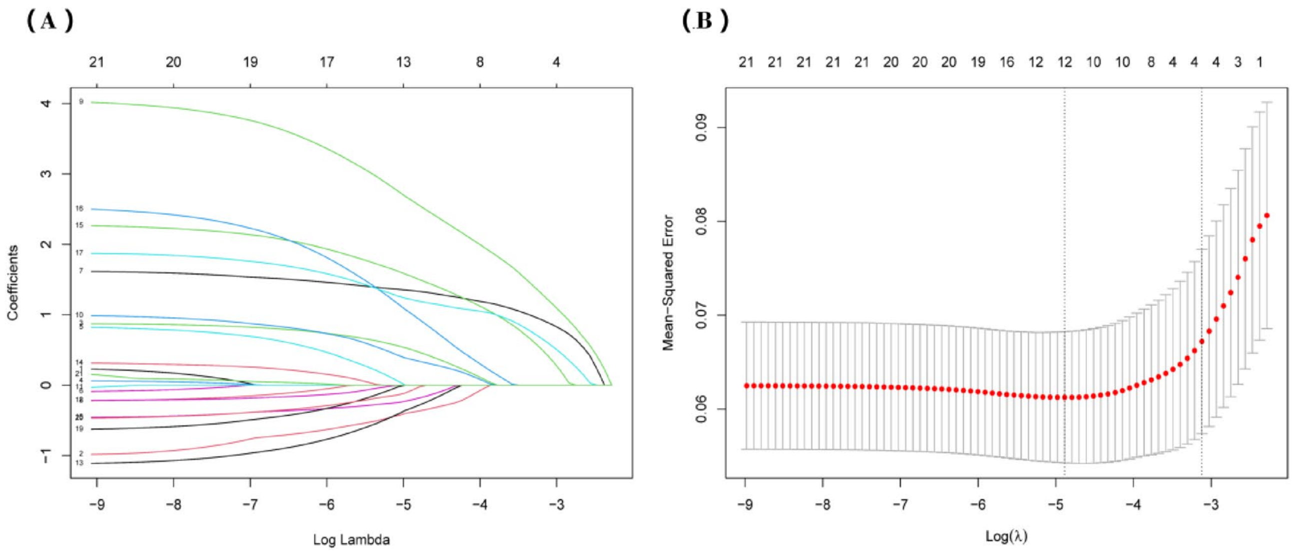

Fig. 1. (**A**) 12 variables screened from 21 based on LASSO regression.A coefficient profile plot was produced against the log (λ) sequence. (**B**) Plot of the results of cross-validation, and the red dots in the figure represent the target parameters corresponding to each lambda.

Variable	Estimate	Std.Error	OR (95%CI)	P-value
BMI	0.9492	0.4290	2.58(1.14–6.19)	*< 0.05*
Hypoproteinemia	1.6080	0.4812	4.99(1.95–13.02)	*< 0.05*
Timing of postoperativeantimicrobial use	3.9027	1.0472	49.53(9.73–91.01)	*< 0.05*
Previous abdominal surgery	2.0093	0.4860	7.46(2.93–20.01)	*< 0.05*
Total hospital days	2.2688	0.8926	9.67(2.06–76.46)	*< 0.05*
Type of pathology	1.5315	0.4994	4.62(1.78–12.76)	*< 0.05*

Table 3. Multivariate regression model based on LASSO regression results. OR = odds ratio;CI = confidence interval;*p < 0.05.

the model at various probability thresholds, while the blue curve shows true positives at each threshold. These curves provide a clearer visual representation of the nomogram's overall benefit (Fig. 5B,D).

