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Development and validation of a nomogram for predicting postoperative pulmonary complications in older patients undergoing noncardiac thoracic surgery: a prospective, bicentric cohort study

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Abstract

Background The ARISCAT score, a prospectively developed generic classification for postoperative pulmonary complications (PPCs), has shown excellent predictive performance in general surgery. However, there is no reliable classification instrument for PPCs prediciton in thoracic surgery.

Objective This study aimed to develop and validate a novel nomogram for estimating the risk of pulmonary complications in older patients (≥ 65 years) within 30 days after NCTS.

Methods A nomogram was developed using predefined candidate predictors of 30-day PPCs. It was fitted with least absolute shrinkage and selection operator and logistic regression methods. Internal validation was performed using a bootstrap-resampling approach, while external validation used an independent, temporally separated cohort. The model's performance was assessed based on its discriminative potential (area under the receiver operating characteristic curve [AUC]), predictive ability (calibration plots), and clinical utility (net benefit).

Results In the development (n = 1449) and validation (n = 449) cohorts, 34.9% and 31.4% of patients, respectively, developed pulmonary complications 30 days post-surgery. The final nomogram incorporated eight predictors (age, surgical approach, desaturation of < 92% for more than 2 min, duration of surgery, smoking status, FEV_1/FVC%, respiratory infection in the last 30 days, and neoadjuvant chemotherapy). The nomogram showed excellent discrimination (AUC = 0.866, 95% confidence interval [CI], 0.846–0.885), calibration (Hosmer- Lemeshow test, P = 0.97) and overall performance (Brier score = 0.014) in the development cohort. Similar results were observed in the external validation cohort (AUC = 0.825, 95% CI, 0.786–0.864). A decision curve analysis indicated that the nomogram offers a positive net benefit compared with the ARISCAT and LAS VEGAS scores.

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Conclusions This novel nomogram can reliably identify older patients with a high risk for pulmonary complications within 30 days after NCTS.

Trial registration ChiCTR2100051170.

Keywords Older patients, Noncardiac thoracic surgery, Postoperative pulmonary complications, Prediction

Background

In 2022, China recorded over 1.3 million cases of thoracic cancer, particularly lung and esophageal cancer, with a significant proportion occurring in older patients (aged 65 and above) [1–3]. Surgical excision remains the best curative option for thoracic cancer [4]. Pulmonary complications are common and potentially fatal after thoracic surgery, with prevalence rates ranging from 20–60%, depending on definitions and patient populations [5–7]. Postoperative pulmonary complications (PPCs) contribute significantly to attributable morbidity, mortality, and healthcare costs, especially fin older patients [7–10].

Minimizing the risk of PPCs is crucial for patients scheduled for noncardiac thoracic surgery (NCTS). However, accurately identifying patients at intermediate and high risk of PPCs remains challenging, limiting the effectiveness of clinical guidance and targeted monitoring and preventive interventions [11]. Several prediction models for PPCs have been proposed. The "Assess Respiratory Risk In Surgical Patients In Catalonia" (ARISCAT) score, despite of the best-performing model, was derived from a broad demographic of surgical patients and specialties and may not accurately assess patients recovering from NCTS with specific risks (such as reduced lung parenchyma function, impaired mucociliary clearance, and pain-related inhibition of the respiratory muscles). Moreover, the ARISCAT score does not include intraoperative variables and has not been updated since its introduction in 2010, potentially underestimating contemporary morbidity [12]. Furthermore, external validation of the ARISCAT score in a trial based on a large European data registry showed varying performances across different geographic populations, raising concerns about its applicability to a Chinese population without specific validation [13]. Other predictive models have not been routinely adopted in thoracic surgery, primarily due to inconsistent outcome definitions, limited external validation, absence of one-lung ventilation (OLV)-related factors, and challenges in integrating stratified care into clinical practice [11, 14–19]. Additionally, a 2022 systematic review and external validation study revealed that few existing models had undergone external validation, and none showed acceptable performance. Specifically, none achieved a lower 95% confidence interval (CI) estimate for area under the receiver operating characteristics curve (AUC) of ≥ 0.7. All risk scores reported in the external validation were at a high or unclear risk of bias [11]. Subsequently, the same research group assessed the risk of PPCs in adults undergoing elective surgery using the GSU-Pulmonary Score; however, its superior performance was limited to abdominal surgery [20].

This study aims to develop and validate, both internally and externally, a novel nomogram for estimating the risk of pulmonary complications in older patients within 30 days after NCTS.

Methods

The study protocol was published before the analysis, and its deviations were documented in Supplementary Digital Content S1 [21].

Ethics

The study protocol adhered to the guidelines outlined in the Declaration of Helsinki and was approved by the Institutional Review Boards of the Guangzhou Institute of Cancer Research, the Affiliated Cancer Hospital, Guangzhou Medical University (IRB number 202111ZN), and the second Affiliated Hospital of Guangzhou University of Chinese Medicine (IRB number 202220001). All patients received verbal and written information about the study and the use of perioperative data during the preoperative anesthesia assessment, and provided written consent.

