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Analysis of risk factors for hypoxemia in PACU for patients undergoing thoracoscopic lung cancer resection based on logistic regression model

Xi Luo[1], Yanmei Ying[1], Lu Yin[1] and Pan Chang[2,3*]

Abstract

Objective This study aims to identify risk factors of hypoxemia in patients undergoin thoracoscopic lung surgery during their stay in the post-anesthesia care unit (PACU). Hypoxemia was defined as any instance of SpO_2 ≤90% lasting for more than one minute during the PACU stay.

Methods We conducted a prospective research involving 398 patients who underwent elective thoracoscopic lung surgery in West China Hospital, Sichuan University, from April to July 2024. Patients were classified into hypoxemia and non-hypoxemia groups based on the presence of hypoxemia in the PACU. We compared clinical data between the two groups to identify factors influencing hypoxemia. Variables with statistical significance ($P<0.05$) in univariate analysis were included in logistic regression to identify independent risk factors for hypoxemia.

Results Among the 398 patients studied, 149 (37.4%) experienced hypoxemia. Univariate analysis indicated significant differences in age, BMI, height, ASA classification, hypertension, diabetes, lung function test with Forced Expiratory Volume at 1 s / Forced Vital Capacity (FEV1/FVC), and awakening time between the groups. Logistic regression revealed that age, BMI, ASA classification, hypertension, diabetes, and awakening time were independent risk factors for hypoxemia during anesthesia recovery, while preoperative SpO_2 upon entering operating room (OR = 0.882, 95% CI: 0.783–0.993, $P=0.038$) was identified as a protective factor.

Conclusion Age, BMI, ASA classification, and preoperative conditions such as hypertension and diabetes are found to contribute to an increased incidence of hypoxemia in PACU following thoracoscopic lung surgery. Emphasizing preoperative lung function assessments and enhanced monitoring may also facilitate timely interventions, thereby improving post-anesthesia recovery and patient outcomes.

Keywords Hypoxemia, PACU, Thoracoscopic lung surgery, Logistic regression, Postoperative recovery, SpO_2, Post-extubation pain, Duration of PACU stay

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Introduction

Lung cancer is the most prevalent malignant tumor worldwide, accounting for approximately 14% of all new cancer cases annually [1]. Surgery remains the primary treatment modality. With the rapid development of minimally invasive techniques, thoracoscopic lung surgery has become widely adopted due to its advantages, including reduced postoperative pain, minimal impact on lung function, fewer complications, quicker recovery, and shorter hospital stays [2]. However, despite these benefits, respiratory complications, particularly hypoxemia, remain common during the post-anesthesia care unit (PACU) recovery period and can significantly affect patient outcomes [3–7].

Hypoxemia, characterized by inadequate oxygen levels in the blood, is commonly defined by a peripheral oxygen saturation (SpO_2) ≤ 90% for more than one minute [8–10]. Causes of hypoxemia during recovery include surgical trauma, residual anesthetics, respiratory depression, and impaired ventilation-perfusion matching [11]. Hypoxemia not only delays recovery and extubation but also increases the risk of cardiovascular complications and postoperative morbidity and mortality [12]. Reported incidence rates of postoperative hypoxemia following thoracoscopic surgery range from 30% to over 35% [13–15].

Although several studies have explored risk factors for hypoxemia in broader surgical or ICU populations, there is a significant lack of research specifically focusing on hypoxemia in the PACU among patients undergoing thoracoscopic lung cancer surgery [16, 17]. This is a critical knowledge gap, as the PACU is a high-risk phase where early respiratory deterioration can develop rapidly and unpredictably. Currently, few studies offer clear evidence on perioperative predictors of hypoxemia in this specific population, limiting the ability of clinicians to identify at-risk patients and take preemptive action.

In light of this gap, the present study aims to analyze the perioperative risk factors associated with hypoxemia in the PACU following thoracoscopic lung cancer surgery, based on a prospective observational cohort. By identifying independent predictors through logistic regression modeling, we hope to assist clinicians in early risk assessment, optimize postoperative care, and develop tailored preventive strategies. Ultimately, this study seeks to enhance patient safety, reduce complications, and contribute practical clinical evidence to thoracic surgical and anesthetic practice.

Materials and methods

Study population

This prospective observational study received approval from the Ethical Committee of the West China Hospital of Sichuan University on 24 February 2024 (Approval No. 2024 – 611), and was registered with the Chinese Clinical Trial Registry (Registration No. ChiCTR2400083595, http://www.chictr.org.cn). We screened 398 patients who underwent thoracoscopic lung surgery under general anesthesia and were admitted to the PACU at West China Hospital between April and July 2024. Written informed consent was obtained from all participants before entering the trial, and the study adhered to the Declaration of Helsinki.