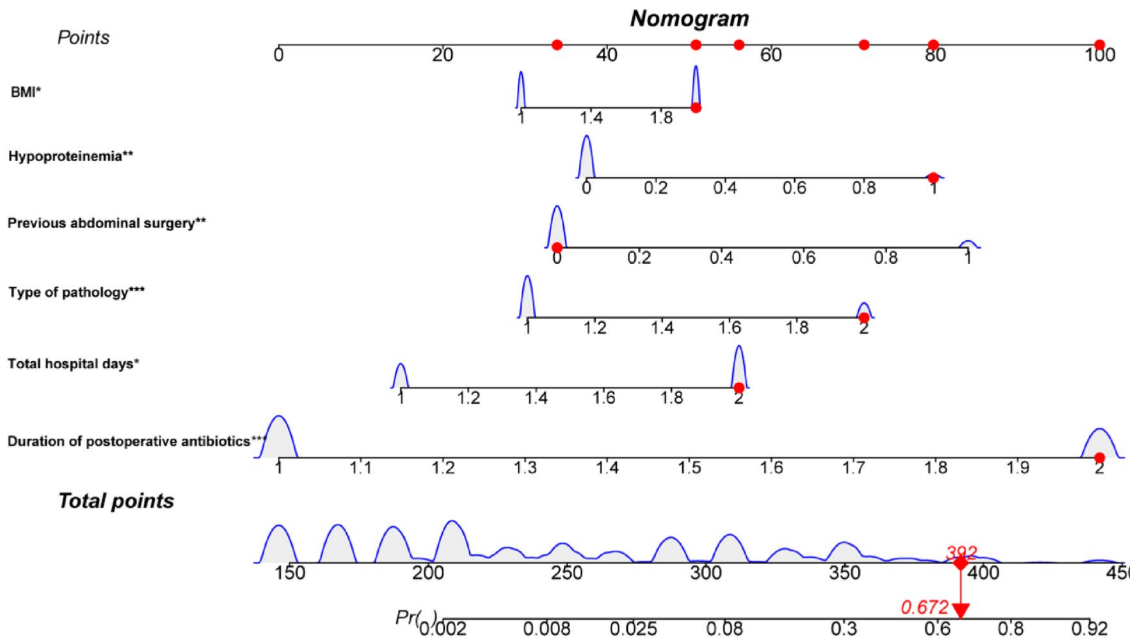

Fig. 2. Nomogram to predict the risk of surgical site infection in hysterectomized patients.

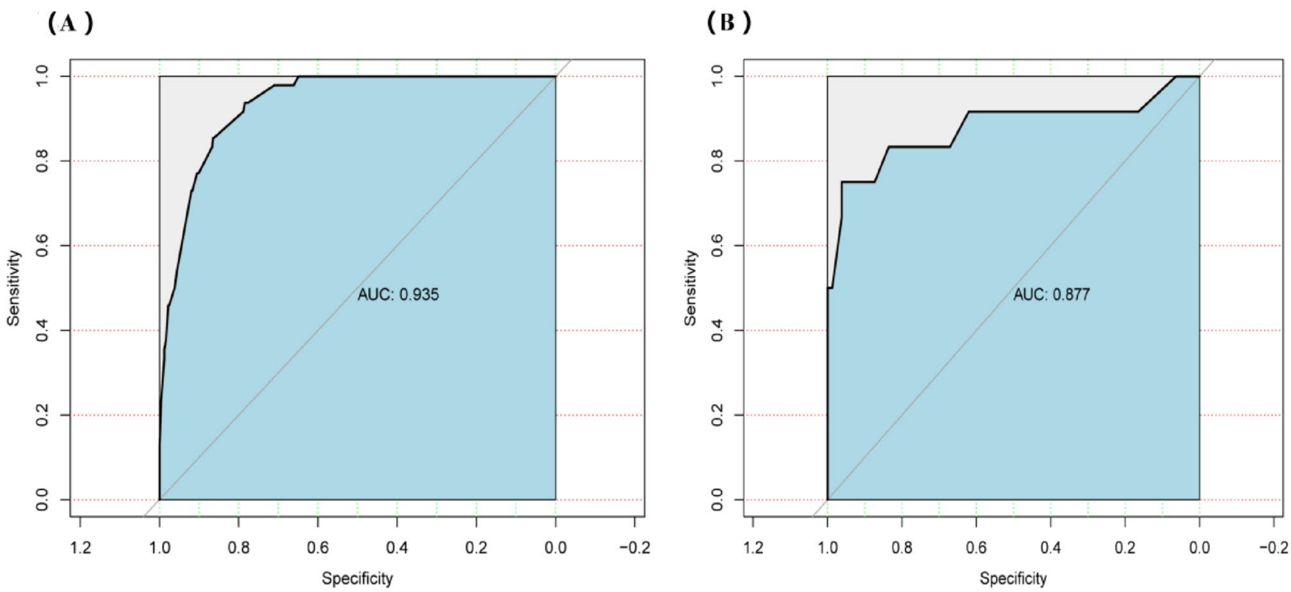

Fig. 3. (**A**) Received Operating Characteristic Curve (ROC) for the training set; (**B**) Received Operating Characteristic Curve (ROC) for the validation set.