Perioperative management

Intraoperative management was at the discretion of the treating anesthesiologist according to institutional practice. A standardized institutional ERAS protocol was recommended for all patients, as described in previous studies [22]. As well, pre-rehabilitation strategies were prescribed to patients who were at intermediate- to high-risk based on ARISCAT scores [12].

Data acquisition

All preoperative and intraoperative data from the anesthesia Information System and patient records of the hospital were collected prospectively by independent investigators blinded to the outcome evaluation. The investigators collected routine, anonymized data without changing the clinical care pathways and uploaded them to the Epidata V.4.6 database. For the development

cohort, we included patients aged 65 years and above who underwent NCTS with general anesthesia and OLV between 8 October, 2021 and 30 April, 2023 at the Guangzhou Institute of Cancer Research, the Affiliated Cancer Hospital, Guangzhou Medical University. For the external validation cohort, we analyzed eligible patients between 4 May, 2023 and 30 April, 2024 at the Second affiliated Hospital of Guangzhou University of Chinese Medicine. The exclusion criteria for both cohorts were an American Society of Anesthesiologists (ASA) physical status classification of 5, reoperation due to postoperative complications, scheduled postoperative admission to the intensive care unit (ICU), and a life expectancy of < 30 days due to extensive tumour metastasis. Patients who missed their follow-up appointments after surgery were also excluded.

We considered both preoperative (demographic characteristics and comorbidity status) and intraoperative predictor variables for the development of nomogram based on the investigators' consensus on measurable variables and the results of previous study results [21]. A detailed questionnaire on predictor variables and definitions is provided in Supplementary Digital Content S2.

Outcomes

The primary outcome was the occurrence of pulmonary complications within 30 days after surgery. The following pulmonary complications, defined based on the Standardized Endpoints in Perioperative Medicine Core Outcome Measures in Perioperative and Anesthetic Care (StEP-COMPAC), were recorded: atelectasis, respiratory failure, acute respiratory distress syndrome, pneumonia, pleura effusion, contralateral pneumothorax, bronchospasm, aspiration pneumonitis, and unplanned or prolonged invasive mechanical ventilation [23]. Additionally, we included prolonged oxygen supplementation and chest tube-dwelling as thoracic surgery-specific complications (Supplementary Digital Content S3). From the day of surgery until postoperative day 30, patients were monitored daily by a trained registered nurse anesthetist, either at the bedside or by phone (if discharged). The secondary outcomes included postoperative length of hospital stay (LOS) and 30-day and 90-day mortality.

Sample size

Based on previous literature and a retrospective study at our center, the anticipated incidence of 30-day PPCs in a mixed cohort of older patients undergoing thoracic procedures was approximately 40% [24, 25]. To estimate the required sample size for a logistic regression model, we followed the principle of 10 events per variable (EPV). Initially, we aimed for a development cohort of at least 1000 patients. However, once this target sample size was reached, the observed incidence of 33.6% was lower than expected, resulting in an effective EPV value of approximately 7.6. Consequently, we adjusted the sample size in the development cohort to at least 1440 patients based on the observed incidence and an EPV value of 10, while accounting for a 10% attrition rate. For external validation, assuming an AUC of 0.8 and a 30% outcome rate, we determined that 440 patients would be needed, accounting for the 10% attrition rate [26].

Statistical analyses

The categorical characteristics of the participants in the development and validation cohorts were compared using Pearson's Chi-squared test, Fisher's exact test, or Kruskal-Wallis test. Differences in continuous variables between cohorts were evaluated using an independent Student's t-test or Wilcoxon rank-sum test, depending on the normality of the data. All hypothesis tests were two-tailed, with a priori significance set at $P < 0.05$.

For the initial assessment of unadjusted associations between potential predictor variables and PPCs, univariable logistic regression analyses were conducted. Collinearity was assessed using the variance inflation factor (VIF). In cases of collinearity among a few variables, clinical judgement was applied to select the most relevant variables for inclusion in the multiple regression model. Variables with P-values < 0.05 in the unadjusted univariable logistic models were retained for further consideration. The selected predictor variables were then analysed using the least absolute shrinkage and selection operator (LASSO) regression algorithm, with 10-fold cross-validation employed to determine the optimal tuning parameters (λ). Then, the most significant variables identified by the LASSO regression from the development dataset were used in multivariable logistic regression analyses to develop the most parsimonious model (i.e., easy to use). Finally, predictor variables with P-values < 0.05 in the multivariable logistic regression were incorporated into a nomogram to estimate the probability of PPCs. After constructing the nomogram, internal and external validations were performed in the development and validation cohorts, respectively. Internal validation of the nomogram was assessed using the bootstrap resampling technique with 1000 repetitions. For each bootstrap sample, we refitted and tested the nomogram on the development set to estimate predictive accuracy and correct for bias. To strengthen the generalisability of the nomogram, we conducted temporal external validation using an independent cohort.

