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Risk assessment of postoperative atelectasis in elderly lung cancer patients undergoing thoracoscopic surgery based on a nomogram model

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Abstract

Background Lung cancer is a leading cause of death in the elderly. Thoracoscopic surgery, though minimally invasive, poses a greater risk of postoperative atelectasis in this group owing to age and comorbidities. The aim of this study was to identify risk factors for atelectasis in elderly lung cancer patients and develop a nomogram model for clinical prediction.

Methods Clinical data from 322 elderly patients with lung cancer were retrospectively analysed and split into a training set ($n = 226$) and a validation set ($n = 96$) at a 7:3 ratio. Independent risk factors for postoperative atelectasis were identified via univariate and multivariate logistic regression. A nomogram prediction model was constructed and evaluated for discrimination (ROC curves), calibration (Hosmer–Lemeshow test, calibration curves), and clinical utility (decision curve analysis, DCA).

Results The multivariate logistic regression analysis revealed that the independent risk factors for postoperative atelectasis ($P < 0.05$) were age ≥ 70 years, a smoking history, decreased preoperative forced expiratory volume in one second (FEV1), and lobectomy. The areas under the ROC curves of the nomogram model were 0.826 (95% CI: 0.767–0.885) and 0.918 (95% CI: 0.802–0.991) in the training and validation sets, respectively. The calibration curves demonstrated a strong consistency between the predicted and observed outcomes. The DCA curves revealed that the model provided a high net clinical benefit when the threshold probability ranged from 0.07 to 0.60, with a maximum net benefit of 73%.

Conclusion The independent risk factors identified for postoperative atelectasis in elderly lung cancer patients undergoing thoracoscopic surgery are age ≥ 70 years, smoking history, reduced preoperative FEV1, and lobectomy.

Keywords Elderly lung cancer patients, Thoracoscopy, Atelectasis, Nomogram, Risk factors

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Introduction

Lung cancer is one of the most prevalent and deadly malignant tumours worldwide, and its incidence is increasing, particularly among the elderly population [1–3]. The rapid advancement of thoracoscopic techniques has significantly expanded their application in lung cancer surgeries owing to their minimally invasive nature, faster recovery, and lower complication rates [4, 5]. However, elderly patients are at a substantially greater risk of postoperative complications due to declining physiological function and multiple comorbidities, with atelectasis being one of the most common complications that can severely impact prognosis [6–8].

Postoperative atelectasis not only prolongs hospital stays but also increases the risk of complications such as infections and respiratory failure, thereby exacerbating the medical burden on patients [8, 9]. Consequently, an accurate risk assessment for postoperative atelectasis in elderly lung cancer patients is crucial for formulating individualized intervention strategies. However, current research predominantly focuses on individual risk factors, and comprehensive predictive tools specifically designed for postoperative atelectasis in elderly lung cancer patients are lacking.

The nomogram model, a user-friendly and visually intuitive predictive tool, translates complex statistical models into scoring systems, enabling clinicians to quickly identify high-risk patients and design personalized interventions [10]. In this study, we collected clinical and perioperative data from 322 elderly patients with lung cancer. Using univariate and multivariate logistic regression analyses, we identified the independent risk factors for postoperative atelectasis and subsequently developed and validated a nomogram prediction model. The performance of the model was comprehensively evaluated using calibration curves, receiver operating characteristic (ROC) curves, and a decision curve analysis (DCA). The aim of this study is to provide a scientific basis for a precise preoperative risk assessment and early intervention for high-risk patients, with the ultimate goal of reducing the incidence of postoperative atelectasis and improving postoperative outcomes and quality of life in this population.

Materials and methods

General information

In this retrospective study, the clinical data of 322 elderly lung cancer patients who underwent thoracoscopic surgery at our hospital between January 2022 and October 2024 were analysed. The inclusion criteria were as follows: (1) age ≥ 60 years; (2) preoperative diagnosis of lung cancer with thoracoscopic surgery as the chosen surgical method; (3) inclusion of patients with and without postoperative atelectasis, with a diagnosis of atelectasis based on postoperative imaging findings and clinical manifestations [11]; and (4) availability of complete preoperative and postoperative clinical records, including perioperative indicators. The exclusion criteria were as follows: (1) history of other malignancies; (2) lobectomy or sublobar resection with positive margins; (3) severe cardiac, hepatic, or renal insufficiency; (4) incomplete preoperative or postoperative records; and (5) patients who did not complete postoperative follow-up. All the clinical data were extracted from the electronic medical record system of our hospital. The study was approved by the hospital ethics committee and adhered to ethical principles.

Treatment methods

All patients in this study underwent thoracoscopic surgery performed by experienced thoracic surgeons. The surgical approach was selected based on the tumour location, size, and preoperative pulmonary function assessment. The procedures included sublobar resection (such as wedge resection or segmentectomy) and lobectomy. Intraoperative techniques strictly adhered to the principles of oncologic safety, with intraoperative frozen pathology used to evaluate the margin status and ensure surgical completeness. Perioperative management included assessment of the preoperative pulmonary function and optimization of nutritional status to enhance postoperative recovery. Postoperative care included routine prophylactic antibiotics to prevent infection and encouragement of early mobilization starting on the first postoperative day, with gradual increases in activity levels to promote recovery of the pulmonary function. All patients underwent routine postoperative imaging to evaluate atelectasis and other complications. For patients diagnosed with postoperative atelectasis, targeted interventions were implemented, including mechanical assistance for sputum clearance, bronchoscopic suctioning, and physical rehabilitation therapies such as respiratory function exercises and vibration-assisted sputum clearance techniques. Severe cases received additional interventions as needed, including non-invasive positive pressure ventilation (NPPV) or endotracheal intubation to maintain airway patency and improve ventilation.

Data collection

The data for this study were obtained from the electronic medical record system and imaging database of our hospital, comprising preoperative, intraoperative, and postoperative variables. Preoperative data included demographic characteristics (e.g., age, sex, body mass index [BMI]), smoking history, comorbidities (e.g., diabetes, hypertension, cardiovascular disease), and pulmonary function (assessed via forced expiratory volume in one second [FEV1]). Intraoperative data comprised the surgical duration (< 3 h or ≥ 3 h) and extent of resection (sublobar resection or lobectomy). Postoperative data included the need for postoperative mechanical ventilation, length of hospital stay, and 30-day perioperative mortality. The diagnosis of atelectasis was based on postoperative imaging findings (chest X-ray or CT) demonstrating partial or complete collapse of the lung parenchyma, accompanied by clinical symptoms such as dyspnoea or coughing. All the data were independently extracted and cross-verified by two researchers to ensure completeness and accuracy.