Discussion

Surgical site infection (SSI) presents a significant challenge following hysterectomy, leading to prolonged hospital stays and increased healthcare costs. Internationally, SSI data from hysterectomies are used to assess hospital care quality, with potential financial penalties for hospitals exceeding certain infection thresholds in terms of insurance reimbursement[8]. Previous studies underscore that SSI rank among the costliest hospital-acquired infections in the United States, adding up to $10 billion annually[9,10]. Patients with SSI experience a three- to five-fold longer hospital stay, double the healthcare costs, and a three-fold higher risk of rehospitalization compared to those without SSI.In our hospital, we initially identified 21 potential variables associated with SSI development post-hysterectomy. Through rigorous LASSO and multivariate regression analyses, which mitigate covariance between variables[11], we pinpointed six critical factors: BMI ≥ 24, hypoproteinemia diagnosis, ≥ 3 days of postoperative antibiotics, history of abdominal surgery, total hospital days ≥ 10, and malignancy pathology type.Based on these six independent risk factors, we developed a predictive model designed as a practical and effective tool for anticipating the likelihood of postoperative SSI in hysterectomy patients within clinical settings. We assessed

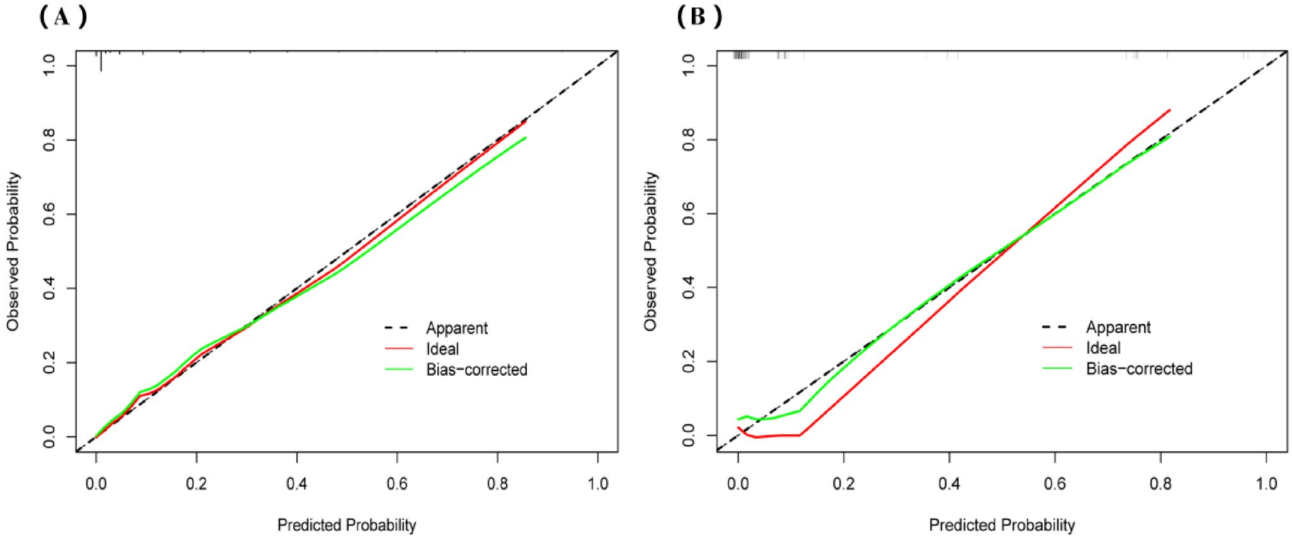

Fig. 4. (**A**) Calibration plot of the training set. (**B**) Calibration plot for the validation set. The x-axis represents the predicted probability of SSI infection by the nomogram, and the y-axis represents the actual infection rate of SSI. The 45-degree reference line signifies perfect calibration.