Once derived, the predictive performance of the nomogram in both the development and validation cohorts was evaluated using recommended best practices. Nomogram discrimination was assessed using the AUC (mean,

95% CI), with a value > 0.8 indicating strong discrimination. We further calibrated the nomogram using a calibration plot. The Hosmer-Lemeshow test with a P value > 0.05 indicates good calibration. The overall accuracy of the nomogram was measured using the Brier score. Additionally, a decision curve analysis was conducted to evaluate the net benefit of the nomogram, considering the value and consequences of interventions based on the predictions. These results were compared with the performance of the previously published ARISCAT and Local ASsessment of VEntilatory management during General anesthesia (LAS VEGAS) scores in the overall cohort.

In the exploratory analyses, we examined the association between PPCs and other outcomes, including postoperative LOS and 30-day and 90-day mortality. We used the Mann-Whitney U test to compare postoperative LOS between patients with and without PPCs. The Kruskal-Wallis test was used to compare postoperative LOS across groups according to the number of PPCs (0, 1, 2–3, or ≥4). The Mantel-Haenszel test was used to analyse trends in 30-day and 90-day mortality in the groups based on the number of PPCs.

All analyses were conducted using R statistics V.4.2.2 (R Project for Statistical Computing).

Data processing and missing data

We applied several validated preprocessing algorithms to each patient's electronic case report forms (eCRFs) and medical records containing heterogeneous variables to address outliers, missing values, and normalization. Data on the primary outcome were complete for all participants. Our prespecified approach was to conduct a complete case analysis for predictor variables with missing values ≤ 5%. Predictor variables with missing values > 5% were excluded from the main analysis. For predictor variables < 5% missing values, we used random forest imputation with the missForest package to handle missing data. The proportions of missing values for potential predictors are reported in Supplementary Digital Table S1.

Quality assurance

To assess the quality of the patient recruitment process and data collection, an independent observer audited the CRFs of a random sample of 190 patients (10% of the overall cohort) from both centers. In each center, the number of patients audited was proportional to the number of patients recruited, with 145 patients audited from the development center and 45 patients from the validation center. This audit confirmed that the eligibility criteria were applied correctly. The data sample included 85 items per patient, covering all predictors and outcomes used in the model. The audited identified 183 instances (1.13% of the audited data) of missing data or errors, primarily involving continuous variables for the OLV period. General training sessions were held to instruct the investigators on how to complete the structured questionnaire and to identify the PPCs recorded in the charts.

Results

Study population

We assigned 1655 patients aged 65 and above, who underwent NCTS between 8 October, 2021 and 30 April, 2023, to the development cohort. In total, 35 patients who declined enrollment, 4 who required additional surgery during the follow-up, 25 who were scheduled for postoperative ICU admission, 2 with life expectancy of < 30 days, and 340 with missing information, were excluded. For the external validation cohort, we identified 523 patients aged 65 and above who underwent NCTS from 4 May, 2023 to 30 April, 2024. In total, 12 patients who declined enrollment, 2 who underwent additional surgery during the follow-up, 7 who were scheduled for postoperative ICU admission, 1 with a life expectancy of < 30 days, and 173 with missing information, were excluded. The final development and validation cohorts comprised 1449 and 449 patients, respectively. The flowchart of study is shown in Fig. 1.

Patient demographics and clinical characteristics were generally comparable in both the development and validation cohorts (Supplementary Digital Table S2). No differences were observed in the incidence of a composite of PPCs or any component of PPCs between the cohorts (Supplementary Digital Table S3).

Proposed nomogram for PPCs

The results of the LASSO regression analysis of the independent variables are provided in Supplementary Digital Table S4. Some significant variables, such as duration of anesthesia and OLV, were excluded due to high collinearity with duration of surgery, as indicated by the VIF values (Supplementary Digital Table S5). Preoperative SpO_2 < 95%, functional status, asthma, fluid therapy, ventilation mode, and the fraction of inspired oxygen showed no significant association with PPCs (P > 0.05) (Supplementary Digital Table S6). Finally, eight predictors were selected based on non-zero coefficients from the LASSO regression analysis (Supplementary Digital Fig. S1a-b).

Moreover, eight independent predictor variables of PPCs—age, surgical approach, desaturation of < 92% for more than 2 min, duration of surgery, smoking status,

