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ORIGINAL RESEARCH

A Nomogram for Predicting Pulmonary Complications Following Laparoscopic Surgery in Elderly Patients After the COVID-19 Pandemic

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Background: Postoperative pulmonary complications (PPCs) are common and serious after laparoscopic surgery, better than cardiac complications in predicting long-term mortality after non-cardiac surgery. In the post-epidemic era, the specific incidence of PPCs and their risk factors remain unclear.

Methods: This two-center retrospective study used the eligible patients' demographics and clinical characteristics to develop a prediction model. These patients who had undergone laparoscopic surgery from January 2023 to April 2024 were randomized into the training set and validation set. The main outcome was the incidence of PPCs. The multi-input processing method was used for missing data imputation. The variables with a *P*-value ≤0.05 and the covariates considered meaningful in clinical practice in univariate logistic regression analysis were subjected to multivariate logistic regression analysis to determine the independent risk factors of PPCs. The ROC, AUC, calibration curve, and clinical decision curve analysis of both sets were used to evaluate the model's predictive accuracy.

Results: 278 patients (21.21%) developed PPCs. Surgical site and the comorbidities (except pulmonary diseases), pulmonary abnormalities, 24-h white blood cell count, and 24-h neutrophil percentage before surgery were independent risk factors for PPCs and used for the establishment of a nomogram prediction model for PPC risk in elderly patients. The AUC value, sensitivity, and specificity were 0.88, 75.4%, and 87.6% respectively in the model's ROC curve. Internal verification (AUC: 0.86) confirmed the model's good calibration and discrimination abilities. Clinical decision curve analysis showed that the model had a positive clinical net benefit within the risk threshold range of 0%~30%.

Conclusion: This study identified the high-risk individuals of PPCs in elderly patients. PPC risk in elderly patients after laparoscopic surgery could be effectively reduced by optimizing surgical site selection, controlling preoperative comorbidities, adjusting preoperative lung conditions, and monitoring preoperative 24-h white blood cell count and neutrophil percentage.

Keywords: nomogram, postoperative pulmonary complications, laparoscopic surgery, elderly patients

Introduction

Postoperative pulmonary complications (PPCs), common after laparoscopic surgery,[1,2] better predict the long-term mortality after non-cardiac surgery over cardiac complications.[3] The incidence of PPCs in different operations varies from 2% to 40%.[4,5] Elderly patients, with declined physiological organ reserve and increased probability of comorbidities like cardiovascular and cerebrovascular diseases and diabetes mellitus as the background, are more apt to suffer PPCs, especially in the first postoperative week; this adversely affects patients' postoperative rehabilitation, quality of life, and even long-term prognosis.[2,4,6,7]

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The COVID-19 pandemic has introduced new dimensions to PPC risk assessment. Emerging evidence suggests dual mechanisms for SARS-CoV-2-related PPC exacerbation: (1) direct pulmonary damage from viral infection,[8] and (2) systemic impacts from modified perioperative protocols, including limitations in preoperative viral screening.[9] Following China's December 2022 healthcare policy reform, which marked a pivotal transition in pandemic control strategies. Although direct pre-pandemic comparisons are unavailable, this transitional period provides critical insights into evolving PPC patterns under healthcare system restructuring. This retrospective study therefore investigates the incidence and risk stratification of PPCs in elderly laparoscopic surgery patients during the post-pandemic recovery phase (2023-–2024), addressing the knowledge gap in complication profiles under contemporary surgical practice conditions.

This study explored the risk factors of PPCs after laparoscopic surgery in elderly patients through retrospective analysis and investigated various preoperative-related risk factors to construct a nomogram model to predict PPCs in elderly patients, to accurately identify preoperative risk factors and help medical workers identify high-risk patients with PPCs. With protective perioperative management and in-time diagnosis and treatment, elderly patients are expected to have a lower incidence of PPCs after laparoscopic surgery and a better surgical prognosis.

Materials and Methods

Study Population

This study retrospectively analyzed the clinical data of 1338 elderly patients who underwent laparoscopic surgery with tracheal intubation under general anesthesia in Neijiang First People's Hospital and the First Affiliated Hospital of Chongqing Medical University from January 2023 to April 2024. All the patients were over 60 years old, both male and female patients were recruited. Their ASA grade was grade I or II according to the American Society of Anesthesiologists (ASA) physical status classification system. The patients without complete clinical data or necessary clinical data closely related to this study; with serious cardiovascular and cerebrovascular events (acute cerebral infarction, cardiac arrest, acute myocardial infarction, etc.) during operation, serious respiratory diseases (acute exacerbation of chronic obstructive pulmonary disease, significant lung function impairment caused by lung tissue resection, pulmonary hypertension/respiratory insufficiency/failure caused by any reason, severe asthma, etc.) before operation, or preoperative tumor metastasis or long-term chemotherapy; or without general anesthesia/tracheal intubation, were excluded.

This retrospective study strictly abided by the Helsinki Declaration and the ethical standards promulgated by the National Health and Wellness Committee of the People's Republic of China, and was approved by the Ethics Committee of Neijiang First People's Hospital (No. 2024–17) and the Ethics Committee of the First Affiliated Hospital of Chongqing Medical University (No. 20195801). All analyzed data were derived from existing anonymized medical records and did not involve any interventional procedures or additional patient contact. In accordance with the ethics committee's regulations, this research qualifies for exemption from obtaining patient informed consent, we strictly abide by the international patient data protection guidelines to ensure data security and privacy.

