



The chest X-ray score baseline in predicting continuous oxygen therapy failure in low-risk aged patients after thoracic surgery

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Background: Radiographic severity assessment can be instrumental in diagnosing postoperative pulmonary complications (PPCs) and guiding oxygen therapy. The radiographic assessment of lung edema (RALE) and Brixia scores correlate with disease severity, but research on low-risk elderly patients is lacking. This study aimed to assess the efficacy of two chest X-ray scores in predicting continuous oxygen therapy (COT) treatment failure in patients over 70 years of age after thoracic surgery.

Methods: From January 2019 to December 2021, we searched for patients aged 70 years and above who underwent thoracic surgery and received COT treatment, with a focus on those at low risk of respiratory complications. Bedside chest X-rays, RALE, Brixia scores, and patient data were collected. Univariate, multivariate analyses, and 1:2 matching identified risk factors. Receiver operating characteristic (ROC) curves determined score sensitivity, specificity, and predictive values.

Results: Among the 242 patients surviving to discharge, 19 (7.9%) patients experienced COT failure. COT failure correlated with esophageal cancer surgeries, thoracotomies (36.8% *vs.* 9%, $P=0.003$; 26.3% *vs.* 9.4%, $P=0.004$), and longer operation time (3.4 *vs.* 2.8 h, $P=0.003$). Surgical approach and RALE score were independent risk factors. The prediction model had an area under the curve (AUC) of 0.839 [95% confidence interval (CI), 0.740–0.938]. Brixia and RALE scores predicted COT failure with AUCs of 0.764 (95% CI, 0.650–0.878) with a cut-off value of 6.027 and 0.710 (95% CI, 0.588–0.832) with a cut-off value of 17.134, respectively, after 1:2 matching.

Conclusions: The RALE score predict the risk of COT failure in elderly, low-risk thoracic patients better than the Brixia score. This simple, cheap, and noninvasive method helps evaluate postoperative lung damage, monitor treatment response, and provide early warning for oxygen therapy escalation. Further studies are required to confirm the validity and applicability of this model in different settings and populations.

Keywords: Radiographic assessment of lung edema score (RALE score); Brixia score; continuous oxygen therapy failure (COT failure); predicting; chest radiograph

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Introduction

Patients undergoing thoracic surgery, especially elderly individuals undergoing lung resection and esophageal cancer radical surgery, are at a higher risk of experiencing postoperative pulmonary complications (PPCs) (1,2). These PPCs are most prevalent during the initial seven days following surgery and can range from pulmonary atelectasis to acute respiratory distress syndrome (ARDS). One of these PPCs, acute hypoxemic respiratory failure (AHRF), often increases the risk of postoperative failure

in continuous oxygen therapy (COT) support. In October 2021, the European Respiratory Society (ERS) guidelines recommended the use of either high-flow nasal cannula (HFNC) or COT for postoperative patients after extubation, particularly those at low risk of pulmonary complications, and favored HFNC over COT in cases of AHRF (3). However, it is important to note that this recommendation is conditional and based on evidence of low certainty due to the lack of relevant research, especially in subgroups of elderly patients and those at low risk. Other guidelines recommend conducting specific trials for these vulnerable populations (4).

With the global aging population, there is a growing number of patients aged 70 years and above undergoing open-chest surgery. This demographic is more prone to developing PPCs, such as AHRF, which increase the risk of surgical mortality and complications (5). While certain preoperative risk factors have been closely associated with AHRF and COT treatment failure (6), there is a lack of studies examining the predictive value of common bedside chest X-rays in these patients. In thoracic surgery, bedside chest X-rays are often taken within 24 h postoperatively to assess thoracic conditions and provide information about postoperative complications. Currently, various scoring systems are used to evaluate chest X-ray images, including the radiographic assessment of lung edema (RALE) score (7), Brixia score (8), Toussie score (9), Al-Smadi score (10), and percentage/area opacification. In 2018, Warren *et al.* first reported that the RALE score could independently predict the severity of ARDS in terms of oxygenation and outcomes (7), and some study have applied the RALE score to the evaluation and of patients after lung (11), esophagus (12), and heart surgery (13). Subsequently, it has demonstrated valuable applications in predicting the prognosis of coronavirus disease 2019 (COVID-19) patients (14). In 2020, Borghesi *et al.* conducted a retrospective study of 302 patients with COVID-19 and reported that the Brixia score, a new chest X-ray scoring system, could independently predict the risk of in-hospital mortality in Caucasian patients in Italy (8). Several subsequent studies have reported a close association between the Brixia score and the severity and prognosis of COVID-19, supporting clinical decision-making and the development of predictive models (15,16). However,

Highlight box

Key findings

- Our study reveals that for low-risk patients aged 70 years and above: (I) routine postoperative continuous oxygen therapy (COT) is appropriate, but about 7.85% necessitate escalated oxygen therapy. (II) Transitioning from COT to high-flow nasal cannula (HFNC) yields satisfactory outcomes. (III) The radiographic assessment of lung edema (RALE) score, coupled with surgical details, is a superior predictor of COT failure within 24 h post-surgery compared to the Brixia score.

What is known and what is new?

- Despite the increasing popularity of HFNC for postoperative oxygen therapy, COT continues to be the established standard. According to the guidelines from the European Respiratory Society (ERS), both HFNC and COT are recommended options for low-risk postoperative patients. In settings with limited resources, particularly among individuals aged over 70 years after thoracic surgery, choosing COT might be a more economically viable option.
- However, despite these considerations, there is a notable absence of predictive research on COT failure. This gap in knowledge highlights the need for further investigation into factors influencing the success or failure of COT in postoperative patients, particularly in resource-constrained settings.

What is the implication, and what should change now?

- Given the growing elderly population and prevalent use of COT in postoperative thoracic care, our findings offer new perspectives. The RALE score's efficacy in early COT failure prediction, combined with convenient bedside chest X-ray scoring, can guide oxygen therapy escalation effectively. This approach holds promise for achieving satisfactory results in resource-limited settings, potentially influencing clinical practices and resource allocation policies.

it is important to note that the Brixia score has only been reported in the context of COVID-19.

COT, the primary postoperative respiratory treatment, is potentially more cost-effective in low-income countries due to resource limitations, despite variable costs between nations and hospitals. Guidelines suggest noninvasive ventilation (NIV) or continuous positive airway pressure (CPAP) for AHRF following COT failure. HFNC may be considered for patients with low tolerance to low oxygen levels (17). Our study, focusing on low-risk thoracic surgery patients aged 70 years and above, administered postoperative COT, with HFNC recommended upon COT failure. Chest X-ray scores within 24 h postoperatively were investigated for predicting COT failure and establishing a link between radiological findings and clinical status.

The aim of this study was to assess the effectiveness of two chest X-ray scores, the RALE score and the Brixia score, in predicting COT treatment failure in patients over 70 years of age after thoracic surgery. We present this article in accordance with the TRIPOD reporting checklist (available at <https://jtd.amegroups.com/article/view/10.21037/jtd-23-1786/rc>).