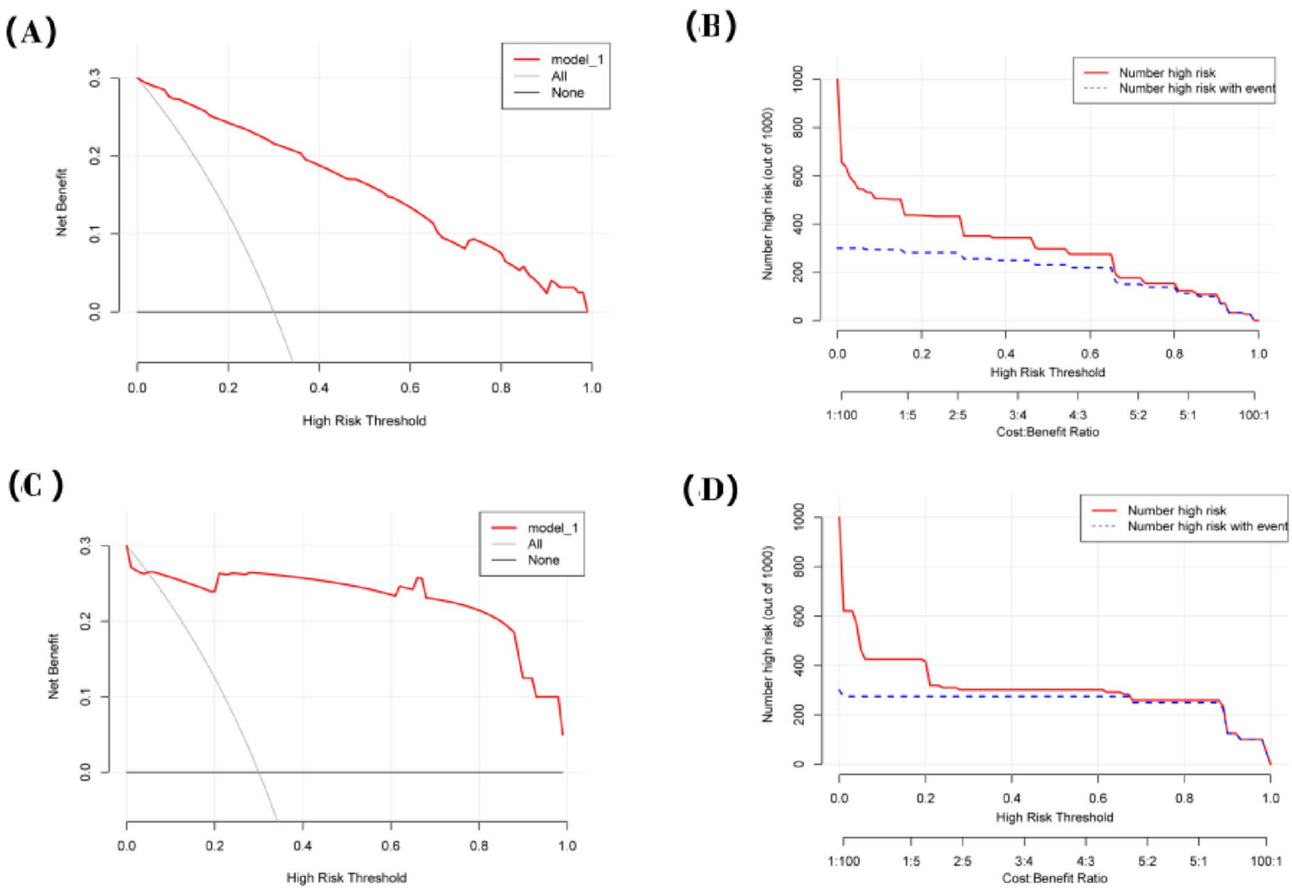

Fig. 5. (**A**) Decision curve analysis (DCA) of the training set, (**B**) Clinical impact curve (CIC) analysis of the training set, (**C**) Decision curve analysis (DCA) of the validation set, (**D**) Clinical impact curve (CIC) analysis of the validation set.

the model's performance using ROC and calibration curves, demonstrating its robust predictive accuracy for SSI occurrence post-hysterectomy. Furthermore, findings from decision curve analysis (DCA) and clinical impact curve (CIC) plots underscored the model's favorable net clinical benefit. To enhance usability, we created a nomogram enabling clinicians to swiftly gauge a patient's SSI risk following hysterectomy, streamlining assessment without computational complexity.