Statistical methods

The data analysis was performed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA) and R software (version 4.2.2, R Foundation for Statistical Computing, Vienna, Austria). Categorical variables were expressed as frequencies and percentages, and differences between groups were assessed using the chi-square test. The continuous variables were usually expressed as mean ± standard deviation (mean ± SD), and analysed via the independent t-test. (1) Model development: The dataset was randomly divided into a training set (70%) and validation set (30%). The training set was used to develop the nomogram model, whereas the validation set was used for validation. A univariate logistic regression analysis was first conducted to identify the predictors significantly associated with the occurrence of atelectasis. Each variable was independently evaluated for its relationship with atelectasis, and those with $P < 0.05$ were included in the multivariate logistic regression analysis. The multivariate analysis was used to control the potential confounding factors, determine the independent risk factors, and calculate the odds ratios (ORs) with 95% confidence intervals (CIs). The regression coefficients were used to construct the nomogram model. To simplify the interpretation, the coefficients were proportionally scaled, with the smallest coefficient corresponding to 10 points. This scoring method reflects the importance of each variable in the risk of atelectasis, with larger coefficients indicating a greater impact on risk. (2) Model performance evaluation: Model discrimination was assessed by plotting the ROC curves and calculating the area under the curve (AUC). The calibration was evaluated using the calibration curves and the Hosmer–Lemeshow goodness-of-fit test ($P > 0.05$ indicated a good calibration). The clinical utility was evaluated using the DCA. (3) Model validation: Internal validation was conducted using the validation set. The robustness of the model was assessed using the aforementioned performance metrics, including the AUC, calibration curves, and DCA. A significance level of $P < 0.05$ was applied for all the statistical analyses.

Results

General data of the study subjects

In this study, the clinical data of 322 elderly lung cancer patients were retrospectively analysed, and the data of patients who developed postoperative atelectasis ($n = 59$, 18.3%) were compared with the data of patients who did not ($n = 263$, 81.7%). The results are presented in Table 1. The analysis revealed that the proportion of patients aged ≥ 70 years was significantly higher in the atelectasis group than in the non-atelectasis group (69.5% vs. 46.4%, $P = 0.001$). Similarly, the proportion of patients with a smoking history was markedly higher in the atelectasis group than in the non-atelectasis group (71.2% vs. 31.2%, $P < 0.001$). Regarding pulmonary function, the preoperative FEV1 in the atelectasis group was lower than that in the non-atelectasis group (80.8 ± 11.5 vs. 87.2 ± 7.7, $P < 0.001$). Among the perioperative indicators, the proportion of patients who underwent surgery for ≥ 3 h was significantly higher in the atelectasis group (50.8% vs. 19.8%, $P < 0.001$). Similarly, the proportion of patients who underwent lobectomy was higher in the atelectasis group than in the non-atelectasis group (52.5% vs. 25.9%, $P < 0.001$). Conversely, there were no significant differences between the two groups in terms of gender, BMI, diabetes, hypertension, cardiovascular disease, tumour type, stage, location, or preoperative albumin levels ($P > 0.05$). In terms of postoperative outcomes, patients in the atelectasis group were more likely to require mechanical ventilation support (11.9% vs. 3.0%, $P = 0.009$), had a significantly longer hospital stay (9.8 ± 2.0 vs. 8.6 ± 1.1 days, $P < 0.001$), and demonstrated a numerically higher, although statistically nonsignificant, 30-day perioperative mortality rate (3.4% vs. 0.8%, $P = 0.155$).

Overall characteristics of different variables in the training set and univariate analysis results

Table 2 presents the overall characteristics of the different variables in the training set and the results of the univariate analysis of their associations with the risk of postoperative atelectasis. The study revealed that patients aged 70 years and older had a significantly higher incidence of atelectasis than those younger than 70 years (OR = 2.143, 95% CI: 1.095–4.191, $P = 0.026$). Smoking was associated with a higher incidence of atelectasis (OR = 3.941, 95% CI: 1.998–7.771, $P < 0.001$). The preoperative FEV1 value negatively correlated with atelectasis (OR = 0.938, 95% CI: 0.907–0.970, $P < 0.001$). Patients with a surgery duration of ≥ 3 h had a significantly higher incidence of atelectasis than those with a surgery duration of < 3 h (OR = 3.893, 95% CI: 1.960–7.734; $P < 0.001$). Patients who underwent lobectomy had a significantly higher incidence of atelectasis than those who underwent sublobar resection (OR = 3.487, 95% CI: 1.791–6.789, $P < 0.001$).