Data Collection

The research team of each center consisted of or led by anesthesiologists. We organized a series of comprehensive and detailed training courses in two centers in the post-epidemic period, aiming at teaching data collectors how to fill out the structured questionnaire and accurately identify PPCs from medical records. The specific content and definitions of the questionnaire can be found in the supplementary Appendix 1.

The data collection was mainly done through the hospital's electronic medical record system, anesthesia information recording system, or hospital information system from January 2024 to April 2024. The data included demographic characteristics (sex, age, ASA score, body mass index, albumin level, leukocyte count, neutrophil count, C-reactive protein level, lymphocyte count, systemic inflammatory index, platelet to lymphocyte ratio, preoperative comorbidities (other than lung disease) such as hypertension, diabetes mellitus, coronary heart disease, and stroke, etc)., intraoperative conditions (surgical site, anesthesia time, operation time, etc)., and postoperative conditions (incidence of PPCs, severity of PPCs, postoperative neutrophil counts, leukocyte count, and lymphocyte count, etc).

A hot-pursuit approach was applied. Real-time data collection was initiated from the time when a patient was admitted to the hospital to ensure the integrity and accuracy of data. Quality control algorithms were incorporated into the central database and special application programs for remote data recording to verify the accuracy of online data input and identify missing data. The data administrator conducted a rigorous review of the input data and asked the sub-center team members to reconfirm the records' integrity.

Diagnostic Criteria of PPCs

PCCs, according to the systematic review of perioperative medical standard endpoints published by the British Journal of Anaesthesia in 2018,[10] include respiratory failure, atelectasis, pulmonary infection, acute respiratory distress syndrome, aspiration pneumonia, pneumothorax, pleural effusion, bronchospasm, pulmonary embolism, and cardiogenic pulmonary edema. Patients were assigned to two groups according to the absence or presence of PPCs within postoperative 7 days, the non-PPC group and the PPC group. The whole data collection and processing is shown in the flowchart (Figure 1).

Statistical Analysis

SPSS 26.0 software was used for statistical analysis. The measurement data of non-normal distribution were expressed by a median with interquartile interval; the Mann–Whitney *U*-test was used for comparison between groups. The enumeration data were represented by n (%); the χ^2 test was used for between-group comparisons. The included patients were randomized into the training set and validation set at a ratio of 7 to 3. The variates ($P \leq 0.05$) and the covariates considered meaningful in clinical practice in univariate logistic regression analysis were subjected to multivariate logistic regression analysis to determine the risk factors of PPCs. The receiver operating characteristic (ROC) curve and the area under the curve (AUC) were used to evaluate the accuracy of the prediction model. The clinical decision curve was drawn to analyze the actual clinical prediction probability of the model. P-values <0.05 were considered statistically significant.

Results

Detection of Variables and Confirmation of Independent Risk Factors

The incidence and spectrum of PPCs are detailed in Table 1. Notably, pulmonary infection dominated the complication profile (18.7%), underscoring the need for targeted perioperative preventive strategies in elderly surgical populations. The incidence of PPCs in the validation group (23.35%) was higher than in the modeling group (20.28%). Except for preoperative hemoglobin level, postoperative 24h white blood cell count, and no extubation within postoperative 24 h, age, sex, smoking, body mass index, anesthesia time, operation time, surgical type/approach/site, preoperative albumin level, preoperative C-reactive protein level, preoperative white blood cell count, preoperative neutrophil ratio, preoperative lymphocyte percentage, preoperative lung condition, preoperative comorbidities (except pulmonary diseases), analgesic methods, postoperative 24h albumin level, postoperative 24h neutrophil ratio, postoperative 24h lymphocyte percentage, postoperative 24h C-reactive protein level, and postoperative 24h hemoglobin level showed no significant difference between the training and validation groups (Table 2).

In this study, the presence or absence of PPCs was taken as a dependent variable, and all variables in Table 1 were taken as independent variables. With the univariate logistic regression analysis, seven risk factors were finally screened, namely, preoperative white blood cell count, preoperative 24h neutrophil percentage, preoperative 24h lymphocyte percentage, surgical site, preoperative lung condition, preoperative comorbidities (except pulmonary diseases), and analgesic methods (Table 3). Further, the presence or absence of PPCs was taken as the dependent variable (presence: 1; absence: 0), and the variables with a *P*-value ≤0.05 and the covariates considered meaningful in clinical practice in univariate logistic regression analysis were subjected to multivariate logistic regression analysis to determine the independent risk factors of PPCs. The regression analysis showed that surgical site, preoperative comorbidities (except pulmonary diseases), preoperative lung abnormalities, preoperative 24h white blood cell count, and preoperative 24h neutrophil percentage were the independent risk factors of PPCs ($P < 0.05$; Table 4).