Methods

Source of data

This study is a single-center retrospective investigation involving patients aged 70 years and above who underwent surgery at the First Affiliated Hospital of the Army Medical University from January 2019 to December 2021. All postoperative patients received COT upon returning to the hospital ward. A standard bedside chest X-ray was routinely performed within 24 h, and the resulting chest X-ray images were collected and assessed using the RALE score and Brixia score. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical approval for this retrospective study was obtained from the Ethics Committee of the First Affiliated Hospital of the Army Medical University (ethics ID: KY202262). Given the retrospective nature of the study, the requirement for informed consent was waived.

Selection of participants and definitions

Inclusion criteria: patients aged 70 years and above, post-thoracic surgery, receiving COT in the ward, with outcomes of either successful discharge or oxygen therapy escalation

due to COT failure. Exclusion criteria: (I) age <70 years; (II) high-risk patients with preoperative oxygen saturation (SpO_2) <92% and preoperative hemoglobin (Hb) ≤ 10 g/dL, receiving immediate HFNC postoperatively; (III) body mass index (BMI) >24 kg/m²; (IV) history of obstructive sleep apnea, lung transplantation, or other significant medical conditions. Cases with severe record omissions or critical missing information were excluded (*Figure 1*).

COT failure criteria: patients with AHRF, partial pressure of arterial oxygen (PaO_2)/fraction of inspired oxygen (FiO_2) 100–300 mmHg, or SpO_2 <92%, with increased respiratory rate (RR) (>30 breaths per minute), elevated heart rate, and exclusion of hypoxemia from other complications (e.g., bleeding or heart failure) (18). Patients were categorized into the COT success group or COT failure group based on postoperative outcomes. The COT failure group included patients transitioning to HFNC therapy for unresolved mild to moderate AHRF (3,4).

Reintubation criteria: for severe hypoxemia post-COT or HFNC therapy, persistently unresolved moderate hypoxemia after HFNC therapy, hemodynamic instability, deteriorating neurological status, or meeting at least two of the following criteria: persistent or worsening signs of respiratory failure, RR >40 breaths per minute, copious tracheal secretions, pH <7.35, SpO_2 persistently <90% for 5 minutes, and poor response to oxygenation techniques (19).

X-ray scoring systems for severity assessment

After returning to the ward, a bedside chest X-ray was routinely conducted within 24 h of COT treatment, utilizing both anteroposterior (AP) and posteroanterior (PA) projections with a portable digital radiographic device (Technix, Model TMB 400 DR, Grassobbio, Italy). The Brixia scoring system (20) and RLAE system (7) were employed to assess pulmonary abnormalities within 24 h of postoperative COT in the two patient groups.

The Brixia score categorizes the chest X-ray into six regions in AP or PA views, assigning scores based on the characteristics and extent of pulmonary abnormalities: 0 (no abnormality), 1 (interstitial infiltration), 2 (predominantly interstitial), or 3 (predominantly alveolar). The total score ranges from 0 to 18 (*Figure 2A*).

For the RALE score, each radiograph was divided into quadrants, with consolidation scores (0: none, 1: <25%, 2: 25–49%, 3: 50–75%, 4: >75%) representing alveolar opacities' extent within each quadrant. Additionally, density scores (1= hazy, 2= moderate, 3= dense) evaluated overall

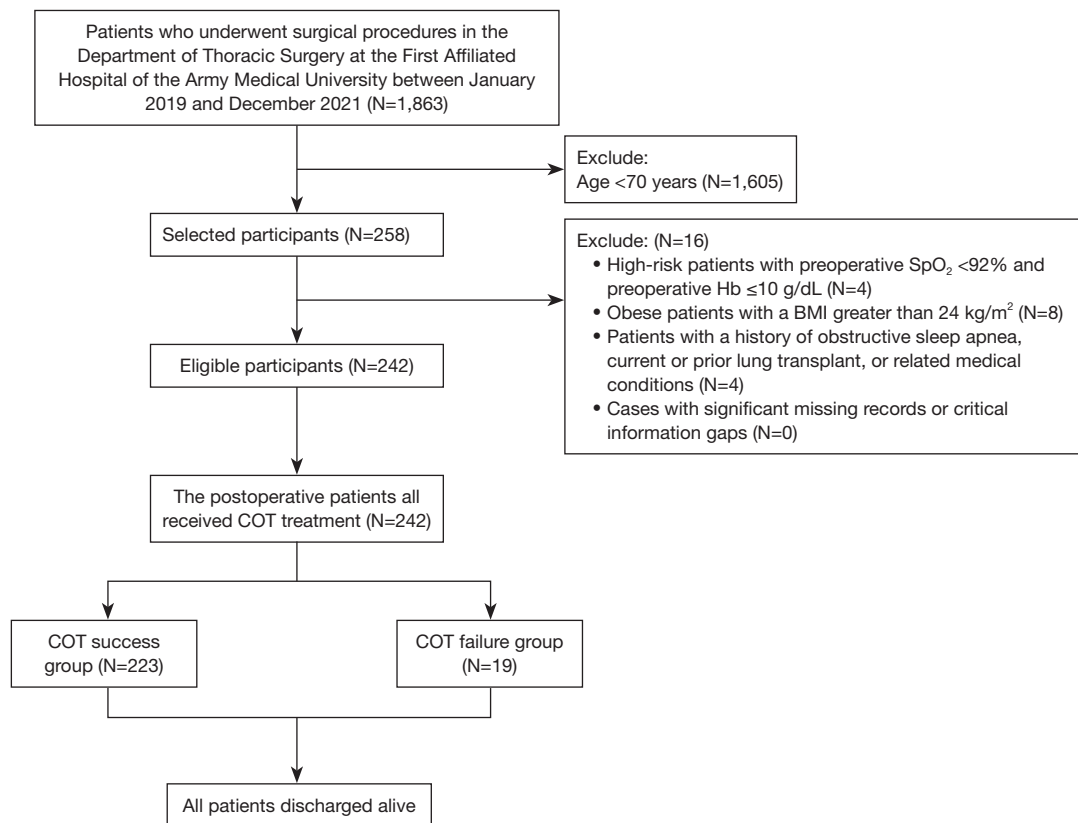


Figure 1 The flow-chart for population selection. SpO₂, saturation of peripheral oxygen; Hb, hemoglobin; BMI, body mass index; COT, continuous oxygen therapy.

opacification density. The final RALE score ranged from 0 (no infiltrates) to 48 (dense consolidation in over 75% of each quadrant) (Figure 2B).

We trained two radiologists with 2 and 3 years of experience, respectively, to apply this scoring system to our chest X-ray images. They independently reviewed and scored all the images, and the average score was used for the analysis. In case of disagreement between the two radiologists, a senior radiologist with more than 10 years of experience and expertise in thoracic imaging reviewed the images and made the final decision.

Data collection

Patient data, including preoperative, intraoperative, and postoperative clinical information, were primarily collected from the electronic medical records system of the First Affiliated Hospital of the Army Medical University. There was no data loss in this study. Preoperative variables included patient age, gender, BMI, smoking index, forced expiratory volume in 1 second/forced vital capacity (FEV₁/

FVC), surgical location, Hb levels, surgical approach, temperature, heart rate, RR, systolic and diastolic blood pressure. Intraoperative variables comprised surgical duration and intraoperative blood loss. Postoperative variables encompassed Brixia score and RALE score.