Table 1 Comparison of general data between two patient groups

Variables	Overall ($n=322$)	Non-atelectasis group ($n=263$)	Atelectasis group ($n=59$)	*P* value
Age, n (%)				0.001
< 70 years	159 (49.4)	141 (53.6)	18 (30.5)	
≥ 70 years	163 (50.6)	122 (46.4)	41 (69.5)	
Gender, n (%)				0.192
Male	172 (53.4)	145 (55.1)	27 (45.8)	
Female	150 (46.6)	118 (44.9)	32 (54.2)	
BMI, n (%)				0.900
< 25 kg/m^2	253 (78.6)	207 (78.7)	46 (78.0)	
≥ 25 kg/m^2	69 (21.4)	56 (21.3)	13 (22.0)	
Smoking, n (%)				< 0.001
No	198 (61.5)	181 (68.8)	17 (28.8)	
Yes	124 (38.5)	82 (31.2)	42 (71.2)	
Diabetes, n (%)				0.754
No	277 (86.0)	227 (86.3)	50 (84.7)	
Yes	45 (14.0)	36 (13.7)	9 (15.3)	
Hypertension, n (%)				0.500
No	214 (66.5)	177 (67.3)	37 (62.7)	
Yes	108 (33.5)	86 (32.7)	22 (37.3)	
Cardiovascular disease, n (%)				0.385
No	254 (78.9)	205 (77.9)	49 (83.1)	
Yes	68 (21.1)	58 (22.1)	10 (16.9)	
Preoperative FEV1 (%)	86.0 ± 8.8	87.2 ± 7.7	80.8 ± 11.5	< 0.001
Tumor type, n (%)				0.862
Adenocarcinoma	209 (64.9)	171 (65.0)	38 (64.4)	
Squamous cell carcinoma	90 (28.0)	74 (28.1)	16 (27.1)	
Large cell carcinoma	23 (7.1)	18 (6.8)	5 (8.5)	
Tumor stage, n (%)				0.930
Stage I	247 (76.7)	202 (76.8)	45 (76.3)	
Stage II	75 (23.3)	61 (23.2)	14 (23.7)	
Tumor location, n (%)				
Left lung	132 (41.0)	108 (41.1)	24 (40.7)	0.956
Right lung	190 (59.0)	155 (58.9)	35 (59.3)	
Preoperative albumin level, n (%)				0.282
< 40 g/L	281 (87.3)	232 (88.2)	49 (83.1)	
≥ 40 g/L	41 (12.7)	31 (11.8)	10 (16.9)	
Surgery duration, n (%)				< 0.001
< 3 h	240 (74.5)	211 (80.2)	29 (49.2)	
≥ 3 h	82 (25.5)	52 (19.8)	30 (50.8)	
Resection scope, n (%)				< 0.001
Sublobar resection	223 (69.3)	195 (74.1)	28 (47.5)	
Lobectomy	99 (30.7)	68 (25.9)	31 (52.5)	
Postoperative mechanical ventilation, n (%)				0.009
Not required	307 (95.3)	255 (97)	52 (88.1)	
Required	15 (4.7)	8 (3)	7 (11.9)	
Length of hospital stay, Mean ± SD (days)	8.8 ± 1.4	8.6 ± 1.1	9.8 ± 2.0	< 0.001
30-day perioperative mortality, n (%)				0.155
No	318 (98.8)	261 (99.2)	57 (96.6)	
Yes	4 (1.2)	2 (0.8)	2 (3.4)	

Abbreviation: FEV1: Forced expiratory volume in one second

Table 2 General characteristics and univariate analysis of risk factors for atelectasis in the training set

Variables	Overall (*n* = 226)	Non-atelectasis group (*n* = 179)	Atelectasis group (*n* = 47)	OR (95%CI)	*P* value
Age,*n*(%)					
< 70 years	110 (48.7)	94 (52.5)	16 (34.0)	Reference	
≥ 70 years	116 (51.3)	85 (47.5)	31 (66.0)	2.143 (1.095,4.191)	0.026
Gender, n (%)					
Male	120 (53.1)	99 (55.3)	21 (44.7)	Reference	
Female	106 (46.9)	80 (44.7)	26 (55.3)	1.532 (0.803,2.924)	0.196
BMI, n (%)					
< 25 kg/m^2	176 (77.9)	136 (76.0)	40 (85.1)	Reference	
≥ 25 kg/m^2	50 (22.1)	43 (24.0)	7 (14.9)	0.553 (0.231,1.325)	0.184
Smoking, n (%)					
No	136 (60.2)	120 (67.0)	16 (34.0)	Reference	
Yes	90 (39.8)	59 (33.0)	31 (66.0)	3.941 (1.998,7.771)	< 0.001
Diabetes, n (%)					
No	198 (87.6)	159 (88.8)	39 (83.0)	Reference	
Yes	28 (12.4)	20 (11.2)	8 (17.0)	1.631 (0.669,3.977)	0.282
Hypertension, n (%)					
No	150 (66.4)	120 (67.0)	30 (63.8)	Reference	
Yes	76 (33.6)	59 (33.0)	17 (36.2)	1.153 (0.589,2.256)	0.679
Cardiovascular disease, n (%)					
No	176 (77.9)	138 (77.1)	38 (80.9)	Reference	
Yes	50 (22.1)	41 (22.9)	9 (19.1)	0.797 (0.356,1.785)	0.581
Preoperative FEV1 (%)	86.1 ± 9.3	87.3 ± 8.0	81.2 ± 12.0	0.938 (0.907,0.970)	< 0.001
Tumor type, n (%)					
Adenocarcinoma	139 (61.5)	107 (59.8)	32 (68.1)	Reference	
Squamous cell carcinoma	68 (30.1)	57 (31.8)	11 (23.4)	0.645 (0.303,1.375)	0.257
Large cell carcinoma	19 (8.4)	15 (8.4)	4 (8.5)	0.892 (0.276,2.877)	0.848
Tumor stage, n (%)					
Stage I	167 (73.9)	132 (73.7)	35 (74.5)	Reference	
Stage II	59 (26.1)	47 (26.3)	12 (25.5)	0.963 (0.462,2.009)	0.920
Tumor location, n (%)					
Left lung	93 (41.2)	75 (41.9)	18 (38.3)	Reference	
Right lung	133 (58.8)	104 (58.1)	29 (61.7)	1.162 (0.601,2.245)	0.655
Preoperative albumin level, n (%)					
< 40 g/L	196 (86.7)	158 (88.3)	38 (80.9)	Reference	
≥ 40 g/L	30 (13.3)	21 (11.7)	9 (19.1)	1.782 (0.756,4.200)	0.187
Surgery duration, n (%)					
< 3 h	171 (75.7)	146 (81.6)	25 (53.2)	Reference	
≥ 3 h	55 (24.3)	33 (18.4)	22 (46.8)	3.893 (1.960,7.734)	< 0.001
Resection scope, n (%)					
Sublobar resection	157 (69.5)	135 (75.4)	22 (46.8)	Reference	
Lobectomy	69 (30.5)	44 (24.6)	25 (53.2)	3.487 (1.791,6.789)	< 0.001

Abbreviation: FEV1: Forced expiratory volume in one second

Multivariate logistic regression analysis

The multivariate logistic regression analysis revealed several significant factors influencing the risk of atelectasis following thoracoscopic surgery in elderly patients with lung cancer. An age of ≥ 70 years was significantly associated with an increased risk (OR = 2.675, 95% CI: 1.129–5.869, $P = 0.014$), as was a smoking history (OR = 4.410, 95% CI: 2.037–9.547, $P = 0.001$). Additionally, the preoperative FEV1 negatively correlated with the postoperative atelectasis (OR = 0.939, 95% CI: 0.904–0.976, $P = 0.001$), whereas patients who underwent lobectomy had a higher likelihood of developing atelectasis (OR = 2.567, 95% CI: 1.011–6.517, $P = 0.047$). The details of the analysis are provided in Table 3.