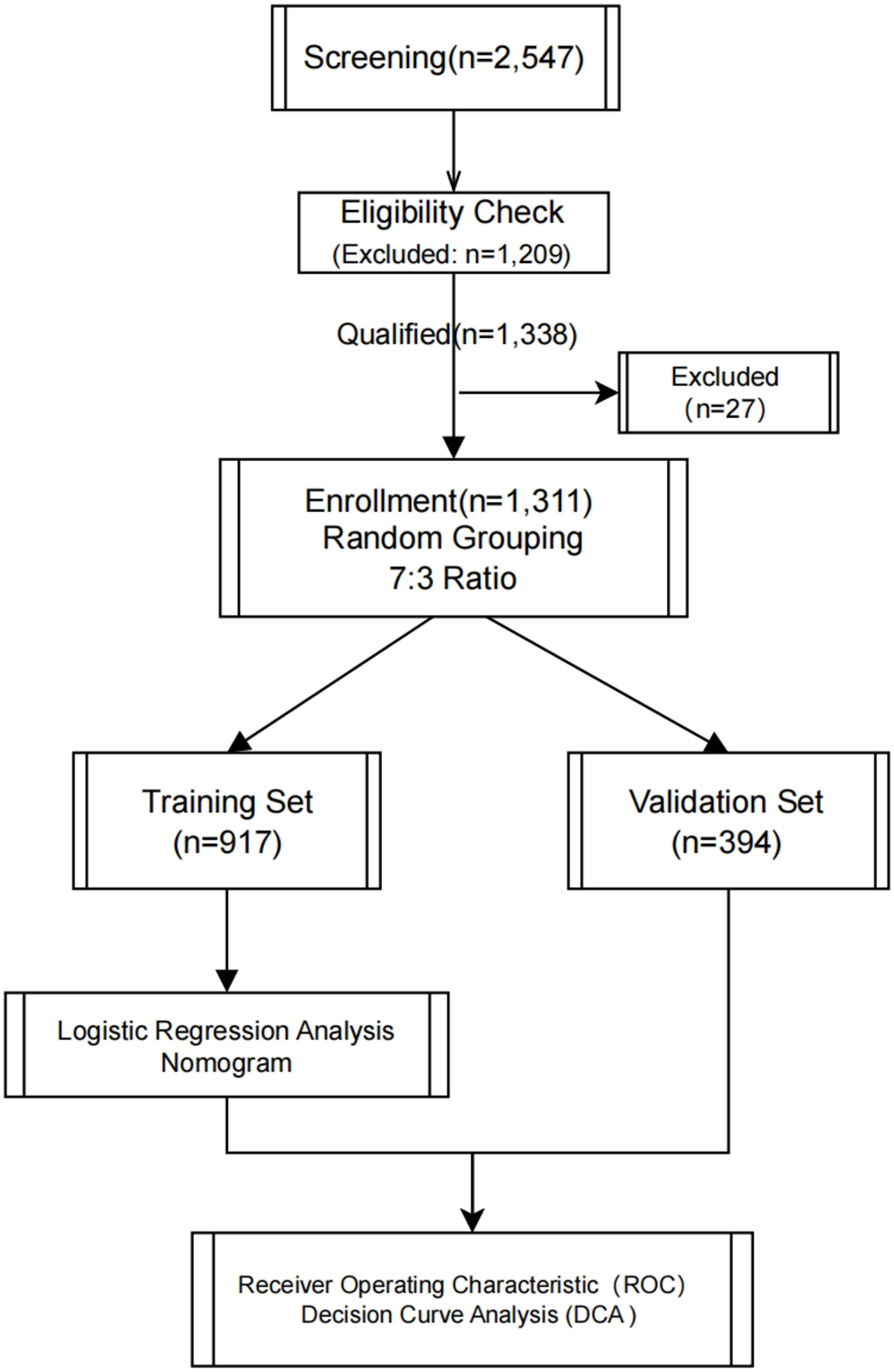

Figure 1 Flow chart of this study.

Construction and Evaluation of the PPC Nomogram Model

The five independent risk factors of PPCs were subjected to stepwise multi-factor regression modeling, and a nomogram was constructed based on the regression results (Figure 2). Surgical site, preoperative comorbidities (except pulmonary diseases), preoperative lung abnormalities, preoperative 24h white blood cell count, and preoperative 24h neutrophil percentage were considered as key predictors of PPCs.

Table 1 Incidence and Types of Postoperative Pulmonary Complications (PPCs)

PPCs Category	Number of Cases	Percentage (%)
Total PPCs	278	21.21
Subtypes of PPCs		
- Respiratory failure	160	12.20
- Atelectasis	47	3.58
- Pulmonary infection	29	2.21
- ARDS	9	0.69
- Aspiration pneumonia	5	0.38
- Pneumothorax	6	0.46
- Pleural effusion	5	0.38
- Bronchospasm	7	0.53
- Pulmonary embolism	4	0.31
- Cardiogenic pulmonary edema	6	0.46
Concurrent PPCs		
- Patients with ≥2 PPCs	24	8.63*

Notes: Percentages are calculated relative to the total cohort (n=1311), except for concurrent PPCs (relative to total PPCs cases, n=278).*Percentage of patients with multiple PPCs among total PPCs cases.