Statistical analysis

This study employed SPSS (version 26.0; IBM, NY, USA), R (version 4.3.1; R Foundation, Austria), and Python (version 3.1.5) for statistical analysis, with a two-tailed P value threshold of <0.05. Normality of continuous variables was assessed using the Kolmogorov-Smirnov test. Normally distributed data were presented as mean ± standard deviation; otherwise, median and quartiles were utilized. Categorical variables were expressed as frequencies and percentages.

Initial risk factor screening involved univariate analysis. For normally distributed data, two-sample *t*-tests were applied, and non-normally distributed data were analyzed using the Mann-Whitney *U*-test. Categorical variables were

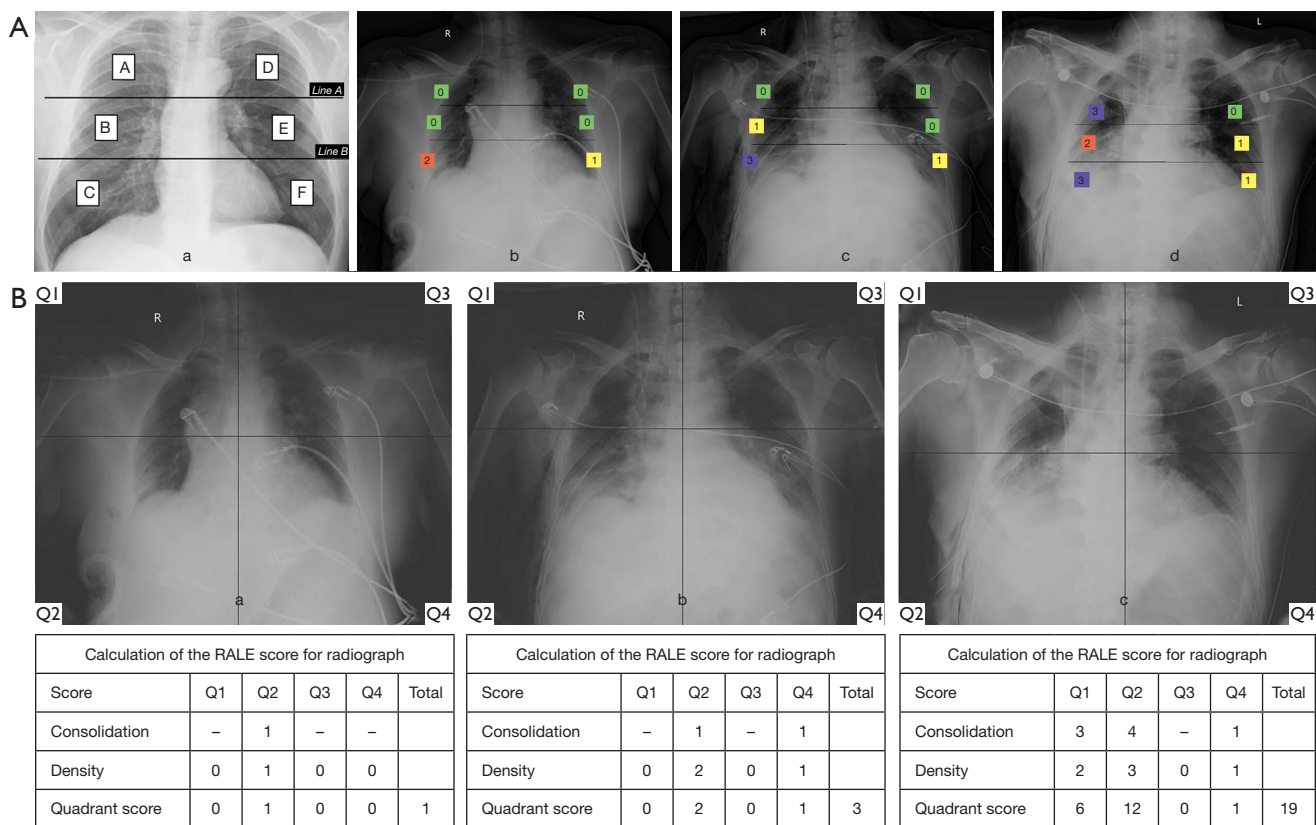


Figure 2 Examples of Brixia and RALE scores for three patients. (A) (a) Division of lungs into six zones on frontal chest radiograph. Line A is drawn at the level of the inferior wall of the aortic arch. Line B is drawn at the level of the inferior wall of the right inferior pulmonary vein; (b) Brixia score of a 71-year-old female patient in the COT success group after lung resection within 24 h postoperatively; (c) Brixia score of a 70-year-old male patient in the COT failure group after esophageal cancer radical surgery within 24 h postoperatively; (d) Brixia score of a 72-year-old male patient in the COT failure group after lung resection within 24 h postoperatively. (B) (a) RALE score of a 71-year-old female patient in the COT success group after lung resection within 24 h postoperatively; (b) RALE score of a 70-year-old male patient in the COT failure group after esophageal cancer radical surgery within 24 h postoperatively; (c) RALE score of a 72-year-old male patient in the COT failure group after lung resection within 24 h postoperatively. RALE, radiographic assessment of lung edema; COT, continuous oxygen therapy.

compared using Chi-squared or Fisher’s exact test. Variables with $P < 0.1$ or clinical significance in univariate analysis were further assessed in multivariable logistic regression for independent risk factors.

Propensity score analysis with 1:2 matching was conducted using the nearest neighbor method, employing a caliper width set to 0.1 times the standard deviation of the logit of the propensity score. Results were visualized through forest plots. Model calibration and discrimination were evaluated using the Hosmer-Lemeshow test, calibration curves, receiver operating characteristic (ROC) curves, and area under the curve (AUC). ROC curves for COT failure prediction were generated using independent risk factors before and after

matching. Clinical utility was assessed through decision curves and clinical impact curves analysis.

Results

Baseline characteristics

In a group of 1,863 patients undergoing thoracic surgery, 242 met the inclusion criteria and received postoperative COT. Among them, 223 had successful COT, while 19 (7.85%) faced COT failure and were subsequently escalated to HFNC therapy, lasting an average of 6 days (ranging from 2 to 27 days). All patients were discharged

Table 1 Baseline characteristics of the two groups before matching

Characteristic	COT success (n=223)	COT failure (n=19)	P
Gender, male	122 (54.7)	14 (73.7)	0.149
Age, years	72 [71–75]	73 [71–76]	0.280
BMI, kg/m ²	23.6 [21.5–25.5]	21.1 [20.2–26.0]	0.217
Smoking index	0 [0–420]	0 [0–400]	0.415
FEV ₁ /FVC, %	79.72 [76.12–85.12]	80.51 [68.99–87.8]	0.954
COPD	27 (12.1)	3 (15.8)	0.714
Hypertension	35 (15.7)	3 (15.8)	0.662
Diabetes	19 (8.5)	3 (15.8)	0.394
Location			0.003
Lung	192 (86.1)	11 (57.9)	
Esophagus	20 (9.0)	7 (36.8)	
Others	11 (4.9)	1 (5.3)	
Operation times, h	2.8 [2.1–3.3]	3.4 [2.5–4.6]	0.003
Hb, g/L	131.6±15.5	133.6±12.7	0.597
Temperature, °C	36.5 [36.3–36.6]	36.5 [36.5–36.7]	0.071
HR, beats/minute	79 [74–85]	81 [75–85]	0.490
RR, bpm	20 [19–20]	20 [19–20]	0.589
SBP, mmHg	128 [123–139]	127 [124–139]	0.808
DBP, mmHg	76 [71–81]	76 [73–80]	0.653
Surgical approach			0.004
Thoracoscopy	188 (84.3)	8 (42.1)	
Thoracotomy	21 (9.4)	5 (26.3)	
Thoracoabdominal laparoscopy	14 (6.3)	6 (31.6)	
Peroperative bleeding, mL	150 [100–200]	200 [100–250]	0.033
Brixia score	3 [2–5]	5 [3–8]	0.003
RALE score	4 [2–6]	10 [2–17]	0.002