Construction of the nomogram prediction model

Based on the results of the multivariable analysis, the relevant variables were incorporated into the nomogram

Table 3 Multivariate logistic regression analysis of factors affecting atelectasis

Variables	β	SE	Wald χ^2	OR	95%CI	*P*-value
Age ≥ 70 years	0.984	0.401	6.022	2.675	1.219 ~ 5.869	0.014
Smoking	1.484	0.394	14.18	4.410	2.037 ~ 9.547	0.001
Preoperative FEV1	-0.063	0.019	10.49	0.939	0.904 ~ 0.976	0.001
Resection scope (lobectomy)	0.943	0.475	3.756	2.567	1.011 ~ 6.517	0.047

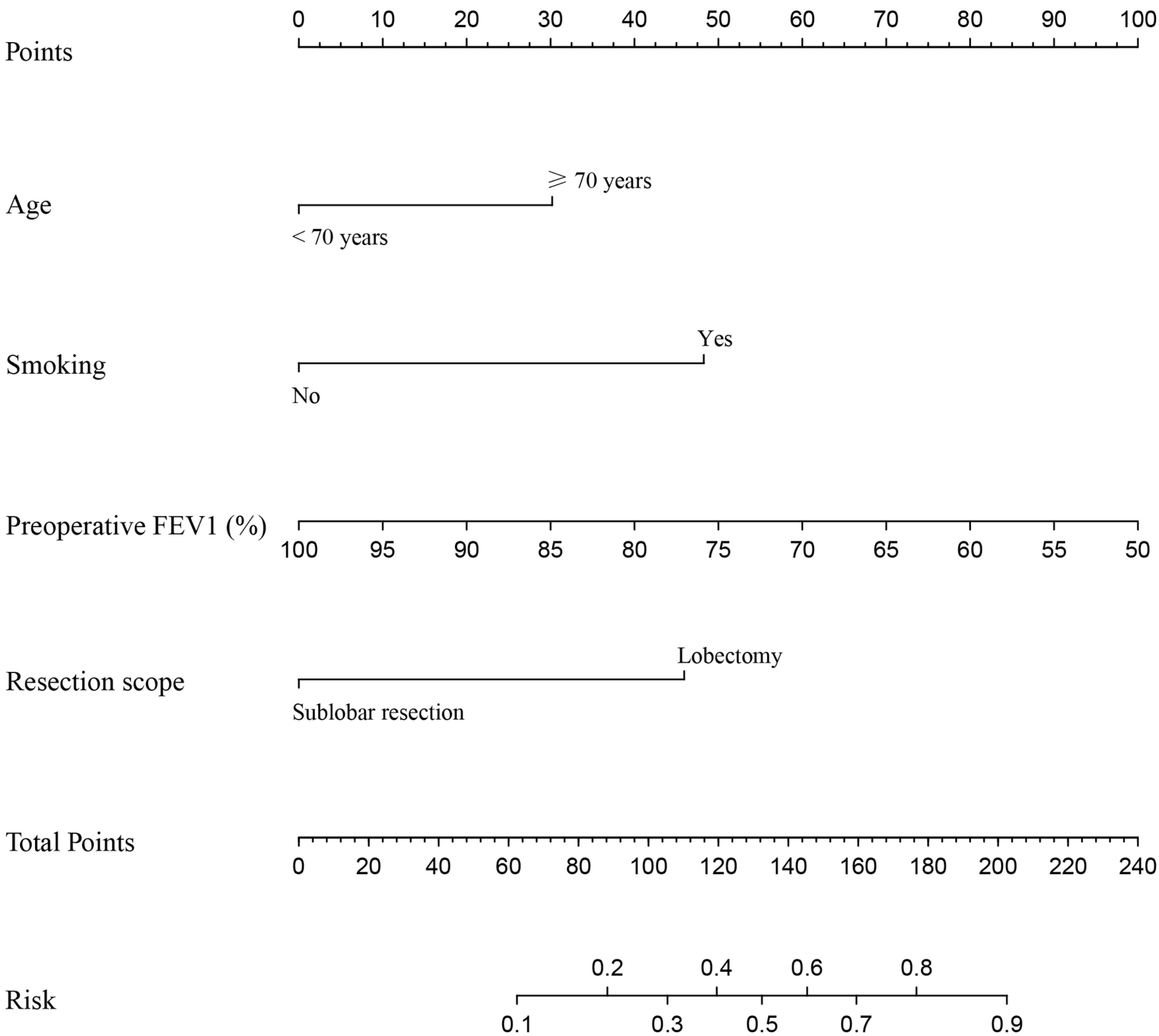

Fig. 1 A nomogram model constructed based on independent risk factors identified via multivariate logistic regression analysis. The model enables the users to locate the position of each variable on its corresponding axis. For each patient variable, a vertical line is drawn to the points axis to determine the individual score. These scores are then summed to calculate the total points. A vertical line is subsequently drawn from the total points axis to the lower scale, providing the predicted risk of postoperative atelectasis

prediction model. Each variable was assigned a specific score: age ("< 70 years" = 0 points, "≥ 70 years" = 30.18 points), smoking ("no" = 0 points, "yes" = 48.26 points), preoperative FEV1 ("100" = 0 points, "95" = 10 points, "90" = 20 points, "85" = 30 points, "80" = 40 points, "75" = 50 points, "70" = 60 points, "65" = 70 points, "60" = 80 points, "55" = 90 points, "50" = 100 points), and resection scope ("sublobar resection" = 0 points, "lobectomy" = 45.92 points). The total score was obtained by summing the scores of all the variables, and the corresponding probability was determined from the nomogram (Fig. 1).

Predictive value of the nomogram for atelectasis in the training and validation sets

The ROC curves were plotted for both groups. The AUC of the nomogram prediction model was 0.826 (95% CI: 0.767–0.885) in the training set and 0.918 (95% CI: 0.802–0.991) in the validation set. The C-index for the prediction model was 0.826 in the training set and 0.922 in the validation set, indicating a good discriminatory ability (Fig. 2).

Calibration curves for predicting atelectasis in the training and validation sets

The Hosmer–Lemeshow goodness-of-fit test was performed for the prediction model in both the training and validation sets, with *P* values greater than 0.05 in both cases. This finding indicates that the predicted probabilities of the atelectasis occurrence were in good agreement with the observed values. These results demonstrate that the model exhibited a satisfactory calibration performance in both the training and validation sets (Fig. 3).