Inclusion criteria

1. Age ≥ 18 years.
2. Elective thoracoscopic lung surgery.
3. ASA classification I-III.
4. Postoperative admission to the PACU with endotracheal intubation (controlled ventilation).

Exclusion criteria

1. Preoperative hypoxemia.
2. Previous thoracoscopic surgery.
3. Contraindications to anesthesia-related medications.
4. Severe deterioration during recovery requiring ICU transfer.

Anesthesia, surgery, and recovery methods

Upon admission to the operating room, intravenous access was established, and routine monitoring (heart rate, blood pressure, oxygen saturation, respiratory rate) was initiated. For preoxygenation, patients received oxygen via a mask at a flow rate of 8–10 L/min for 3 min before anesthesia induction. Anesthesia induction involved administering intravenous propofol (1-2.5 mg/kg), sufentanil (0.1–0.5 μg/kg), cisatracurium (0.15 mg/kg), midazolam (1–2 mg), and penehyclidine hydrochloride (0.5-1 mg). Assisted ventilation was provided after loss of consciousness, and a double-lumen endotracheal tube was inserted with video guidance. Mechanical ventilation was initiated with pure oxygen, employing a respiratory rate of 12–16 breaths/min, tidal volume of 6–8 ml/kg, and an inspiratory to expiratory ratio of 1:2. One-lung ventilation commenced before surgery, with adjustments made as necessary. Following chest closure, bilateral lung ventilation was restored, and anesthesia was maintained with a continuous intravenous infusion of remifentanil (0.1–0.2 μg/kg/min) and inhalation of 1-2% sevoflurane.

Postoperatively, patients were transferred to the PACU while still intubated, with mechanical ventilation parameters consistent with those used during surgery. Extubation was carried out on reaching extubation criteria with patients fully conscious, having good spontaneous efforts. To prevent respiratory depression from residual neuromuscular blockade, intravenous neostigmine

(0.02 mg/kg) and atropine (5–10 μg/kg) were administered before extubation. After extubation, patients received oxygen via face mask at 3–6 L/min for 15 min, and SpO_2 was monitored. If SpO_2 remained ≥ 92%, further observation occurred without oxygen supplementation; otherwise, oxygen therapy was continued.

Study methods

Clinical data collection and observation indicators

A clinical data collection form was developed to gather comprehensive patient information, including demographics (gender, age, height, weight, BMI, ASA classification), preoperative smoking and alcohol history, comorbidities (hypertension, diabetes, heart disease, hypothyroidism, hyperthyroidism), preoperative tests (pulmonary function tests: FEV1/FVC, Metabolic Equivalent of Task (MET) to evaluate exercise tolerance, hemoglobin levels), and surgery and anesthesia-related factors. These included surgical details (surgery type, surgical site and position, surgical duration, one-lung ventilation duration, intraoperative blood loss and fluid balance), anesthesia-related variables (anesthesia duration, ventilation mode, intraoperative administration of propofol, sufentanil, remifentanil, and cis-atracurium), vital signs (SpO_2 upon entering OR before anesthesia induction, heart rate, respiratory rate), pain scores (VAS upon PACU admission and discharge, and immediate post-extubation pain), as well as PACU outcomes (duration of PACU stay, delayed awakening, nausea, vomiting, chills, agitation, catheterization time, and the incidence of hypoxemia). VAS upon PACU admission and discharg was assessed using a Visual Analog Scale (VAS) ranging from 0 ('no pain') to 10 ('worst pain') [18]. Patients marked their pain level on a 10 cm line immediately after extubation. Exercise tolerance was classified using Metabolic Equivalent of Task (MET) values: <3 MET (light activities), 3–6 MET (moderate activities), and >6 MET (vigorous activities) [19]. Patients self-reported daily activities via a standardized questionnaire, and responses were mapped to MET values from validated tables.

Data were collected via bedside interviews and the West China Hospital Information Management System and the Anesthesia and Surgery Clinical Information System, encompassing basic patient information, intraoperative conditions, anesthesia usage, and PACU recovery details. The surgery duration was defined as the interval from skin incision to closure, while anesthesia duration encompassed from the time propofol injection was initiated to the session of continuous infusion of remifentanil.

Hypoxemia assessment

Hypoxemia was defined according to established literature and clinical practice. In this study, hypoxemia was defined and used interchangeably with peripheral oxygen saturation (SpO_2), specifically referring to any instance of SpO_2 ≤90% lasting for more than one minute after endotracheal tube (ETT) removal during the PACU stay [20]. No arterial oxygen partial pressure (PaO_2) measurements were included in this definition due to routine invasive arterial puncture for blood pressure measurement and arterial blood gas analysis was not performed for all patients, this study defined hypoxemia based on peripheral oxygen saturation (SpO_2) since SpO_2 is also widely used for hypoxemia screening. All patients were immediately transported to the PACU after the cessation of anesthetic infusion in the operating room and received the recovery period in the PACU where perioperative management was provided by trained anesthesiologists and nurses following standardized PACU protocols.