Data are presented as number (percentage), median [interquartile range] or mean ± standard deviation. COT, continuous oxygen therapy; BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; RALE, radiographic assessment of lung edema.

alive. Noteworthy preoperative differences were observed, especially in surgical location (P=0.003). Specifically, 20 (9.0%) of the COT group underwent esophageal cancer radical surgery, compared to 7 (36.8%) in the COT failure group. The COT failure group also had a significantly longer average operation time (3.4 vs. 2.8 h, P=0.003) and a higher proportion of thoracotomy (26.3% vs. 9.4%,

P=0.004) (Table 1).

Within 24 h postoperatively, patients experiencing COT failure exhibited higher Brixia and RALE scores compared to the success group (P=0.003 and P=0.002, respectively). Propensity score matching (1:2) maintained significant differences in esophageal cancer cases (P=0.034), operation time (P=0.007), and thoracotomy proportion (P=0.008).

Table 2 Baseline characteristics of the two groups after matching

Characteristic	COT success (n=34)	COT failure (n=19)	P
Gender, male	22 (64.7)	14 (73.7)	0.555
Age, years	72 [71–74]	73 [71–76]	0.349
BMI, kg/m ²	22.04±3.10	22.54±3.43	0.591
Smoking index	0 [0–525]	0 [0–400]	0.604
FEV ₁ /FVC, %	77.50±7.75	79.32±9.77	0.460
COPD	6 (17.6)	3 (15.8)	0.836
Hypertension	8 (23.5)	4 (21.1)	0.863
Diabetes	5 (14.7)	3 (15.8)	0.916
Location			0.034
Lung	29 (85.3)	11 (57.9)	
Esophagus	3 (8.8)	7 (36.8)	
Others	2 (5.9)	1 (5.3)	
Operation time, h	2.7±1.26	3.74±1.39	0.007
Hb, g/L	130.62±11.10	133.58±12.69	0.381
Temperature, °C	36.5 [36.3–36.6]	36.5 [36.5–36.7]	0.071
HR, beats/minute	76.68±9.33	80.26±8.56	0.173
RR, bpm	20 [19–20]	20 [19–20]	0.589
SBP, mmHg	128.41±11.8	128.32±12.39	0.978
DBP, mmHg	77.5±8.23	77.58±9.05	0.974
Surgical approach			0.008
Thoracoscopy	28 (82.4)	8 (42.1)	
Thoracotomy	3 (8.8)	5 (26.3)	
Thoracoabdominal laparoscopy	3 (8.8)	6 (31.6)	
Peroperative bleeding, mL	150 [87.5–200]	200 [100–250]	0.080
Brixia score	3 [2–4]	5 [3–8]	0.001
RALE score	3.5 [2–5]	10 [2–17]	0.012

Data are presented as number (percentage), median [interquartile range] or mean ± standard deviation. COT, continuous oxygen therapy; BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; RALE, radiographic assessment of lung edema.

Following the matching, Brixia and RALE scores remained significantly different between groups ($P=0.001$ and $P=0.012$, respectively). However, median scores in both groups increased. The COT success group had a median Brixia score of 3 (range: 2–4) and a median RALE score of 3.5 (range: 2–5), while the COT failure group had a median Brixia score of 5 (range: 3–8) and a median RALE score of

10 (range: 2–17) (*Table 2*). For continuous variables with a significance level of $P<0.05$, their data distribution will be visually represented using box plots (*Figures 3,4*).

Construction of the prediction model

As shown in *Table 3*, the results of univariate logistic

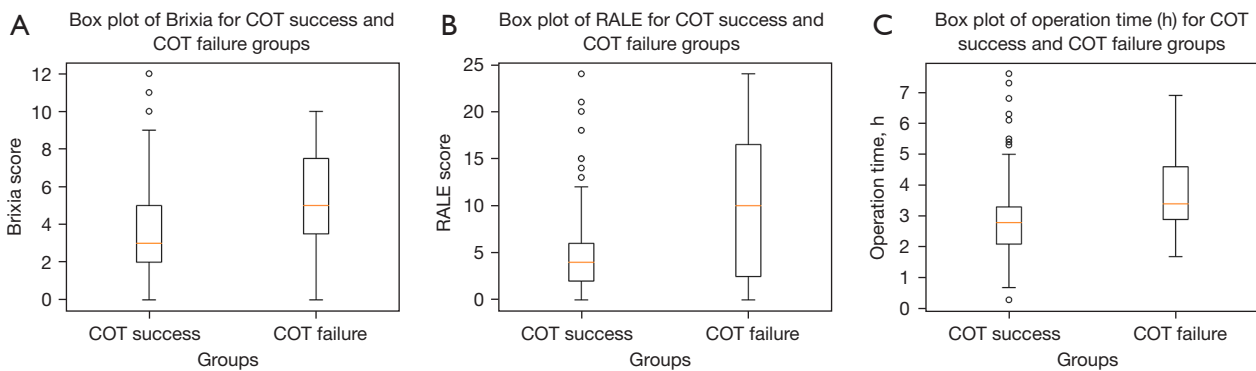


Figure 3 The data distribution in COT success and COT failure groups before matching. The boxes depict the IQR, with the median indicated by a horizontal line inside each box. Whiskers extend to the minimum and maximum values within 1.5 times the IQR. Outliers beyond this range are individually plotted. (A) Distribution of Brixia scores in the two groups; (B) data distribution of RALE scores in the two groups; (C) data distribution of operation time in the two groups. COT, continuous oxygen therapy; RALE, radiographic assessment of lung edema; IQR, interquartile range.

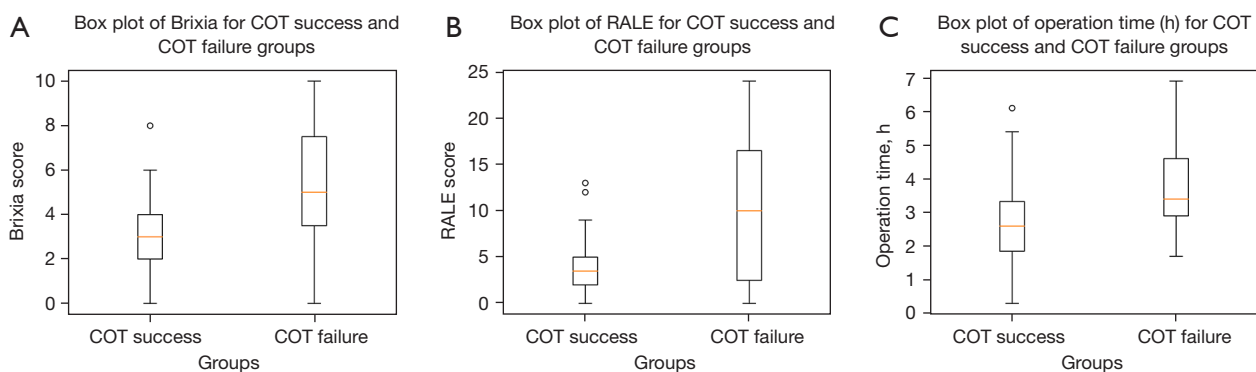


Figure 4 The data distribution in COT success and COT failure groups after matching. The boxes depict the IQR, with the median indicated by a horizontal line inside each box. Whiskers extend to the minimum and maximum values within 1.5 times the IQR. Outliers beyond this range are individually plotted. (A) The distribution of Brixia scores in the two groups; (B) the data distribution of RALE scores in the two groups; (C) the data distribution of operation time in the two groups. COT, continuous oxygen therapy; RALE, radiographic assessment of lung edema; IQR, interquartile range.