Clinical value of the nomogram prediction model

The clinical value of the nomogram prediction model for assessing the risk of postoperative atelectasis in elderly lung cancer patients undergoing thoracoscopic surgery was evaluated using DCA. The DCA curve demonstrated that when the threshold probability ranged from 0.07 to 0.60, the model achieved a high net clinical benefit, with the net benefit consistently above zero and peaking at 73%. These findings indicate that the model offers significant advantages in identifying high-risk patients and optimizing clinical intervention strategies within this range (Fig. 4).

Discussion

Atelectasis is a common complication following thoracoscopic surgery and may lead to impaired lung function, increased risk of postoperative infections, and adverse effects on patient recovery and prognosis [12， 13]. To identify high-risk patients more effectively, in this study, a nomogram prediction model for postoperative atelectasis based on the clinical characteristics and perioperative indicators of elderly patients with lung cancer was developed and validated. The model provides a scientific basis for a precise preoperative assessment and individualized interventions. The results indicated that an age of ≥70 years, a smoking history, decreased preoperative FEV1, and lobectomy were independent risk factors for postoperative atelectasis.

An age of ≥70 years is a significant independent risk factor for postoperative atelectasis in elderly lung cancer patients undergoing thoracoscopic surgery. This may be attributed to decreased lung tissue elasticity, weakened respiratory muscles, and reduced pulmonary reserve in older patients [14, 15]. Additionally, elderly patients often have comorbid chronic diseases, such as COPD and cardiovascular disorders, which further increase the risk of postoperative ventilation insufficiency [16, 17]. For

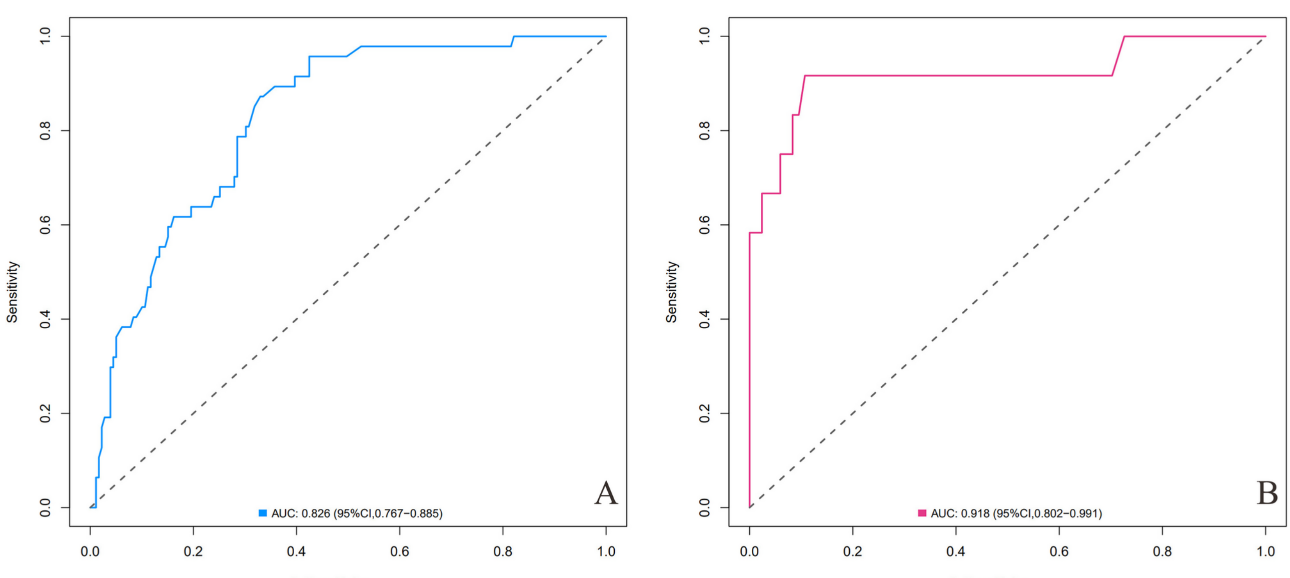

Fig. 2 Receiver operating characteristic (ROC) curves for the predictive performance of the nomogram in the training cohort (**A**) and validation cohort (**B**). (**A**) ROC curve for the training set, presenting an AUC of 0.826 (95% CI: 0.767–0.885), indicating an excellent discriminative ability for distinguishing patients with and without atelectasis. (**B**) ROC curve for the validation set, with an AUC of 0.918 (95% CI: 0.802–0.991), demonstrating a strong predictive performance in an independent dataset. Explanation: the x-axis represents 1-specificity (false-positive rate), and the y-axis represents sensitivity (true positive rate). The diagonal dashed line represents the performance of a random classifier (AUC = 0.5). A larger area under the curve indicates a better model performance