Table 2 Demographic Characteristics

Variables	Total (n = 1311)	Validation Set (n = 394)	Training Set (n = 917)	Statistic	*P*
Age (years) M (Q_1, Q_3)	72 (67, 78)	71 (67, 77)	72 (67, 79)	Z = −1.81	0.07
BMI (kg/m^2), M (Q_1, Q_3)	22.20 (20, 24.22)	22.225 (20.09, 24.39)	22.20 (20, 24.22)	Z = −0.37	0.71
Anesthesia time (min), M (Q_1, Q_3)	194 (135, 260)	200 (135, 260)	190 (138, 258)	Z = −0.003	0.99
Operation time (min), M (Q_1, Q_3)	155 (100, 220)	160 (100, 220)	155 (104, 220)	Z = −0.12	0.91
Preoperative ALB (g/L), M (Q_1, Q_3)	39.00 (36.00, 42.95)	39.35 (36.03, 42.98)	39 (36.00, 42.90)	Z = −0.54	0.59
Preoperative CRP (mg/L), M (Q_1, Q_3)	3.00 (2.90, 3.00)	3.00 (2.05, 3.00)	3.00 (3.00, 3.00)	Z = −0.26	0.79
Preoperative Hgb(g/L), M (Q_1, Q_3)	124 (107, 136)	125 (109, 139)	123 (106, 135)	Z = −1.97	0.05
Preoperative WBC (10^9/L), M (Q_1, Q_3)	5.94 (4.70, 7.34)	6.16 (4.84, 7.59)	5.820 (4.67, 7.30)	Z = −2.23	0.06
Preoperative neu (%), M (Q_1, Q_3)	65.30 (57.90, 74.00)	65.55 (58.13, 74.75)	65.30 (57.80, 73.70)	Z = −1.14	0.26
Preoperative lym (%), M (Q_1, Q_3)	23.20 (15.75, 30.20)	22.65 (14.73, 29.70)	23.40 (16.20, 30.40)	Z = −1.82	0.07
Postoperative 24h ALB (g/L), M (Q_1, Q_3)	30.10 (27.00, 34.00)	30.00 (27.533, 33.28)	30.50 (27.00, 34.00)	Z = −0.68	0.50
Postoperative 24h Lym (%), M (Q_1, Q_3)	9.10 (5.50, 13.60)	8.85 (5.30, 12.58)	9.20 (5.70, 14.00)	Z = −1.62	0.11
Postoperative 24h WBC (10^9/L), M (Q_1, Q_3)	9.17 (7.01, 11.48)	9.69 (7.50, 12.03)	8.82 (6.84, 11.34)	Z = −3.17	0.00
Postoperative 24h Neu (%), M (Q_1, Q_3)	84.40 (78.55, 89.10)	84.95 (79.68, 89.38)	84.20 (77.80, 89.00)	Z = −1.90	0.06
Postoperative 24h Hgb (g/L), M (Q_1, Q_3)	112 (97, 124)	116 (97, 126)	112 (97, 122)	Z = −1.72	0.09
Postoperative 24h CRP (mg/L), M (Q_1, Q_3)	3.00 (3.00, 21.60)	3.00 (3.00, 36.78)	3.00 (3.00, 18.30)	Z = −1.27	0.20
PPCs, n (%)				χ^2 = 1.55	0.21
PPC group	278 (21.21)	92 (23.35)	186 (20.28)		
Non-PPC group	1033 (78.80)	302 (76.65)	731 (79.72)		
Sex, n (%)				χ^2 = 0.43	0.51
Male	821 (62.62)	252 (63.96)	569 (62.05)		
Female	490 (37.38)	142 (36.04)	348 (37.95)		
Smoking, n (%)				χ^2 = 0.09	0.76
No	1068 (81.47)	319 (80.96)	749 (81.68)		
Yes	243 (18.54)	75 (19.04)	168 (18.32)		

(*Continued*)

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Table 2 (Continued).

Variables	**Total (n = 1311)**	**Validation Set (n = 394)**	**Training Set (n = 917)**	**Statistic**	***P***
Surgical type, n (%)				χ^2 = 0.90	0.34
Emergent	172 (13.12)	57 (14.47)	115 (12.54)		
Non-emergent	1139 (86.88)	337 (85.53)	802 (87.46)		
Surgical approach, n (%)				χ^2 = 0.72	0.40
Open surgery	289 (22.04)	81 (20.53)	208 (22.68)		
Laparoscopy	1022 (77.96)	313 (79.44)	709 (77.32)		
Surgical site, n (%)				χ^2 = 0.90	0.83
Gastrointestinal system	1211 (92.37)	360 (91.37)	851 (92.80)		
Hepatobiliary system	45 (3.43)	16 (4.06)	29 (3.16)		
Urological system	37 (2.82)	12 (3.05)	25 (2.73)		
Female reproductive system	18 (1.37)	6 (1.52)	12 (1.31)		
Preoperative lung condition, n (%)				χ^2 = 0.05	0.83
Abnormal	261 (19.91)	77 (19.54)	184 (20.07)		
Normal	1050 (80.09)	317 (80.46)	733 (79.94)		
Preoperative comorbidities (except pulmonary diseases), n (%)				χ^2 = 0.34	0.56
No	992 (75.67)	294 (74.62)	698 (76.12)		
Yes	319 (24.33)	100 (25.38)	219 (23.88)		
Analgesic methods, n (%)				χ^2 = 7.90	0.10
PCIA	1024 (78.11)	295 (74.87)	729 (79.50)		
PCIA+TAP	236 (18.00)	80 (20.31)	156 (17.01)		
PCEA	14 (1.07)	3 (0.76)	11 (1.20)		
TAP	12 (0.92)	7 (1.78)	5 (0.55)		
No	25 (1.91)	9 (2.28)	16 (1.75)		
No extubation within postoperative 24 h, n (%)				χ^2 = 5.85	0.12
No	1301 (99.24)	387 (98.22)	914 (99.67)		
Yes	10 (0.76)	7 (1.78)	3 (0.33)		

Abbreviations: M, median; Q_1, 1st quartile, Q_3, 3rd quartile; BMI body mass index; ALB albumin level; Lym lymphocyte percentage; WBC white blood cell count; Neu neutrophil ratio; Hgb hemoglobin level; CRP C-reactive protein; PCEA patient-controlled epidural analgesia; PCIA patient-controlled intravenous analgesia; TAP transversus abdominis plane block, CRP C-reactive protein.