regression analysis revealed significant associations ($P < 0.1$) between COT failure and surgical location, duration of surgery, surgical approach, RALE score, Brixia score, and preoperative body temperature.

In the multivariate logistic regression analysis, two independent risk factors for COT failure were identified: the surgical approach thoracotomy [odds ratio (OR) = 3.19, 95% CI: 0.85–11.91, $P = 0.084$] and thoracoabdominal laparoscopy (OR = 8.96, 95% CI: 2.43–32.98, $P = 0.001$), and the RALE score (OR = 1.18, 95% CI: 1.08–1.28, $P < 0.001$). A forest plot was generated to illustrate the impact and confidence intervals of each independent variable (Figure S1).

Furthermore, after conducting 1:2 propensity score

matching, similar results were observed. The univariate analysis revealed significant associations ($P < 0.1$) between COT failure and surgical location, surgical procedure, Brixia score, RALE score, and preoperative body temperature. Two independent risk factors for the failure of COT, identified through multivariate analysis, include the duration of surgery (OR = 2.14, 95% CI: 1.16–3.95, $P = 0.015$) and RALE score (OR = 1.27, 95% CI: 1.09–1.47, $P = 0.002$) (Table 4). For relevant forest plots, please refer to Figure S2.

Validation of the prediction model

The calibration curve and Hosmer-Lemeshow test

Table 3 Prognostic factors for COT failure before matching

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Age	1.07 (0.92–1.24)	0.374		
Sex				
Female	Ref			
Male	0.43 (0.15–1.24)	0.118		
BMI	0.91 (0.78–1.05)	0.200		
Smoking index	1.00 (1.00–1.00)	0.891		
Location				
Lung	Ref			
Esophagus	6.11 (2.13–17.52)	0.001		
Others	1.59 (0.19–13.42)	0.672		
FEV ₁ /FVC	0.99 (0.94–1.04)	0.779		
COPD				
No	Ref			
Yes	1.36 (0.37–4.98)	0.641		
Hypertension				
No	Ref			
Yes	1.01 (0.28–3.64)	0.991		
Diabetes				
No	Ref			
Yes	2.01 (0.54–7.53)	0.299		
Hb	1.01 (0.98–1.04)	0.596		
Operation time	1.69 (1.21–2.37)	0.002		
Surgical approach				
Thoracoscopy	Ref			
Thoracotomy	5.60 (1.68–18.67)	0.005	3.19 (0.85–11.91)	0.084
Thoracoabdominal laparoscopy	10.07 (3.07–33.09)	<0.001	8.96 (2.43–32.98)	0.001
Peroperative bleeding	1.00 (1.00–1.00)	0.639		
Brixia score	1.38 (1.14–1.67)	0.001		
RALE score	1.19 (1.11–1.29)	<0.001	1.18 (1.08–1.28)	<0.001
Temperature	10.35 (0.96–112.02)	0.054		
HR	1.02 (0.96–1.08)	0.505		
RR	1.15 (0.65–2.04)	0.623		
SBP	0.99 (0.96–1.03)	0.712		
DBP	1.02 (0.96–1.08)	0.480		

COT, continuous oxygen therapy; OR, odds ratio; CI, confidence interval; BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; RALE, radiographic assessment of lung edema; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Table 4 Prognostic factors for COT failure after matching

Variables	Univariate analysis		Multivariate analysis	
	OR (95% CI)	P value	OR (95% CI)	P value
Age	1.08 (0.91–1.28)	0.391		
Sex				
Female	Ref			
Male	0.74 (0.23–2.40)	0.612		
BMI	1.00 (0.85–1.18)	0.985		
Smoking index	1.00 (1.00–1.00)	0.672		
Location				
Lung	Ref			
Esophagus	6.68 (1.65–27.00)	0.008		
Others	1.27 (0.12–13.46)	0.841		
FEV ₁ /FVC	1.03 (1.00–1.10)	0.453		
COPD				
No	Ref			
Yes	1.34 (0.30–6.02)	0.699		
Hypertension				
No	Ref			
Yes	1.10 (0.360–3.31)	0.991		
Diabetes				
No	Ref			
Yes	1.09 (0.23–5.16)	0.916		
Hb	1.01 (0.97–1.06)	0.616		
Operation time	1.94 (1.21–3.12)	0.006	2.14 (1.16–3.95)	0.015
Surgical approach				
Thoracoscopy	Ref			
Thoracotomy	4.06 (0.99–16.63)	0.051		
Thoracoabdominal laparoscopy	7.31 (1.67–32.00)	0.008		
Peroperative bleeding	1.00 (1.01–1.00)	0.104		
Brixia score	1.59 (1.20–2.11)	0.001		
RALE score	1.25 (1.1–1.41)	<0.001	1.27 (1.09–1.47)	0.002
Temperature	20.53 (0.87–485.75)	0.061		
HR	1.04 (0.97–1.11)	0.293		
RR	1.15 (0.64–2.09)	0.639		
SBP	1.00 (0.95–1.05)	0.977		
DBP	1.00 (0.94–1.07)	0.974		

COT, continuous oxygen therapy; OR, odds ratio; CI, confidence interval; BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; RALE, radiographic assessment of lung edema; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.

confirmed the model's good fit (Figure S3, Hosmer-Lemeshow χ^2 : 11.858, $P=0.245$). The ROC curve demonstrated promising discriminatory ability (AUC: 0.768, 95% CI: 0.715–0.821). Surgical approach has an AUC of 0.718 (95% CI: 0.661–0.774), Brixia score has an AUC of 0.703 (95% CI: 0.646–0.761, cutoff: 2.187), and RALE score has an AUC of 0.712 (95% CI: 0.655–0.769, cutoff: 3.997) (Figure 5, Table 5).