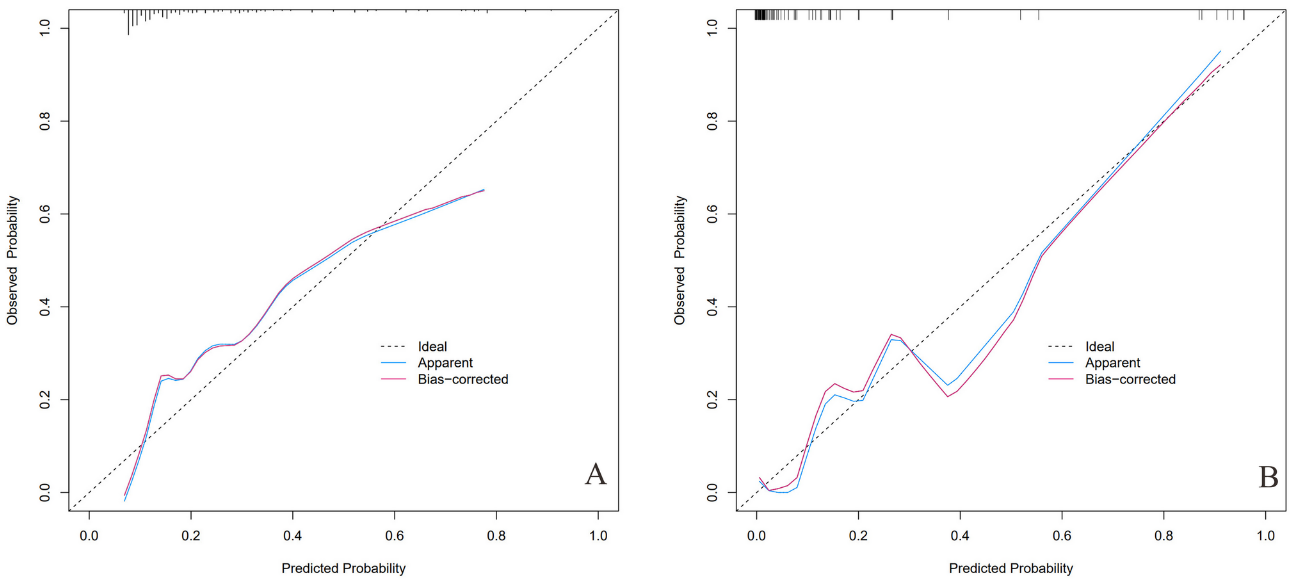

Fig. 3 Calibration plots of the nomogram for predicting atelectasis in the training set (**A**) and validation set (**B**). (**A**) Calibration plot for the training cohort. (**B**) Calibration plot for the validation cohort. The plots include three lines: the ideal line (dashed), which represents a perfect agreement between the predicted and observed probabilities; the apparent line (blue), which represents the raw calibration of the model; and the bias-corrected line (red), which is adjusted via cross-validation to account for overfitting. Apparent and bias-corrected lines that are closer to the ideal line indicate a better calibration performance of the model

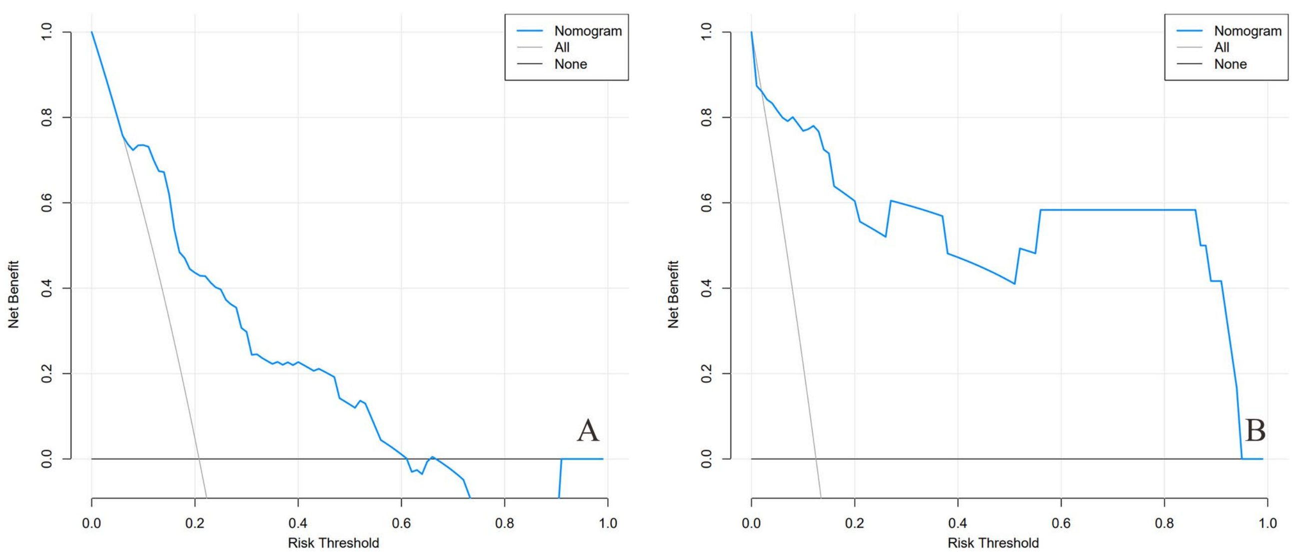

Fig. 4 Decision curve analysis (DCA) for the nomogram for predicting atelectasis risk in the training set (**A**) and validation set (**B**). (**A**) DCA for the training cohort. (**B**) DCA for the validation cohort. The curves illustrate the net clinical benefit across various risk thresholds. The blue curve represents the net benefit of the nomogram, the "All" curve (grey) assumes that all patients develop atelectasis, and the "None" curve (black) assumes that none of the patients develop atelectasis. Explanation: for threshold probabilities ranging between 0.07 and 0.60, the nomogram (blue curve) provides greater net clinical benefit than the "All" and "None" strategies. These findings demonstrate the utility of the nomogram in guiding clinical decision-making and intervention strategies

high-risk elderly patients, comprehensive preoperative pulmonary function assessment is essential, along with respiratory rehabilitation training to improve the pulmonary reserve. Intraoperatively, individualized anaesthesia strategies should be employed to minimize the suppression of pulmonary ventilation. Postoperative management should focus on early mobilization, mechanical assistance for sputum clearance, and non-invasive ventilation techniques, such as continuous positive airway pressure (CPAP), to maintain alveolar patency [18–21]. Moreover, a multidisciplinary team collaboration, including the input from respiratory and nutrition specialists, plays a crucial role in optimizing perioperative management. This approach helps reduce the incidence of atelectasis and improves patient outcomes [22].

In addition to age, a smoking history, and decreased preoperative FEV1 significantly increase the risk of postoperative atelectasis. Chronic smoking damages the ciliary function and alveolar elasticity, leading to an impaired clearance of airway secretions [23, 24]. Patients with a decreased preoperative FEV1 are more prone to postoperative ventilation impairment owing to an insufficient pulmonary reserve [25]. To address these high-risk factors, smoking cessation should be encouraged at least four weeks prior to surgery [26], along with respiratory rehabilitation training to improve pulmonary function. Postoperatively, enhanced airway management, including mechanical assistance for sputum clearance, bronchodilators, and nebulized inhalation therapy, should be implemented to maintain airway patency. When necessary, non-invasive ventilation or oxygen therapy can provide additional support. These comprehensive measures help reduce the incidence of atelectasis and improve postoperative recovery outcomes [27–29].

Among surgery-related factors, lobectomy has been identified as another significant risk factor. This may be attributed to the greater extent of surgical trauma and the reduction in lung volume following the procedure. Lobectomy not only increases the risk of airway secretion retention but also potentially leads to diminished lung expansion capacity and further impairment of the pulmonary reserve [30, 31]. To address these challenges, preoperative optimization of pulmonary function is crucial, including respiratory rehabilitation training when necessary to enhance tolerance. Postoperative interventions should include deep breathing exercises, postural drainage, and mechanical assistance for clearing secretions. These measures should be complemented by non-invasive ventilation or lung recruitment therapy to restore lung expansion function. Optimizing perioperative management is essential for improving postoperative outcomes in patients undergoing lobectomy [32–35].