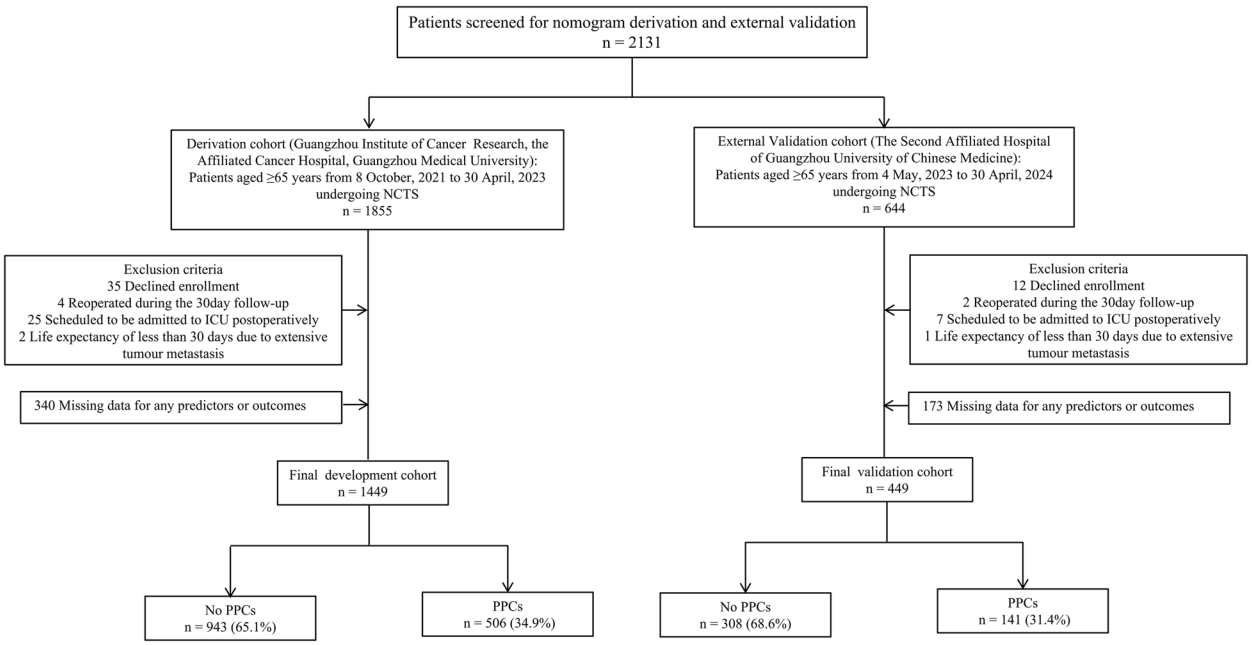

Fig. 1 Study flowchart. NCTS, noncardiac thoracic surgery; ICU, intensive care unit; PPCs, postoperative pulmonary complications

Table 1 Final multivariable model of predictor variables associated with postoperative pulmonary complications in the development cohort

Variables	β (SE)	aOR (95% CI)	*P* values
Age, year	0.064 (0.014)	1.066 (1.038–1.096)	<0.001
Approach of surgery			
RATS	[1 Ref]	[1 Ref]	
VATS	0.834 (0.167)	2.301 (1.664–3.203)	<0.001
Thoracotomy	2.082 (0.241)	8.020 (5.028–12.94)	<0.001
Desaturation of < 92% for more than 2 min	1.028 (0.202)	2.795 (1.881–4.163)	<0.001
Duration of surgery, min	0.005 (0.001)	1.005 (1.003–1.006)	<0.001
Smoking status			
Never	[1 Ref]	[1 Ref]	
Former	1.227 (0.159)	3.412 (2.508–4.671)	<0.001
Current	1.998 (0.238)	7.376 (4.653–11.84)	<0.001
FEV_1/FVC %			
≥75	[1 Ref]	[1 Ref]	
50–75	0.565 (0.179)	1.759 (1.237–2.500)	<0.001
< 50	2.021 (0.369)	7.547 (3.752–16.05)	<0.001
Respiratory infection in the last 30 days	1.203 (0.198)	3.329 (2.264–4.926)	<0.001
Neoadjuvant chemotherapy	1.212 (0.154)	3.361 (2.488–4.556)	<0.001

RATS robotic-assisted thoracic surgery, *VATS* video-assisted thoracic surgery, *FEV_1* forced expiratory volume in 1 second, *FVC* forced vital capacity, *β,* β estimates, *SE* standard error, *aOR* adjusted odds ratio, *CI* confidence interval

FEV_1/FVC%, respiratory infection in the last 30 days, and neoadjuvant chemotherapy—were identified using multivariable logistic regression. The adjusted odds ratios and coefficients for these variables are shown in Table 1.

Figure 2 shows the proposed nomogram, which incorporates eight variables with 14 attributes. Each attribute within these variables was assigned a score on the