Sample size calculation

Based on previous studies, the incidence of postoperative hypoxemia in patients undergoing thoracic surgery was estimated to be 30% [15]. With a margin of error ($\triangle$) of 5%, the sample size was calculated as follows:

$N=\{U\alpha/\triangle\}^2\times P(1-P)=\{1.96/0.05\}^2\times 0.3\times (1-0.3)=323.$

Considering a 15% loss to follow-up, the expected sample size was estimated at 371 patients:

$323\times(1+15\%)=371.$

Statistical methods

Statistical analysis was performed using SPSS 26.0. Normally distributed data were expressed as mean ± standard deviation (SD) and compared between groups using an independent sample t-test. Non-normally distributed data were expressed as median (interquartile range) [M (Q1, Q3)] and compared using the non-parametric Mann-Whitney U test. Categorical variables were expressed as frequency and percentage (n, %), and comparisons between groups were conducted using Fisher's exact test or χ^2 test. Variables with $P<0.05$ in univariate analysis were included in a multivariate logistic regression analysis, and results were presented as odds ratios (OR) with 95% confidence intervals (CI).

Results

Figure 1 shows the flow diagram for research plan. A total of 525 patients were initially screened for this study, and 127 were excluded based on inclusion and exclusion criteria, resulting in 398 patients being included in the final statistical analysis. Among these, 149 patients (37.4%) developed hypoxemia during their stay in the PACU.

Univariate analysis demonstrated significant differences between the hypoxemia and non-hypoxemia groups in preoperative SpO_2 upon entering the operating room (OR) and immediate post-extubation pain. Preoperative SpO_2 upon entering the OR was significantly lower in the hypoxemia group compared to the