The duration of postoperative antimicrobial use holds significant weight in our nomogram, highlighting its paramount importance as an independent risk factor for SSI in hysterectomy patients compared to others. This duration encompasses both perioperative prophylaxis and therapeutic antibiotic use, with perioperative administration typically lasting up to 48 h post-surgery. Prolonged therapeutic antimicrobial use beyond 48 h correlates with changes in specific inflammatory markers like procalcitoninogen (PCT) and C-reactive protein, indicating an increased risk of developing surgical site infections. Hypoproteinemia is an independent risk factor for postoperative surgical site infections (SSI). Before surgery, hypoproteinemia results in inadequate protein reserves, lowering the body's stress tolerance and immune function. This impairment hinders post-surgical tissue healing and diminishes infection resistance, thereby escalating the likelihood of complications, disease progression, and mortality[12]. Research outcomes consistently advocate for sustained and tailored preoperative nutritional support as pivotal in lowering the incidence of SSI in such patients[13–15]. The duration of hospitalization emerged as an independent risk factor in our study. Our analysis also incorporated preoperative hospital days, which exhibited a statistically significant correlation with postoperative surgical site infections (SSI), consistent with prior research[16,17].

The investigation of surgical complications following hysterectomy remains a prominent research area. Our study specifically focuses on postoperative SSI, while previous studies, such as Schmidt et al[18], have developed and validated tools for assessing preoperative clinical risks associated with complications occurring within 30 days post-hysterectomy, encompassing a broad spectrum that includes SSI among others. Schmidt et al. expanded their assessment to include post-hysterectomy complications related to malignant conditions, in addition to benign gynecological conditions previously studied[19]. Their findings identified three modifiable factors to mitigate postoperative complications: opting for minimally invasive hysterectomy, improving glycemic control, and avoiding preoperative blood transfusions. They also highlighted that BMI > 40, gynecological cancers, and a history of prior abdominal surgery independently increase the risk of postoperative complications, findings that parallel our study results to some extent. Sloth[20] et al. formulated clinical guidelines for hysterectomy in Denmark. Their study concluded that there were no significant differences in outcomes between subtotal and total hysterectomy. They found that variations in operative time, intraoperative bleeding, and postoperative infections were minimal and lacked statistical significance. Additionally, the research highlighted that hysterectomy combined with bilateral salpingo-oophorectomy was associated with a reduced risk of postoperative infections. In a separate study, Bruno[21] et al. developed a risk assessment model specifically for minimally invasive hysterectomy. Their analysis focused on intraoperative and postoperative complications, revealing that age, BMI, and the type of disease showed statistically significant associations with minor postoperative complications. Furthermore, BMI, history of previous surgeries, and surgeon experience were identified as factors significantly associated with major postoperative complications in their comprehensive risk assessment model.Previous studies[22–24] have identified various high-risk factors associated with surgical site infections (SSI) following total hysterectomy, including surgical approach, ASA classification, and intraoperative blood loss. Additionally, Tuomi, Tserenpuntsag and Pop-Vicas[25–27] concluded that the prolonged duration of surgery leads to tissue pulling damage and extended exposure of tissues and organs to air, facilitating conditions for pathogenic bacterial colonization and increasing infection risk. However, these factors did not demonstrate significant effects on postoperative SSI in the results of our study. This discrepancy may stem from differences in the study population characteristics, hospital environments, and medical care conditions.

Our study successfully developed a predictive model for postoperative SSI in patients undergoing hysterectomy. However, it is important to acknowledge some limitations due to its retrospective, single-center design. To enhance reliability, we conducted internal validation by splitting the dataset into training and validation sets. External validation of the predictive model remains necessary for broader applicability in clinical settings. In conclusion, our predictive model based on LASSO regression analysis demonstrated strong predictive efficiency for predicting SSI in hysterectomy patients. This tool holds promise for early identification of high-risk patients and could contribute to refining treatment protocols in clinical practice.

Conclusions

In our study, we identified BMI ≥ 24 kg/m^2, hypoproteinemia diagnosis, postoperative antibiotic duration ≥ 3 days, history of prior abdominal surgery, total hospital stay ≥ 10 days, and malignancy pathology as independent risk factors for postoperative surgical site infections (SSI) in total hysterectomy patients. Developing a nomogram using these factors, characterized by simplicity and applicability, demonstrates strong predictive ability. Such a tool holds promise for informing clinical decisions and optimizing treatment strategies.

Data availability

The data related to this study has been made to be uploaded as supporting information.

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Author contributions

Hui Shao: data analysis,writingthe paper. Lili Feng:study design, manuscript preparation.XiujuanWang:data collection and assessment, manuscript preparation. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethics approval

The authors assert that they have secured proper approval from the Ethics Committee of Nanjing Medical University and have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. Our study was reported as described by the ARRIVE guidelines (Ethics approval reference number: 20210329).

Additional information

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