Table 3 Univariate Logistic Regression Analysis of Risk Factors of PPCs in Elderly Patients

Variables	β	Standard Error	Z	*P*	Odds Ratio (95% CI)
Preoperative ALB	−0.02	0.01	−1.38	0.169	0.98 (0.95~1.01)
Postoperative 24h ALB	−0.02	0.01	−1.17	0.241	0.98 (0.96~1.01)
Preoperative Lym	−0.14	0.02	−7.15	<0.001	0.87 (0.84~0.90)
Preoperative WBC	0.33	0.03	11.33	<0.001	1.40 (1.32~1.48)
Preoperative Neu	0.09	0.01	6.80	<0.001	1.09 (1.07~1.12)
Postoperative 24h Hgb	0.01	0.00	1.21	0.224	1.01 (1.00~1.01)
Postoperative 24h CRP	−0.00	0.00	−1.49	0.137	1.00 (0.99~1.00)
Surgical site					
Gastrointestinal system					1.00 (reference)
Female reproductive system	1.94	0.59	3.27	0.001	6.95 (2.18~22.21)
Urological system	2.36	0.44	5.37	<0.001	10.55 (4.47~24.92)
Hepatobiliary system	2.57	0.43	6.03	<0.001	13.03 (5.66~30.01)
Preoperative lung condition					
Abnormal					1.00 (reference)
Normal	−0.99	0.18	−5.41	<0.001	0.37 (0.26~0.53)

(*Continued*)

Table 3 (Continued).

Preoperative comorbidities (except pulmonary diseases)					
No					1.00 (reference)
Yes	1.26	0.17	7.22	<0.001	3.53 (2.51~4.98)
Analgesic methods					
PCIA					1.00 (reference)
PCEA	1.46	0.61	2.38	0.017	4.32 (1.30~14.39)
PCIA+TAP	1.19	0.19	6.21	<0.001	3.30 (2.26~4.80)
TAP	1.24	0.92	1.35	0.177	3.46 (0.57~20.92)
No	−0.30	0.76	−0.39	0.694	0.74 (0.17~3.30)

Abbreviations: ALB, albumin level; Lym, lymphocyte percentage; WBC, white blood cell count; Neu, neutrophil ratio; Hgb, hemoglobin level; CRP, C-reactive protein; PCEA, patient-controlled epidural analgesia; PCIA, patient-controlled intravenous analgesia; TAP, transversus abdominis plane block.

Table 4 Multivariate Logistic Regression Analysis of Risk Factors of PPCs in Elderly Patients

Variables	β	Standard Error	Z	*P*	Odds Ratio (95% CI)
Intercept	−7.60	1.06	−7.18	<0.001	0.00 (0.00 ~ 0.00)
Preoperative WBC	0.36	0.04	10.13	<0.001	1.43 (1.33 ~ 1.53)
Preoperative Neu	0.03	0.01	2.59	0.010	1.03 (1.01 ~ 1.06)
Surgical site					
Gastrointestinal system					1.00 (reference)
Female reproductive system	0.97	0.73	1.32	0.187	2.64 (0.63 ~ 11.14)
Urological system	2.43	0.53	4.56	<0.001	11.38 (4.00 ~ 32.34)
Hepatobiliary system	2.50	0.55	4.59	<0.001	12.24 (4.20 ~ 35.64)
Preoperative lung condition					
Abnormal					1.00 (reference)
Normal	−1.01	0.24	−4.21	<0.001	0.36 (0.23 ~ 0.58)
Preoperative comorbidities (except pulmonary diseases)					
No					1.00 (reference)
Yes	1.29	0.23	5.67	<0.001	3.65 (2.33 ~ 5.71)

Abbreviations: WBC, white blood cell count; Neu, neutrophil ratio.

With the PPC nomogram model, the ROC curve was drawn, and the AUC was 0.88 (95% CI: 0.85~0.90), the sensitivity was 75.4%, and the specificity was 87.6% (Figure 3A). This indicates that the nomogram model could well distinguish elderly patients with PPCs from non-PPC patients. The internal verification of the PPC nomogram model was based on the data of the verification group. As shown in Figure 3B, the AUC was 0.86 (95% CI: 0.82~0.90), the sensitivity was 94.4%, and the specificity was 62.6%. This indicates that the nomogram model has good discrimination and accuracy. The good consistency between the calibration curve.

The calibration curve of the PPC nomogram model was close to the standard curve, and the test result showed a *P* value equal to 0.36 (Figure 4A) and the standard curve indicates no significant difference between the predicted probability and actual probability of PPCs (Figure 4B). This indicates that consistency is present between the predicted probability and actual probability of PPCs.

The clinical decision curve can evaluate the application value of a predictive model in clinical practice, and its analysis of our prediction model indicates the high clinical practicability of the model (Figure 5A).

The Hosmer-Lemeshow test showed the predictive efficiency of the PPC nomogram in the patient cohort ($P = 0.145$) and the clinical decision curve analysis showed its prediction range (Figure 5B). This indicates the good clinical application of the PPC nomogram model.