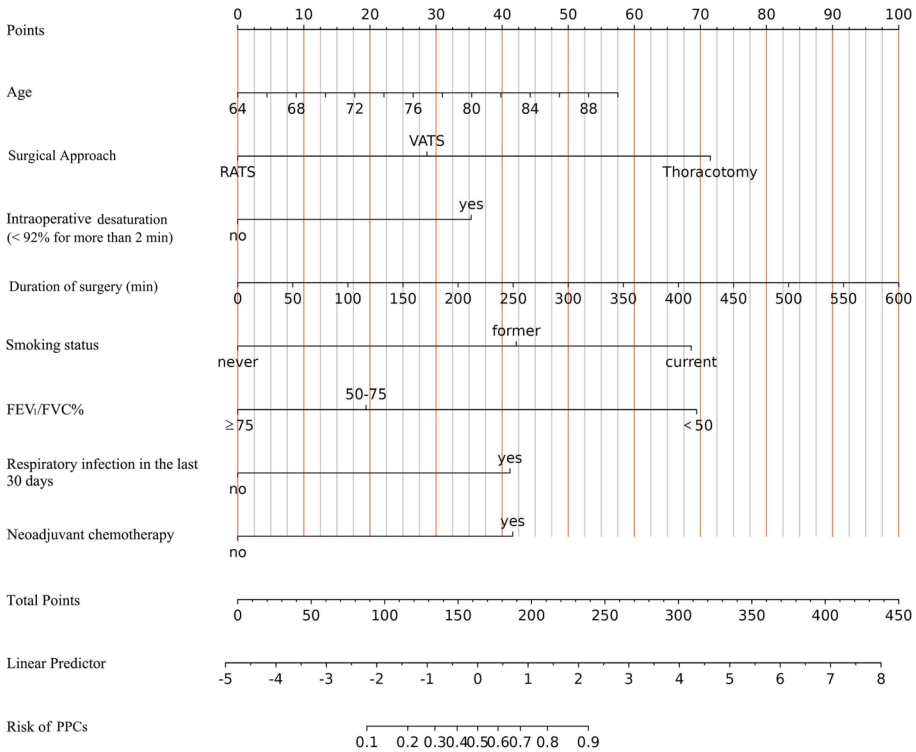

Fig. 2 Derived nomogram. FEV_1, forced expiration volume in 1 second; FVC, forced volume capacity; PPCs, postoperative pulmonary complications. VATS, video-assisted thoracic surgery; RATS, robotic-assisted thoracic surgery

point scale. By summarizing each score, the corresponding probability of PPCs can be determined from the nomogram.

Nomogram performance in the development cohort

The nomogram exhibited strong discrimination with an AUC value of 0.866 (95% CI: 0.846–0.885) (Fig. 3a). Calibration plots showed good calibration across the range of predicted and observed incidence of PPCs (Hosmer–Lemeshow test, $P = 0.97$) (Supplementary Digital Fig. S2a). The decision curve analysis showed a net benefit across predicted probability thresholds ranging form 0–92% (Fig. 4a). The scaled Brier score was 0.014 (95% CI: 0.013–0.015). Internal validation with 1000 bootstrap resampling analyses revealed strong discrimination (mean AUC = 0.862, 95% CI: 0.841–0.882) (Supplementary Digital Fig. S3).

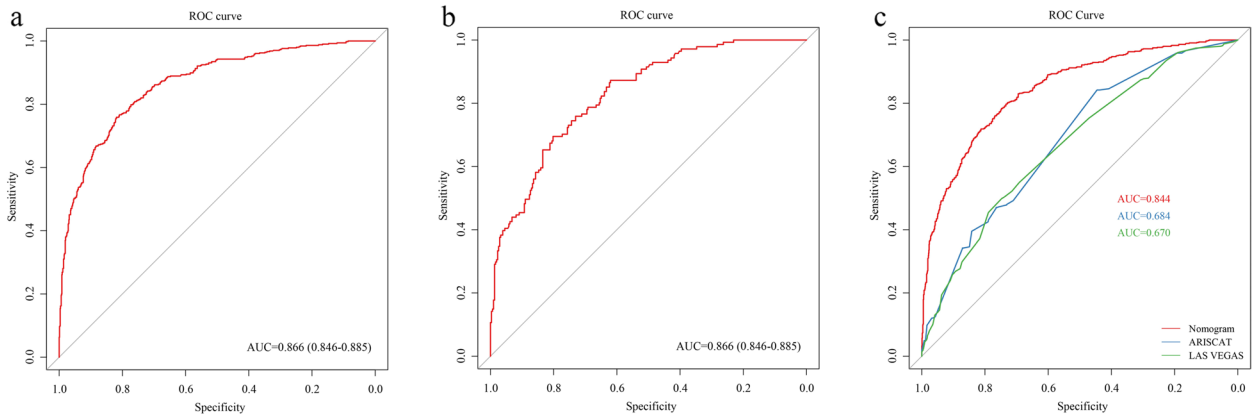

Fig. 3 Discriminative ability of the nomogram (Red) in the development cohort (a), external validation cohort (b), and in comparison with the ARISCAT (Blue) and LAS VEGAS (Green) scores (c). ROC, receiver operating characteristic; AUC, area under the ROC curve; ARISCAT, Assess Respiratory Risk In Surgical Patients In Catalonia; LAS VEGAS, Local ASsessment of VEntilatory management during General AneSthesia