For the Established Model, the accuracy was 0.785, sensitivity was 0.737, specificity was 0.789, positive predictive value (PPV) was 0.230, and negative predictive value (NPV) was 0.972. Surgical approach showed an accuracy of 0.822, sensitivity of 0.579, specificity of 0.843, PPV of 0.239, and NPV of 0.959. The Brixia score demonstrated an accuracy of 0.798, sensitivity of 0.474, specificity of 0.825, PPV of 0.188, and NPV of 0.948. The RALE score has an accuracy of 0.855, sensitivity of 0.632, specificity of 0.874, PPV of 0.300, and NPV of 0.965 (Table 5). The decision curve (Figure S4) and clinical impact curve (Figure S5) illustrated that, in comparison to “no treatment” and “full treatment” strategies, the use of this model results

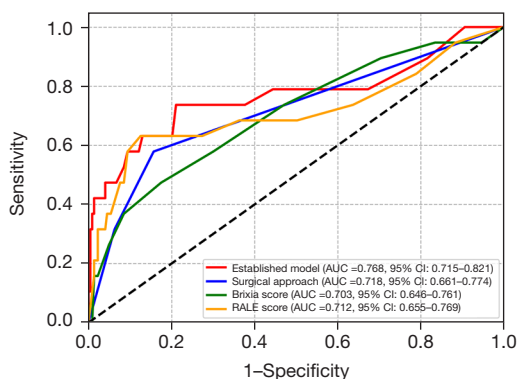


Figure 5 Receiver operating characteristic curves of 4 predictive models before matching. AUC, area under the curve; CI, confidence interval; RALE, radiographic assessment of lung edema.

Table 5 The predictive performance of established model, surgical approach, Brixia score and RALE score before matching

Model set	AUC (95% CI)	Accuracy	Sensitivity	Specificity	PPV	NPV	Brixia cut-off points	RALE cut-off points
Established model	0.768 (0.715–0.821)	0.785	0.737	0.789	0.230	0.972	1.338	2.676
Surgical approach	0.718 (0.661–0.774)	0.822	0.579	0.843	0.239	0.959	–	–
Brixia score	0.703 (0.646–0.761)	0.798	0.474	0.825	0.188	0.948	2.187	–
RALE score	0.712 (0.655–0.769)	0.855	0.632	0.874	0.300	0.965	–	3.977

RALE, radiographic assessment of lung edema; AUC, area under the curve; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

in increased clinical net benefit across nearly all probability thresholds, indicating strong clinical utility.

After 1:2 propensity score matching, our calibration curve affirmed a well-fitted model (Figure S6). The Hosmer-Lemeshow goodness-of-fit test supported this, yielding a χ^2 value of 8.410 with P of 0.395. The established model attained an AUC of 0.839 (95% CI: 0.740–0.938). Operation time, for predicting COT failure, has an AUC of 0.715 (95% CI: 0.594–0.837). Brixia score exhibited an AUC of 0.764 (95% CI: 0.650–0.878, cutoff: 6.027), and RALE score has an AUC of 0.710 (95% CI: 0.588–0.832, cutoff: 17.314) (Figure 6, Table 6).

Following matching, the established model's accuracy was 0.774, sensitivity was 0.842, specificity was 0.735, PPV was 0.640, and NPV is 0.893. The accuracy for operation time was 0.736, with sensitivity at 0.737, specificity at 0.735, PPV at 0.609, and NPV at 0.833. Brixia score's accuracy was 0.717, with sensitivity at 0.737, specificity at 0.706, PPV at 0.583, and NPV at 0.828. For RALE score, the accuracy was 0.811, sensitivity was 0.632, specificity was 0.912, PPV was 0.800, and NPV was 0.816 (Table 6). The decision curve (Figure S7) and clinical impact curve (Figure S8) continued to highlight the model's strong clinical utility, surpassing “no treatment” and “full treatment” strategies across a wide range of probability thresholds.

Discussion

Our scoring system has clinical implications for identifying and managing patients who are at risk of developing postoperative respiratory failure after thoracic surgery. By combining the RALE score, which reflects the extent and severity of lung injury, and the surgical approach, which indicates the degree of surgical trauma, our scoring system can provide a simple and convenient way to stratify patients according to their risk of COT failure.

Currently, there is a scarcity of research data on the

effectiveness of COT and HFNC in subgroups of elderly individuals and those with poor lung reserve (4). In the context of these vulnerable populations, this study discovered that in patients aged 70 years and above who are at low risk of respiratory complications: (I) postoperatively, COT can be administered routinely, but a subset, amounting to 7.85%, requires oxygen therapy escalation. (II) Regarding the escalation of oxygen therapy from COT, guidelines recommend NIV and CPAP, with HFNC considered for less tolerant patients. In this study, upgrading to HFNC yielded satisfactory treatment outcomes. (III) Within 24 h postsurgery, the routine bedside chest X-ray score, when combined with the surgical approach, RALE score was better at predicting COT failure than the Brixia score. The surgical approach constitutes a vital predictive parameter in the model established in this study. We categorized surgical approach into thoracoscopy, thoracotomy (OR =5.60, 95% CI: 1.68–18.67, P=0.005), and thoracoabdominal laparoscopy (OR =10.07, 95% CI: 3.07–33.09, P<0.001). With the introduction of minimally invasive surgical concepts and the continual

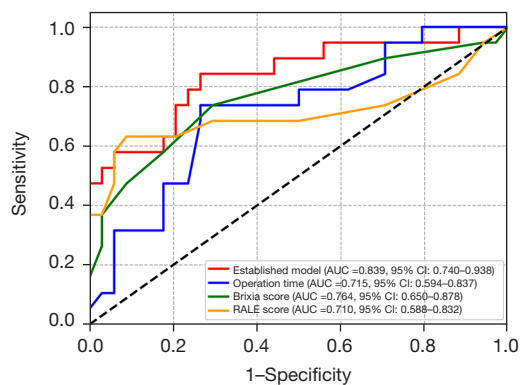


Figure 6 Receiver operating characteristic curves of 4 predictive models after matching. AUC, area under the curve; CI, confidence interval; RALE, radiographic assessment of lung edema.

refinement of laparoscopic techniques, thoracoscopic surgery has gained widespread recognition among both physicians and patients for its safety, reliability, and long-term effectiveness. Conversely, open-chest surgery imposes several disadvantages for patients, including significant surgical trauma, long-term postoperative chronic pain, higher postoperative complications, extended hospitalization periods, and prolonged recovery times (21,22). Currently, open-chest procedures are primarily reserved for challenging surgeries or complex anatomical structures. Thoracoabdominal laparoscopy is predominantly used in esophageal cancer patients, where radical surgery remains the most crucial treatment modality for resectable esophageal cancer. In pursuit of surgical efficacy, this inevitably results in extensive surgery and a higher rate of postoperative complications (23). Furthermore, patients must recover from the trauma inflicted during surgery, such as the extended surgery duration and the wide-ranging traumatized areas experienced by esophageal cancer patients, often involving the neck, chest, and abdomen. Our findings reveal that when the surgical approach is thoracotomy or thoracoabdominal laparoscopy, patients postoperatively are more prone to requiring an upgrade to HFNC therapy compared to those undergoing thoracoscopy, aligning with our expectations.