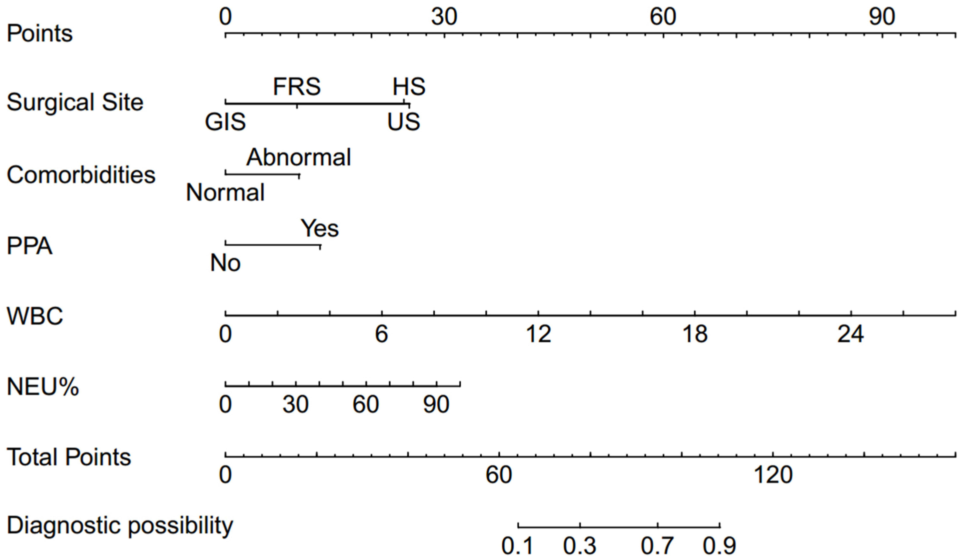

Figure 2 The nomogram used to predict PPCs following laparoscopic surgery in elderly patients.
Abbreviations: GIS, gastrointestinal system, HBS hepatobiliary system, US, urological system, FRS, female reproductive system. PPA, preoperative pulmonary abnormalities, WBC, preoperative 24h white blood cell count, NEU%, preoperative 24h neutrophil percentage.

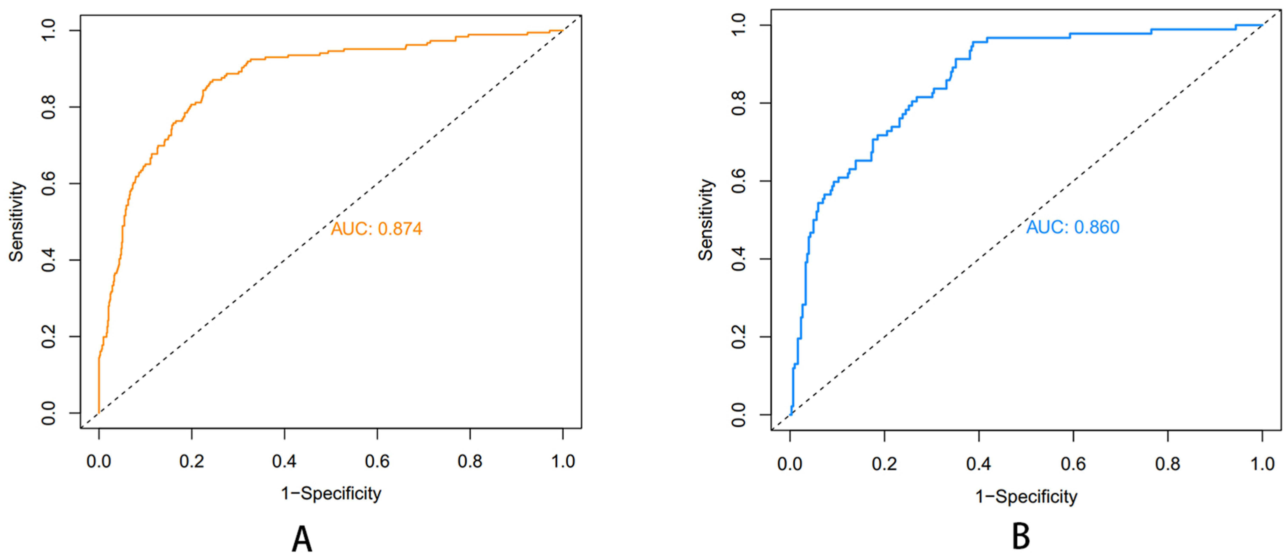

Figure 3 The areas under the receiver operating characteristic curve of the nomogram used to predict PPCs following laparoscopic surgery in elderly patients in the (**A**) training and (**B**) validation cohorts.

Discussion

The five key predictors of PPCs in elderly patients after laparoscopic surgery obtained in this work, namely surgical site, preoperative comorbidities (except pulmonary diseases), preoperative pulmonary abnormalities, preoperative white blood cell count, and preoperative neutrophil percentage. The high AUC (88%) reached with the simplified scoring system fully indicates the scoring system's excellent ability to identify patients with PPC risk. It is worth mentioning that this risk prediction scoring is based on a few accessible variables and thus can serve as an effective evaluation tool for patients in an unknown condition, especially in emergency surgery.

The incidence rate of PPCs in this study is 21.31%, consistent with most previous reports,[1,4,7,10–13] but higher than that in some studies.[14] The difference in incidence may be explained by differences in research methods, treatment