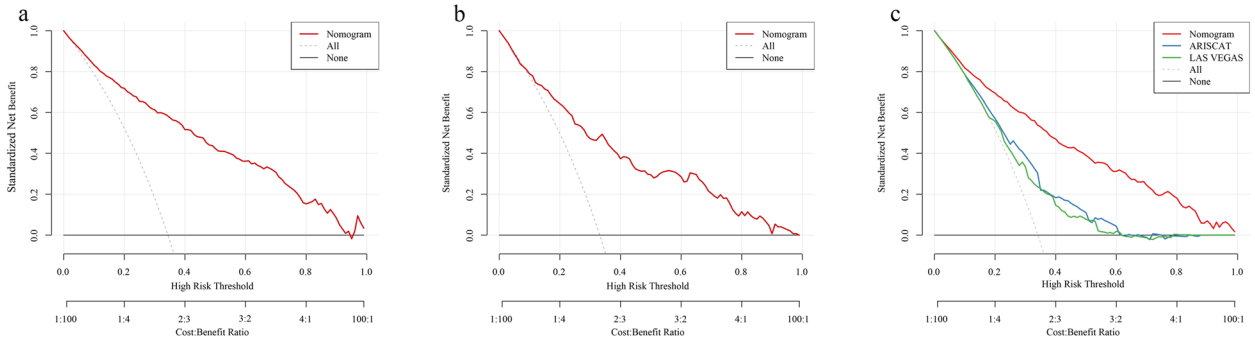

Fig. 4 Decision curve analysis (DCA) plots of the nomogram (Red) in the development cohort (a), external validation cohort (b), and in comparison with the ARISCAT (Blue) and LAS VEGAS (Green) scores (c). PPCs, postoperative pulmonary complications; ARISCAT, Assess Respiratory Risk In Surgical Patients In Catalonia; LAS VEGAS, Local ASsessment of Ventilatory management during General AneSthesia

Nomogram performance in the external validation cohort

The external validation of the nomogram consistently revealed strong discrimination, with an AUC value of 0.825 (95% CI: 0.786–0.864) (Fig. 3b) and good calibration (Hosmer–Lemeshow test, $P = 0.160$) (Supplementary Digital Fig. S2b). The decision curve analysis indicated a net benefit across predicted probability thresholds ranging from 0–99% (Fig. 4b). The scaled Bier score was 0.015 (95% CI: 0.013–0.017).

Nomogram performance compared with the ARISCAT and LAS VEGAS scores

In the overall cohort, the nomogram outperformed the ARISCAT and LAS VEGAS scores. The AUC for the nomogram was 0.844, while the AUCs for the ARISCAT and LAS VEGAS scores were 0.689 and 0.672, respectively, with a statistically significant difference ($P < 0.001$) (Fig. 3c). Moreover, the nomogram showed a more significant net benefit compared to both scores across predicted probability thresholds in the decision curve analysis (Fig. 4c).

Exploratory analyses

A total of 1338 PPCs were recorded in 647 patients (34.1%). Atelectasis was the most common complication (15.6%), followed by prolonged chest tube-dwelling (13.4%) and pneumonia (13.3%) (Supplementary Digital Table S3). The highest incidence of PPCs was observed after esophagectomy (51.3%), followed by lobectomy (36.9%), segmentectomy (27%), mediastinal tumour and pericardium resection (19.1%), and wedge resection (16.8%). In absolute terms, lobectomy was associated with the highest number of complications. Detailed information on the characteristics of PPCs and mortality by specialty is presented in Supplementary Digital Table S7. Postoperative LOS, unexpected ICU admission, and mortality increased significantly with the number of PPCs (Table 2).

Discussion

In this prospective cohort study of older patients undergoing NCTS, we developed and validated a risk prediction nomogram for PPCs. The nomogram

Table 2 Postoperative LOS, ICU admission, and mortality according to the number of PPCs

	No.of PPCs				
	0	1	2–3	≥4	Total
No. (%) of patients	1251 (65.9)	301 (15.9)	266 (14)	80 (4.2)	1898 (100)
Postoperative LOS, median (10–90th percentile), d*	7 (4–15)	9 (7–15)	15 (8–19)	21 (9.4–21.6)	8 (4–18)
ICU-admission, n (%)†	8/1251 (1.4)	12/301 (4)	23/266 (8.6)	18/80 (22.5)	61/1898 (3.2)
30-day mortality, n (%)†‡	1/1247 (0.1)	1/299 (0.3)	5/266 (1.9)	5/80 (6.3)	12/1892 (0.6)
90-day mortality, n (%)†‡	1/1231 (0.1)	2/291 (0.7)	5/264 (1.9)	8/76 (10.5)	16/1862 (0.9)

* Kruskal-Wallis test for comparing medians across four groups, $P<0.001$; †Mantel– Haenszel test for assessing the trend across the four groups, $P<0.001$; ‡Missing values were 6 (0.3%) for 30-day mortality and 36 (1.9%) for 90-day mortality in the overall cohort

PPCs, a composite outcome in which one or more postoperative pulmonary complications might be observed, *LOS* length of hospital stay, *ICU* intensive care unit

showed excellent predictive performance in the development cohort (AUC = 0.866, accurate calibration based on observed vs. estimated risk across the risk spectrum). Furthermore, it maintained its performance in the external validation cohort (AUC = 0.825). Altogether, this novel nomogram reliably identifies older patients at high risk for pulmonary complications within 30 days post-NCTS.

PPCs are critical clinical concerns, as thoracic surgery continues to increase in frequency, even beyond the coronavirus disease 2019 (COVID-19) era [11, 27]. Research indicates that even mild PPCs, such as atelectasis, pleural effusion, or even prolonged oxygen supplementation, are associated with increased adverse outcomes [10]. OLV, which by itself is associated with volutrauma, barotrauma, and atelactrauma, usually occurs with other damaging conditions, such as direct surgical injury, ischemia-reperfusion, and surfactant loss [8, 24]. Older patients are more susceptible to pulmonary complications after thoracic surgery due to their age, existing comorbidities, and frailty [28]. The prediction of multifactorial outcomes, such as PPCs, remains challenging despite their commonality and clinical significance in modern surgery [29]. As stated above, existing predictive models have substantial limitations, which motivate our study to design a parsimonious nomogram specifically for older patients at a high risk of pulmonary complications after NCTS. The nomogram achieved superior accuracy compared to the ARISCAT and LAS VEGAS scores, indicating that the performance of PPCs risk models may vary in accuracy depending on the procedure, patient population, institutions, and regions other than those for which they were originally developed.