The strengths of this study not only lie in its methodology but also in the reliability and practicality of the model, as demonstrated by the specific data. First, the study was based on a large sample of 322 elderly patients with lung cancer, and various preoperative and intraoperative factors were integrated to construct a comprehensive risk assessment model for atelectasis. The model demonstrated a strong discriminatory ability, with an AUC of 0.826 during training. The calibration curves demonstrated a high consistency between the predicted and observed values, and the Hosmer–Lemeshow goodness-of-fit test ($P > 0.05$) further validated the calibration performance of the model. Additionally, DCA indicated that the model provided a high net clinical benefit when the threshold probability ranged from 0.07 to 0.60, peaking at 73%. These findings confirm that the model is not only scientifically rigorous but also highly effective in clinical practice for identifying high-risk patients. These findings provide a reliable basis for individualized interventions, thereby improving patient outcomes.

Although the nomogram prediction model developed in this study demonstrated a high discriminatory ability and clinical utility, it has certain limitations. First, this was a single-centre retrospective analysis. Although the sample size was relatively large, there may have been a selection bias, and the external generalizability of the results requires further validation. Second, this study did not include certain potential factors that may influence the occurrence of atelectasis, such as the adherence of patients to postoperative rehabilitation training, which may limit the comprehensiveness of the model. Additionally, the model validation was primarily based on an internal validation set, thus lacking verification using an external independent dataset. Future multicentre studies are needed to perform an external validation and enhance the robustness and generalizability of the model. Finally, owing to the complexity of the nomogram model, its implementation in clinical practice may require the development of simpler tools or application-based support to facilitate its widespread adoption.

Conclusion

This study developed and validated a nomogram prediction model for postoperative atelectasis in elderly lung cancer patients based on clinical characteristics and perioperative indicators. The results identified that the independent risk factors for atelectasis are age ≥ 70 years, a smoking history, decreased preoperative FEV1, surgical duration ≥ 3 h, and lobectomy. The model demonstrated a good discriminatory ability and calibration performance in both the training and validation sets; DCA indicated a high clinical utility. This model provides a scientific basis for the precise preoperative identification of high-risk patients and can guide the formulation of individualized intervention strategies to reduce the incidence of atelectasis and improve postoperative outcomes. Future multicentre studies are needed to further validate the stability and generalizability of the model, facilitating its application in routine clinical practice.

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Author contributions
Bin Liu designed the study, extracted data, created tables and figures, performed data visualization, and wrote the manuscript. Xi Chen contributed to the study design, reviewed the data, assisted with data visualization, and participated in manuscript drafting. Wuchang Deng conducted the analysis; critically reviewed the tables, figures, and visualizations; and finalized the manuscript.