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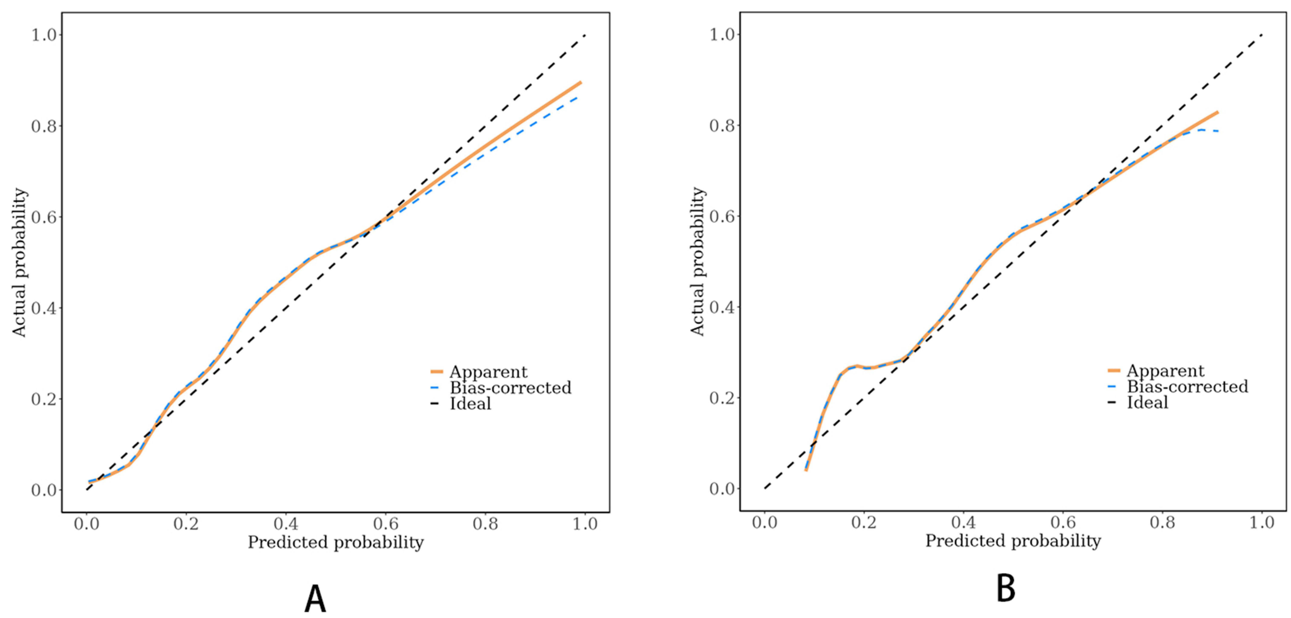

Figure 4 The calibration curves of the nomogram used to predict PPCs following laparoscopic surgery in elderly patients in the (**A**) training and (**B**) validation cohorts.

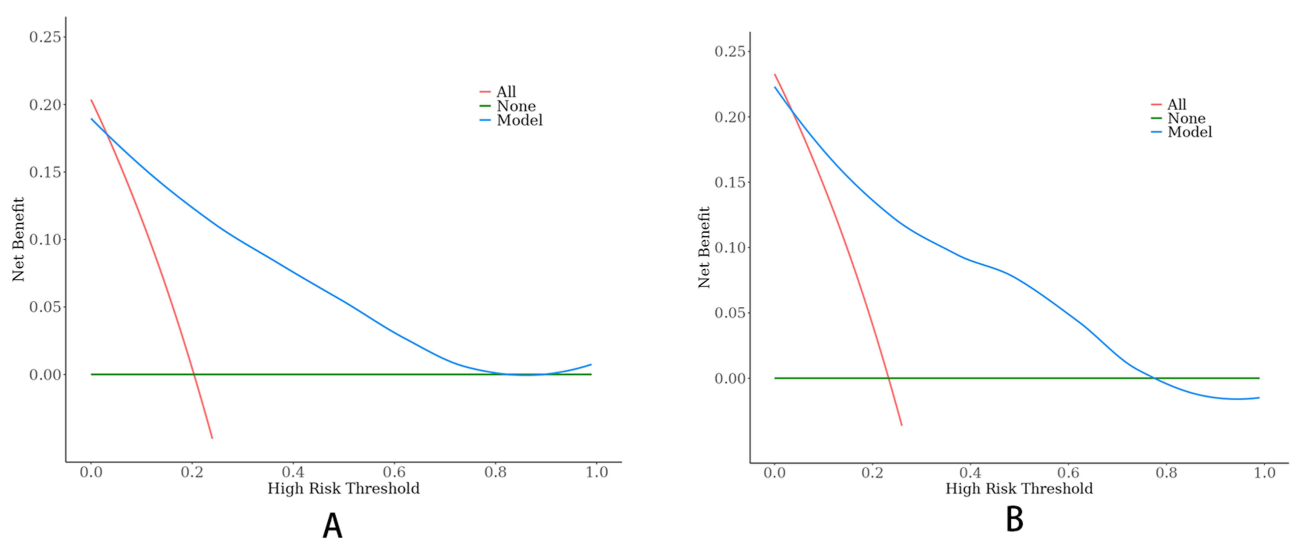

Figure 5 The clinical decision curves of the nomogram used to predict PPCs following laparoscopic surgery in elderly patients in the (**A**) training and (**B**) validation cohorts.

institutions, diagnostic criteria for pulmonary complications, and perioperative management. In this study, we classified the abnormal imaging manifestations and clinical symptoms of the lungs such as cough and expectoration as preoperative pulmonary abnormalities, which have been included as an important predictor of PPCs. Pulmonary abnormalities often lead to enhanced local airway reactivity and lung function changes and may be accompanied by infection or residual immune damage caused by antibiotic use; pulmonary infection is becoming more common among patients in the post-epidemic period.[15,16] The post-pandemic focus accounts for potential lingering effects of SARS-CoV-2 infection (eg, subclinical lung injury, immune dysfunction) and healthcare system adaptations (eg, reduced preoperative screening) that may influence PPCs risk. Older patients with basic diseases, extensive lung lesions, and hypoalbuminemia are more prone to lung infections.[17] These indicators, relatively easy to obtain through routine examination and medical history

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inquiry, are of great significance in condition evaluation. As to whether the incidence of PPCs in patients before and after the COVID-19 epidemic has increased, we are currently conducting a more in-depth comparative study.