Consistent with previous findings, we observed modifiable and non-modifiable risk factors independently associated with the development of PPCs [12, 14–19]. Although these factors have been noted in previous studies, their relative impact on outcomes varied, providing a more specific and contemporary measure of their relevance in the studied setting. Despite the potential for biases and methodological concerns in the derivation of the models, the most frequently highlighted variables were those with the most significant clinical significance [30]. Non-modifiable factors, such as age, FEV_1/FVC%, and respiratory infection in the last 30 days, were strongly associated with PPCs, emphasizing the need for enhanced pre-rehabilitation targeting these factors [20, 27, 31, 32]. Modifiable factors, including smoking status, duration of surgery, and intraoperative hypoxemia, offer an opportunity to validate multidisciplinary approaches, such as the early identification of high-risk patients and effective prevention strategies [25, 27].

Some of the predictors we identified may be unrelated to PPCs risk. For example, thoracotomy, associated with higher levels of invasiveness and pain, might explain the increased risk of PPCs through physiological mechanisms [27]. Nevertheless, there remains specific controversy as to whether robotic-assisted thoracic surgery (RATS) provides any measurable clinical advantages to patients when compared with video-assisted thoracic surgery (VATS) [33]. Recent publications from several randomized clinical trials on the effect of the RATS approach on clinical outcomes have shown promising results [34, 35]. The RAVAL trial found that the RATS approach improved early postoperative outcomes, as measured using the health utility index (7 and 12 weeks) compared to the VATS approach after lobectomy [34]. Similarly, the RVlob trial revealed a statistically significant reduction in pain intensity at Week 4 following RATS lobectomy compared to VATS lobectomy, although the clinical significance was limited [35]. Furthermore, the early results of the RAMIE trial indicated that the RATS approach could achieve significantly shorter surgical duration and better lymph node dissection in patients undergoing esophagectomy compared to the VATS approach, potentially leading to improved postoperative outcomes [36].

Neoadjuvant chemotherapy can cause damage to alveolar epithelial cell and pulmonary interstitial, which may increase the patient's risk of respiratory complications after surgery [37]. Consistent with this, neoadjuvant chemotherapy emerged as a predictor of PPCs after adjusting for covariates. Notably, 90% of patients in the overall cohort who received neoadjuvant chemotherapy were also treated with immunotherapy. This treatment might further contribute to surgical morbidity, presumably because immunotherapy is associated with tumour-related inflammation and pulmonary fibrosis [38]. Consistent with previous work, we observed a strong association between neoadjuvant chemoimmunotherapy and hypoxemic acute respiratory failure, an association likely reinforced by the more prolonged surgical procedures [38]. However, further research is needed to explore on the relationship between chemoimmunotherapy and PPCs after NCTS.

Moreover, it is essential to consider unaccounted confounders or collinearity that are not included in our model. For example, ASA classification did not appear in the final model, likely due to the homogeneity of our sample, with over 75% of patients having ASAII. Although ASA classification can provide certain insight into a patient's overall health status, it lacks specificity and objectivity. Accurate prediction requires comprehensive tools that address patient- and procedure-specific factors. Additionally, our study found no significant correlation between ventilatory settings and PPCs, likely because

most of the population followed a lung-protective ventilation protocol recommended in thoracic surgery [24]. The patient population in our study was relatively fit and had largely preserved lung function, which is noteworthy due to the suggestion that patients with poor respiratory function may benefit more from personalized lung-protective ventilation management than those with better preoperative status [12, 13, 39].

Several aspects of our study enhance its clinical relevance. First, to the best of our knowledge, this is the first prospective study to develop and externally validate a nomogram specifically for predicting the probability of PPCs in older patients undergoing NCTS. Second, our nomogram includes easily assessed intraoperative variables, a critical distinction from most previous models that typically focused solely on preoperative predictors. Third, the based our definition of PPCs on StEP-COMPAC, which has reached consensus as a new global standard, ensuring that our analyses are relevant for future perioperative practice and research. Furthermore, we incorporated prolonged oxygen supplementation and chest tube-dwelling as specific complications of thoracic surgery, facilitating a comprehensive evaluation of postoperative outcomes. Last, although prior models have often assessed the development of pulmonary complications within 5 or 7 days post-surgery, our study extended the evaluation to 30 days, aligning with evidence that the risk of PPCs remains elevated during the first 30 days in patients recovering from surgery [20, 40].