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Data availability
The datasets generated and analysed during the current study are not publicly accessible due to affiliation constraints. However, they can be obtained from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
All research procedures involving human participants comply with the ethical standards of our institution, as well as the principles of the 1964 Declaration of Helsinki and its subsequent amendments or equivalent ethical standards. This study was approved by the Ethics Committee of our institution. Given the retrospective nature of the study and the use of anonymized data, the requirement for informed consent was waived by the Ethics Committee.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global Cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209–49. https://doi.org/10.3322/caac.21660.
2. Kristiansen C, Schytte T, Hansen KH, Holtved E, Hansen O, Academy of Geriatric Cancer Research (AgeCare). Trends in lung cancer in elderly in Denmark, 1980–2012. Acta Oncol. 2016;55(Suppl 1):46–51. https://doi.org/10.3109/0284186X.2015.1114676.
3. Pilleron S, Sarfati D, Janssen-Heijnen M, Vignat J, Ferlay J, Bray F, et al. Global cancer incidence in older adults, 2012 and 2035: A population-based study. Int J Cancer. 2019;144(1):49–58. https://doi.org/10.1002/ijc.31664.
4. Qi F, Xiang M, Deng Y, Huang W, Sun Y. Application of Da Vinci robot and thoracoscopy in radical lung Cancer surgery. J Healthc Eng. 2022;2022:2011062. https://doi.org/10.1155/2022/2011062.
5. Jiao W, Qiu T. The minimally invasive thoracic surgery for lung cancer: a voice from China. Indian J Cancer. 2015;51(Suppl 2):e2. https://doi.org/10.4103/0019-509X.151983.
6. Loran DB, Zwischenberger JB. Thoracic surgery in the elderly. J Am Coll Surg. 2004;199(5):773–84. https://doi.org/10.1016/j.jamcollsurg.2004.08.008.
7. Feng G, Jia Y, Zhao G, Meng F, Wang T. Risk factors for postoperative pulmonary complications in elderly patients undergoing video-assisted thoracoscopic surgery lobectomy under general anesthesia: a retrospective study. BMC Surg. 2024;24(1):153. https://doi.org/10.1186/s12893-024-02444-w.
8. Sachdev G, Napolitano LM. Postoperative pulmonary complications: pneumonia and acute respiratory failure. Surg Clin North Am. 2012;92(2):321–44, ix. https://doi.org/10.1016/j.suc.2012.01.013
9. Fernandez-Bustamante A, Frendl G, Sprung J, Kor DJ, Subramaniam B, Martinez Ruiz R, et al. Postoperative pulmonary complications, early mortality, and hospital stay following noncardiothoracic surgery: A multicenter study by the perioperative research network investigators. JAMA Surg. 2017;152(2):157–66. https://doi.org/10.1001/jamasurg.2016.4065.
10. Malhotra RK, Indrayan A. A simple nomogram for sample size for estimating sensitivity and specificity of medical tests. Indian J Ophthalmol. 2010;58(6):519–22. https://doi.org/10.4103/0301-4738.71699.
11. Lagier D, Zeng C, Fernandez-Bustamante A, Vidal Melo MF. Perioperative pulmonary atelectasis: part II. Clin Implications Anesthesiology. 2022;136(1):206–36. https://doi.org/10.1097/ALN.0000000000004009.
12. Sengupta S. Post-operative pulmonary complications after thoracotomy. Indian J Anaesth. 2015;59(9):618–26. https://doi.org/10.4103/0019-5049.165852.
13. Hoshikawa Y, Tochii D. Postoperative atelectasis and pneumonia after general thoracic surgery. Kyobu Geka. 2017;70(8):649–55. Japanese.
14. Schneider JL, Rowe JH, Garcia-de-Alba C, Kim CF, Sharpe AH, Haigis MC. The aging lung: physiology, disease, and immunity. Cell. 2021;184(8):1990–2019. https://doi.org/10.1016/j.cell.2021.03.005.
15. Skloot GS. The effects of aging on lung structure and function. Clin Geriatr Med. 2017;33(4):447–57. https://doi.org/10.1016/j.cger.2017.06.001.
16. Daitoku K, Suzuki Y, Fukuda I. [Cardiovascular surgery for patients with chronic respiratory failure and respiratory dysfunction]. Kyobu Geka. 2008;61(8 Suppl):624–9. Japanese.
17. Zhu J, Chen H, Luan W. Analysis of risk factors associated with postoperative lower respiratory infections in the elderly patients with lung carcinoma. J Int Oncol. 2016: 95–8.
18. Dankert A, Dohrmann T, Löser B, et al. Pulmonary function tests for the prediction of postoperative pulmonary complications: A systematic review. Dtsch Arztebl Int. 2022;119(7):99.
19. Zollinger A, Hofer CK, Pasch T. Preoperative pulmonary evaluation: facts and Myths. Curr Opin Anaesthesiol. 2001;14(1):59–63. https://doi.org/10.1097/00001503-200102000-00010.
20. Qian M, Yang F, Zhao L, Shen J, Xie Y. Individualized positive end-expiratory pressure Titration on respiration and circulation in elderly patients undergoing spinal surgery in prone position under general anesthesia. Am J Transl Res. 2021;13(12):13835–44.
21. Malbouisson LM, Humberto F, Rodrigues Rdos R, Carmona MJ, Auler JO. Atelectasis during anesthesia: pathophysiology and treatment. Rev Bras Anestesiol. 2008;58(1):73–83. https://doi.org/10.1590/s0034-70942008000100011.
22. Bissett B, Leditschke IA, Green M, Marzano V, Collins S, Van Haren F. Inspiratory muscle training for intensive care patients: A multidisciplinary practical guide for clinicians. Aust Crit Care. 2019;32(3):249–55. https://doi.org/10.1016/j.aucc.2018.06.001.
23. Bakre SA, Al-Farra TS, Al-Farra S. Diffuse alveolar damage and e-cigarettes: case report and review of literature. Respir Med Case Rep. 2019;28:100935. https://doi.org/10.1016/j.rmcr.2019.100935.
24. Pagliuca G, Rosato C, Martellucci S, de Vincentiis M, Greco A, Fusconi M, et al. Cytologic and functional alterations of nasal mucosa in smokers: temporary or permanent damage? Otolaryngol Head Neck Surg. 2015;152(4):740–5. https://doi.org/10.1177/0194599814566598.
25. Chandler D, Mosieri C, Kallurkar A, Pham AD, Okada LK, Kaye RJ, et al. Perioperative strategies for the reduction of postoperative pulmonary complications. Best Pract Res Clin Anaesthesiol. 2020;34(2):153–66. https://doi.org/10.1016/j.bpa.2020.04.011.
26. Mills E, Eyawo O, Lockhart I, Kelly S, Wu P, Ebbert JO. Smoking cessation reduces postoperative complications: a systematic review and meta-analysis. Am J Med. 2011;124(2):144–e1548. https://doi.org/10.1016/j.amjmed.2010.09.013.
27. Divisi D, Di Francesco C, Di Leonardo G, Crisci R. Preoperative pulmonary rehabilitation in patients with lung cancer and chronic obstructive pulmonary disease. Eur J Cardiothorac Surg. 2013;43(2):293–6. https://doi.org/10.1093/ejcts/ezs257.
28. Tao W, Huang J, Jin Y, Peng K, Zhou J. Effect of pulmonary rehabilitation exercise on lung volume and respiratory muscle recovery in lung Cancer patients undergoing lobectomy. Altern Ther Health Med. 2024;30(2):90–6.
29. Cui L, Liu H, Sun L. Multidisciplinary respiratory rehabilitation in combination with non-invasive positive pressure ventilation in the treatment of elderly patients with severe chronic obstructive pulmonary disease. Pak J Med Sci. 2019;35(2):500–5. https://doi.org/10.12669/pjms.35.2.459.
30. Ueda K, Murakami J, Sano F, Hayashi M, Kobayashi T, Kunihiro Y, et al. Assessment of volume reduction effect after lung lobectomy for cancer. J Surg Res. 2015;197(1):176–82. https://doi.org/10.1016/j.jss.2015.03.064.
31. Agostini P, Lugg ST, Adams K, Vartsaba N, Kalkat MS, Rajesh PB, et al. Postoperative pulmonary complications and rehabilitation requirements following lobectomy: a propensity score matched study of patients undergoing video-assisted thoracoscopic surgery versus thoracotomy†. Interact Cardiovasc Thorac Surg. 2017;24(6):931–7. https://doi.org/10.1093/icvts/ivx002.
32. Morano MT, Araújo AS, Nascimento FB, da Silva GF, Mesquita R, Pinto JS, et al. Preoperative pulmonary rehabilitation versus chest physical therapy in patients undergoing lung cancer resection: a pilot randomized controlled trial. Arch Phys Med Rehabil. 2013;94(1):53–8. https://doi.org/10.1016/j.apmr.2012.08.206.
33. Perrin C, Jullien V, Vénissac N, Berthier F, Padovani B, Guillot F, et al. Prophylactic use of noninvasive ventilation in patients undergoing lung resectional

surgery. Respir Med. 2007;101(7):1572–8. https://doi.org/10.1016/j.rmed.2006.12.002.

34. Lai Y, Huang J, Yang M, Su J, Liu J, Che G. Seven-day intensive preoperative rehabilitation for elderly patients with lung cancer: a randomized controlled trial. J Surg Res. 2017;209:30–6. https://doi.org/10.1016/j.jss.2016.09.033.

35. Brocki BC, Andreasen JJ, Langer D, Souza DS, Westerdahl E. Postoperative inspiratory muscle training in addition to breathing exercises and early mobilization improves oxygenation in high-risk patients after lung cancer surgery: a randomized controlled trial. Eur J Cardiothorac Surg. 2016;49(5):1483–91. https://doi.org/10.1093/ejcts/ezv359.

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