Surgical trauma and diseases can trigger inflammatory reactions in the body. Neutrophils and leukocytes play essential roles in the inflammatory process and immune regulation and can be used as predictors of postoperative inflammatory state in the lungs.[18] In recent years, the neutrophil-lymphocyte ratio and systemic immune-inflammation index (the ratio of total platelet and neutrophil count to lymphocyte count) have been used as indices to evaluate immune status and disease susceptibility and can reflect the early PPCs of elderly patients to facilitate early diagnosis and treatment.[18–20] In this study, patients with PPCs had significantly higher preoperative white blood count and neutrophil count than the non-PPC ones, indicating the predictive potential of the two indicators. These variables can be obtained by routine blood tests before an operation, and their significance deserves further evaluation.

This study highlights the significant influence of surgical sites on the incidence of PPCs. Our study involves different laparoscopic surgical procedures of the hepatobiliary system, gastrointestinal system, female reproductive system, urological system, etc., and specifically points out that the proximity of incision position to the chest and diaphragm is one of the key factors for predicting the risk of PPCs. Besides, we found that those incisions closer to the upper abdomen in laparoscopic surgery were significantly associated with the increased incidence of PPCs, consistent with previous reports.[21–23] The closer the incision is to the diaphragm, the more likely the ventilator will be interrupted. Meanwhile, pain will limit chest movement and clamp the diaphragm, aggravate respiratory dysfunction, and increase the risk of PPCs such as atelectasis and infection. Due to complicated procedures such as hepatobiliary and gastrointestinal surgery, prolonged surgery will increase the patients' physiological burden and may trigger more inflammatory responses and immune suppression, thus further increasing the risk.[23] Therefore, less operation time and reasonable postoperative analgesia for laparoscopic surgery can reduce postoperative complications.

In addition to lung diseases like chronic obstructive pulmonary disease and asthma, preoperative comorbidities such as hypertension, diabetes mellitus, heart disease, congestive heart failure, and chronic liver disease are predictive indicators of PPCs in elderly patients undergoing laparoscopic surgery in this study. Previous studies have confirmed the significant association of preoperative comorbidities with PPCs in elderly patients. Zingg et al found that the odds ratio of PPC risk in patients with preoperative comorbidities reached 1.35 and their postoperative hospitalization time was extended to 29.1 days,[24] while the time in patients without preoperative comorbidities was only 16.3 days.[25] Chronic endothelial dysfunction may present in elderly patients with hypertension and increases their risk of PPCs. Patients with diabetes mellitus are more prone to PPCs after surgery, which may be related to the immune cells whose subpopulation of lung-derived dendritic cells coordinate the immune response to infection; these cells can be seriously damaged when diabetic animals are exposed to high glucose levels (hyperglycemia), which damages the downstream immune induction and increases infection risk.[26] These findings provide an important basis for clinical intervention and prevention.

Analgesic methods are not included in the prediction model, but the incidence of PPCs differs with different analgesic methods for laparoscopic surgery, and multi-modal analgesia can significantly reduce patients' PPCs.[3,27,28] This study found that the combination of patient-controlled intravenous analgesia and transversus abdominis plane block could reduce the incidence of PPCs (18%), consistent with previous studies.[29] Multi-modal analgesia can enhance post-operative activities, ensure effective cough and expectoration, and alleviate immunosuppression and immune damage caused by surgical trauma, thus reducing PPCs. It is worth noting that not all analgesic methods bring positive effects. Opioids may have a series of negative effects on patients undergoing surgery by regulating the interaction of the hypothalamic-pituitary-adrenal axis with the autonomic nervous system/immune system, or directly acting on opioid receptors on immune cells' surface.[30] Therefore, patients' actual condition should be considered when applying appropriate multi-modal analgesia in clinical surgery.

This study has the following limitations. First, the data came from two hospitals, and various confounding factors would inevitably interfere with data collection. Second, the definition of pulmonary complications has not been globally unified and the differences in definition may lead to inconsistent conclusions between reports. In addition, the predictive ability of the nomogram needs to be further confirmed by more external verification and prospective research. Furthermore, because the occurrence of PPCs in elderly patients is affected by many factors, including surgical techniques, hardware facilities, and surgical medications, the possible bias in the study could omit some important variables such as intraoperative ventilation mode. Our cohort was exclusively Asian populations, reflecting local demographics. Caution is warranted when extrapolating results to other ethnicities due to potential genetic, environmental, and healthcare disparities. To further improve and verify the model variables, more large-scale, multi-center, high-quality research is needed to more comprehensively reveal the risk factors and protective factors of PPCs in elderly patients.

Conclusion

In conclusion, surgical site, preoperative comorbidities (except pulmonary diseases), preoperative pulmonary abnormalities, preoperative WBC, and preoperative neutrophil percentage are all independent risk factors for PPCs in elderly patients after laparoscopic surgery in the post-epidemic period. Based on this, we build a risk prediction scoring system that is convenient for clinical application and has a solid foundation in statistics. Such a scoring system will enable clinicians to identify risk factors of PCCs more accurately and help formulate more effective perioperative prevention strategies.

Data Sharing Statement

The individual de-identified participant data supporting published results, the study protocol, and the statistical analysis plan are available from the corresponding author upon reasonable request.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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