Nevertheless, our study has several significant limitations. First, the sample size was insufficient to adequately develop a multivariable regression model with 44 predictor variables. To address this, we combined LASSO regression with logistic regression to avoid overfitting and to develop a parsimonious model. Second, our bicentric cohort likely represents the population undergoing thoracic surgery in southern China. However, our results may not be transportable to other regions due to demographic variations, comorbidity, and surgical profiles. However, this concentration also meant that the study had fewer missing data and a more flexible and closer fit for the local population. Third, non-modifiable predictors in this model, such as age, smoking status, and certain comorbidities, are inherently unchangeable. The reliance on these non-modifiable predictors presents a significant limitation in its clinical application. They provide a fixed risk profile that can inform clinicians about the likelihood of PPCs but do not offer actionable avenues for reducing risk. Nevertheless, the model can still serve valuable roles in clinical settings in terms of risk stratification, research catalyst, integration with other tools, and informing policy and guidelines. Fourth, there is always a possibility of unrecognized confounding factors, such as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection, which is an important covariate unaccounted for in our model [11]. Despite high community infection rates, overall perioperative SARS-CoV-2 infection rates have remained low. In our study, elective surgeries were postponed for at least four weeks after COVID-19 diagnosis. Even in the case of a few undetected SARS-CoV-2 infections, the individual risk of PPCs is likely lower in the omicron-variant era among vaccinated patients [20]. In summary, the absolute risk of pulmonary sequelae of COVID-19 and its impact on the discriminative ability of the model are likely minimal. Fifth, our study did not evaluate the interactions between surgical specialties and other factors in the model, although the interaction of model performance with specialty is important for patients. It remains unclear whether the model components vary with surgical specialties. While specific tools may be highly accurate for narrowly defined groups, but they become impractical when multiple tools are required for each patient. Sixth, the sample size for external validation was relatively small, and further external validation studies based on larger, multicluster datasets would be ideal. Finally, despite employing advanced statistical methods, our observational study could not establish definitive etiological relationships.

Conclusions

The novel nomogram, based on eight routinely accessible variables, demonstrates excellent discriminative performance in assessing the risk of PPCs for older patients undergoing NCTS. This tool will assist clinicians in obtaining informed consent, formulating shared decision-making, and improving patient-centered outcomes.

Abbreviations

PPCs	Postoperative pulmonary complications
NCTS	Noncardiac thoracic surgery
ASA	American Society of Anesthesiologists
ARISCAT	Assess Respiratory Risk In Surgical Patients In Catalonia
LAS VEGAS	Local ASsessment of VEntilatory management during General AneSthesia
RATS	Robotic assisted thoracic surgery
VATS	Video assisted thoracic surgery
OLV	One lung ventilation
FEV_1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
LOS	Length of hospital stay
ICU	Intensive care unit
aOR	Adjusted odds ratio
CI	Confidence interval
AUC	Area under the receiver operating characteristic curve
DCA	Decision curve analysis
LASSO	Least absolute shrinkage and selection operator
VIF	Variance inflation factors

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-025-05791-2.

Additional file 1: Supplementary Digital Fig. S1.Features were selected using the LASSO binary logistic regression model. (a) The LASSO model's parameter selection used tenfold cross-validation with the minimum criterion; (b) Log (Lambda) values of the 25 features in the LASSO model. LASSO, least absolute shrinkage and selection operator.

Additional file 2: Supplementary Digital Fig. S2. Calibration plots in the development (a) and external validation cohorts (b).

Additional file 3: Supplementary Digital Fig. S3. Receiver operating characteristic (ROC) curve of internal validation, generated from 1000 bootstrap resampling repetitions. AUC, area under the ROC curve

Additional file 4: Supplementary Digital Content S1 Protocol deviations Supplementary. Digital Content S2a Case report form Supplementary. Digital Content S2b Definitions of predictor variables Supplementary. Digital Content S3 Definition of outcomes

Additional file 5: Supplementary Digital Table S1 Summary of missing predictor variables. Supplementary Digital Table S2 Description of the development and validation cohorts. Supplementary Digital Table S3 Development of postoperative pulmonary complications in the development and validation cohorts. Supplementary Digital Table S4 Variables entered into LASSO regression by univariable logistic regression. Supplementary Digital Table S5 Variance inflation factors (VIF) values of predictor variables. Supplementary Digital Table S6 Variables unrelated to the presence of PPCs by univariable logistic regression. Supplementary Digital Table S7 Characteristics of postoperative pulmonary complications and mortality according to the type of thoracic surgery.

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Data availability
All individual de-identified participant data collected in this study can be available to investigators whose proposed use of the data has been approved by an independent committee. Proposals, with a signed data access agreement, should be directed to 1575041594@qq.com.

Declarations

Ethics approval and consent to participate
This study was approved by the Institutional Review Boards of the Guangzhou Institute of Cancer Research, the Affiliated Cancer Hospital, Guangzhou Medical University (IRB number 202111ZN), and the second Affiliated Hospital of Guangzhou University of Chinese Medicine (IRB number 202220001). Written informed consent was obtained from all patients. This prospective cohort study was registered with the Chinese Clinical Trial Registry as ChiCTR2100051170.

Consent for publication
Consent for publication was obtained from all authors.

Competing interests
The authors declare no competing interests.

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