Currently, for chest X-ray scoring, the lungs are divided into six zones according to the Brixia score, Toussie score, and Al-Smadi score, while the RALE score divides the lungs into four quadrants. Therefore, we selected two representative scoring methods with different divisions for this study. Additionally, considering our focus on patients at low risk of respiratory complications, it is preferable to employ scoring tools with a broader score range. Consequently, we chose the Brixia score and the RALE score. Up to this point, the Brixia score has demonstrated its utility as a clear and straightforward tool, primarily for COVID-19 (24). To the best of our knowledge, our

Table 6 The predictive performance of established model, operation time, Brixia score and RALE score after matching

Model set	AUC (95% CI)	Accuracy	Sensitivity	Specificity	PPV	NPV	Brixia cut-off points	RALE cut-off points
Established model	0.839 (0.740–0.938)	0.774	0.842	0.735	0.640	0.893	4.635	9.271
Operation time	0.715 (0.594–0.837)	0.736	0.737	0.735	0.609	0.833	–	–
Brixia score	0.764 (0.650–0.878)	0.717	0.737	0.706	0.583	0.828	6.027	–
RALE score	0.710 (0.588–0.832)	0.811	0.632	0.912	0.800	0.816	–	17.314

RALE, radiographic assessment of lung edema; AUC, area under the curve; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.

study is the first to evaluate the Brixia score as a predictive indicator for diseases other than COVID-19. The RALE score has been reported to have utility in risk stratification and prognosis in conditions such as pulmonary edema (25), ARDS (26,27) and COVID-19 (28). Our study also revealed the roles of both scores in predicting postoperative COT failure in elderly, low-risk thoracic surgery patients. The RALE score outperformed the Brixia score, especially in the logistic multivariate regression analysis, where the RALE score emerged as an independent risk factor, while the Brixia score did not. The possible explanation for this distinction is that these elderly, low-risk patients showed minimal chest X-ray changes within 24 h, resulting in lower overall scores. In contrast to the narrower score range of the Brixia score (ranging from 0 to 18), the broader range of the RALE score (ranging from 0 to 48) was better equipped to reveal these differences. Our results show that the cut-off value of the RALE score for the established model after matching is 9.271, which means that when a patient's postoperative chest radiograph RALE score is higher than this value, HFNC should be considered instead of COT. We prefer to use the cut-off value after matching because the matching process reduced the imbalance of covariates between the two groups, resulting in a more homogeneous and comparable sample. This suggests that the RALE score might be more sensitive, especially in patients with low scoring levels. For the treatment decision between COT or HFNC after thoracic surgery, the conclusions from previous studies have been inconsistent, with a low level of evidence (29,30). Therefore, we were unable to identify any previously published studies comparing the predictive value of the RALE score for COT failure with our study results.

This study has several limitations. First, it is a single-center retrospective study with a small sample size and a limited patient population. The retrospective data collection and assessment may introduce some unavoidable biases. Therefore, our findings should be further validated in a large sample randomized controlled trial. Second, the COT failure group had relatively few cases. While this reflects the real proportion of COT failure in elderly, low-risk patients, it might lead to insufficient evidence, even though matching statistical corrections had been performed. Third, our model development and validation were based on the same data set, which may lead to overfitting and optimistic estimates of model performance. Although we used bootstrapping to correct for overfitting and to obtain unbiased estimates of model performance, external validation in an independent data set is needed to confirm the validity and reliability of

our model and we plan to conduct a prospective multicenter study in the future to validate our findings.

Conclusions

In summary, regarding postoperative bedside chest X-ray information in elderly, low-risk patients undergoing thoracic surgery, the combination of the RALE score with surgical approach may be more effective in predicting the risk of postoperative COT failure transitioning to HFNC compared to the Brixia score. This routine, cost-effective, and noninvasive approach aids in assessing the severity of postoperative lung lesions, monitoring treatment response, and providing early warning signs for oxygen therapy escalation. However, further prospective research is needed to validate the effectiveness and applicability of this predictive model in different settings and populations.

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Footnote

Reporting Checklist: The authors have completed the TRIPOD reporting checklist. Available at <https://jtd.amegroups.com/article/view/10.21037/jtd-23-1786/rc>

Data Sharing Statement: Available at <https://jtd.amegroups.com/article/view/10.21037/jtd-23-1786/dss>

Peer Review File: Available at <https://jtd.amegroups.com/article/view/10.21037/jtd-23-1786/prf>

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at <https://jtd.amegroups.com/article/view/10.21037/jtd-23-1786/coif>). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. This study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). Ethical approval for this retrospective

study was obtained from the Ethics Committee of the First Affiliated Hospital of the Army Medical University (ethics ID: KY202262). Given the retrospective nature of the study, the requirement for informed consent was waived.

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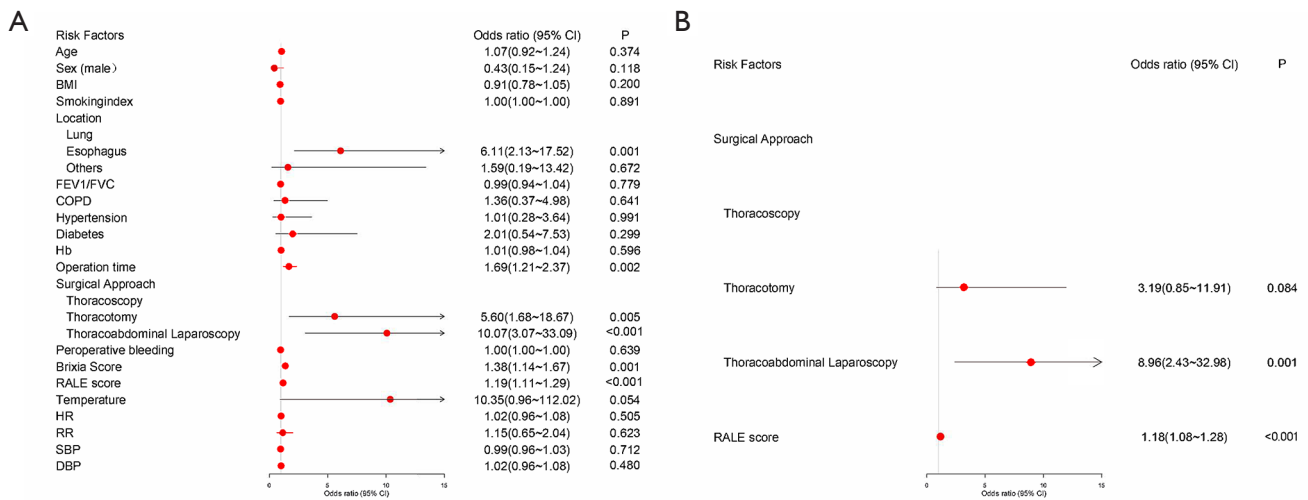


Figure S1 The forest plots for visualizing univariate and multivariate logistic regression analyses before matching, showcasing point estimates and 95% confidence intervals for each predictor. (A) Univariate logistic regression forest plot; (B) multivariate logistic regression forest plot. BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; RALE, radiographic assessment of lung edema; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.

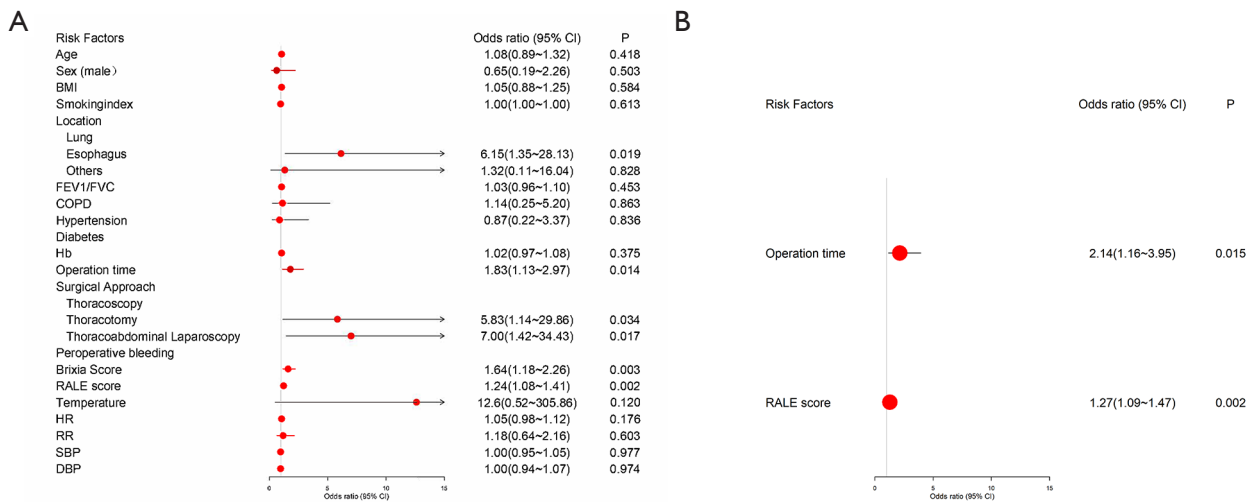


Figure S2 Forest plots for visualizing univariate and multivariate logistic regression analyses after matching, showcasing point estimates and 95% confidence intervals for each predictor. (A) Univariate logistic regression forest plot; (B) multivariate logistic regression forest plot. BMI, body mass index; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; COPD, chronic obstructive pulmonary disease; Hb, hemoglobin; RALE, radiographic assessment of lung edema; HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure.

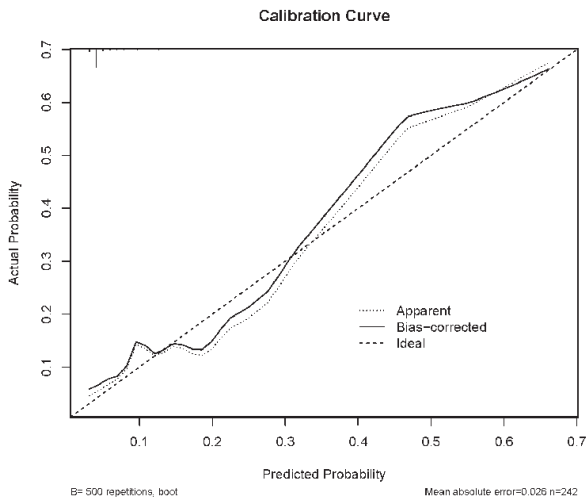


Figure S3 Model calibration and discrimination before matching.

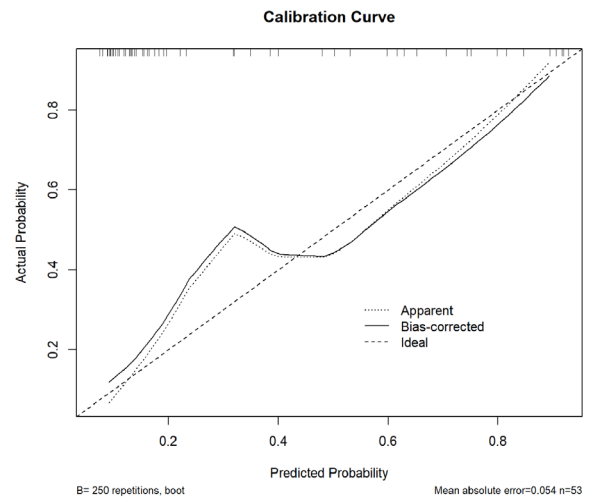


Figure S6 Model calibration and discrimination after matching.

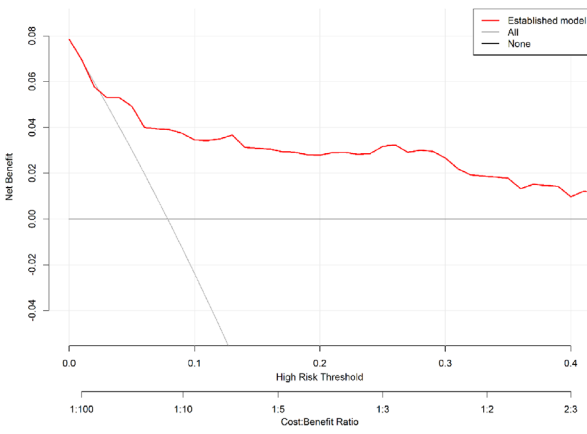


Figure S4 Decision curve analysis curve before matching.

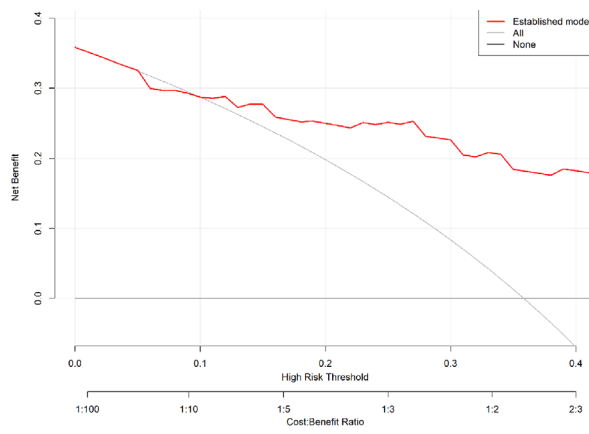


Figure S7 Decision curve analysis curve after matching.

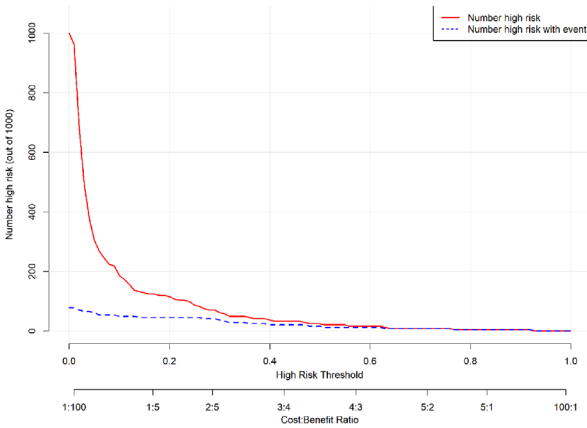


Figure S5 Clinical impact curve before matching.

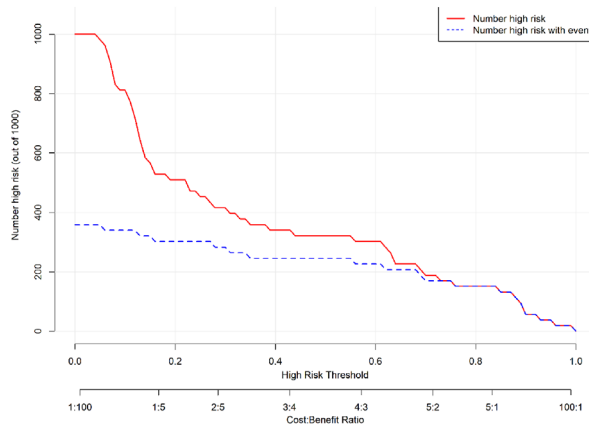


Figure S8 Clinical impact curve after matching.