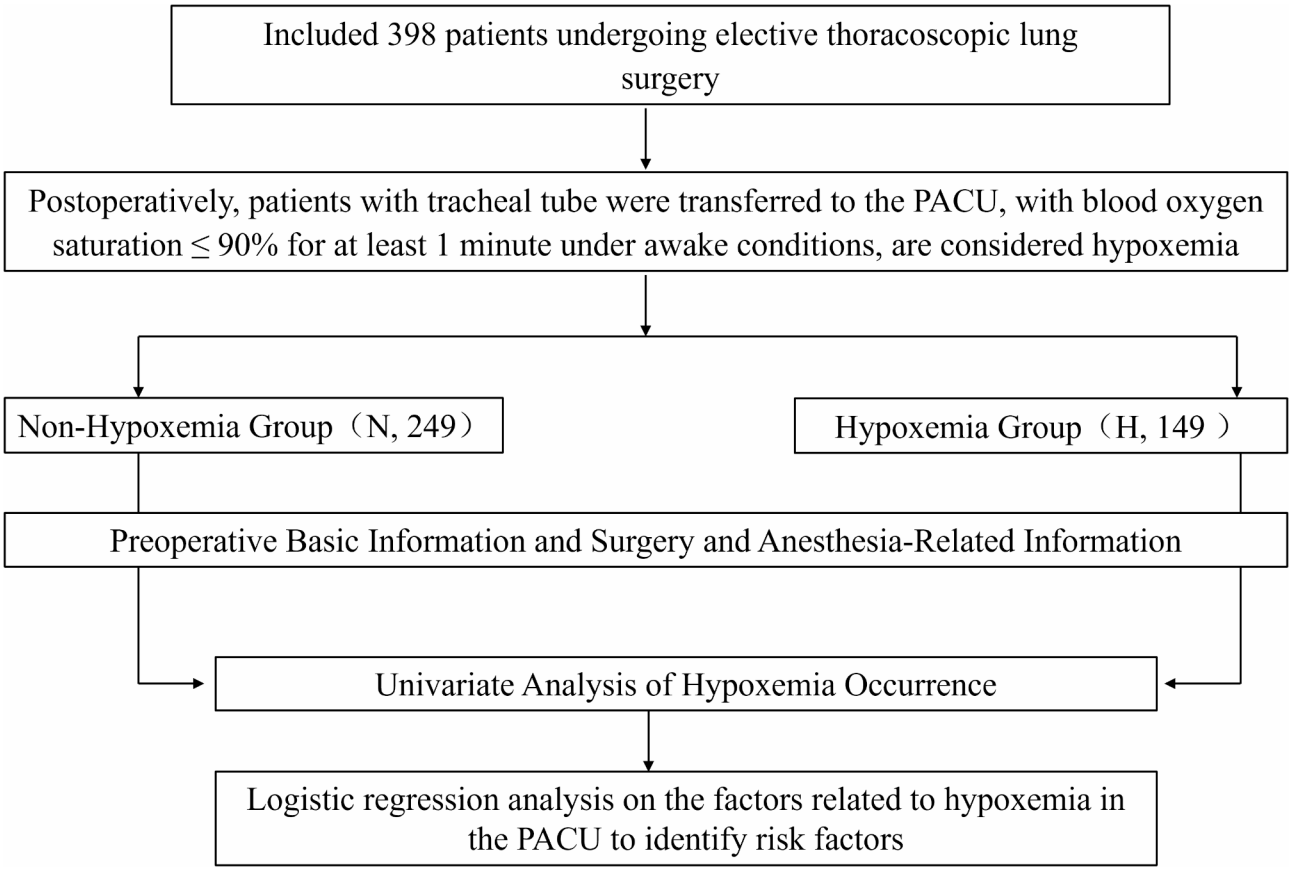

Fig. 1 Flow diagram for research plan

non-hypoxemia group (97.00 [96.00, 98.00] vs. 98.00 [96.00, 99.00], $p = 0.005$), suggesting that lower baseline oxygenation is associated with an increased risk of developing postoperative hypoxemia. Immediate pain upon extubation was significantly higher in the hypoxemia group than in the non-hypoxemia group (2.00 [1.00, 2.00] vs. 1.00 [1.00, 2.00], $p = 0.009$), indicating that post-extubation discomfort may contribute to impaired respiratory effort and subsequent oxygen desaturation. Duration of PACU stay was notably longer in the hypoxemia group (80.0 [66.0, 98.0] minutes vs. 69.50 [58.0, 79.75] minutes, $p < 0.001$), highlighting the clinical impact of hypoxemia on postoperative recovery time.

Other intraoperative variables, including anesthesia duration, surgical duration, single-lung ventilation time, intraoperative fluid volume, intraoperative blood loss, and administered anesthetic agents (propofol, sufentanil, remifentanil, and cis-atracurium), did not show statistically significant differences between the two groups. Additionally, no significant differences were found in surgical position, ventilation mode, surgical site, or type of surgery, suggesting that procedural factors had minimal direct influence on the incidence of hypoxemia (refer to Tables 1 and 2).

To identify independent risk factors for hypoxemia, statistically significant variables from the univariate analysis were included in a multivariate logistic regression model. The logistic regression model demonstrated good fit, as indicated by the Hosmer-Lemeshow test ($P = 0.743$), and a Nagelkerke R^2 of 0.298, suggesting that the included predictors moderately explained the variation in postoperative hypoxemia. The results identified: Age (OR = 1.037, 95% CI: 1.015–1.059, $p = 0.001$), BMI (OR = 1.132, 95% CI: 1.041–1.230, $p = 0.004$), Duration of PACU stay (OR = 1.036, 95% CI: 1.022–1.049, $p < 0.001$), Immediate post-extubation pain (OR = 1.377, 95% CI: 1.115–1.700, $p = 0.003$), as independent risk factors for hypoxemia in the PACU following thoracoscopic lung surgery. Conversely, preoperative SpO_2 upon entering the operating room (OR = 0.882, 95% CI: 0.783–0.993, $p = 0.038$) indicated that higher baseline oxygen saturation levels were associated with a lower likelihood of postoperative hypoxemia (refer to Table 3).

Discussion

The incidence of hypoxemia in patients undergoing thoracoscopic lung surgery in the PACU was observed to be 37.4%, aligning closely with the 34% reported by Liu et

Table 1 Comparison of basic characteristics between two groups of patients

Variables	*Total(n = 398)*	*Hypoxemia(n = 149)*	Non-hypoxemia(*n* = 249)	*p*
Gender				0.293[1]
Male	148	50	98	
Female	250	99	151	
Age (years)				< 0.003[1]
<60	258	79	179	
≥ 60	140	70	70	
BMI (kg/m^2)				0.004[1]
<24	235	77	158	
≥ 24	163	72	91	
Smoking				0.790[1]
No	269	99	170	
Yes	129	50	79	
Smoking Cessation				0.511[1]
No	271	98	173	
Yes	127	51	76	
Alcohol				0.711[1]
No	229	88	141	
Yes	169	61	108	
Breathing Exercises				0.369[1]
No	165	57	108	
Yes	233	92	141	
ASA				0.029[1]
I	9	3	6	
II	319	110	209	
III	70	36	34	
Hypertension				0.005[1]
No	98	49	49	
Yes	300	100	200	
Heart disease				0.459[1]
No	372	137	235	
Yes	26	12	14	
Diabetes				0.008[1]
No	31	19	12	
Yes	367	130	237	
Hyperthyroidism				1.000[1]
No	7	3	4	
Yes	391	146	245	
Hypothyroidism				1.000[1]
No	14	5	9	
Yes	384	144	240	
FEV1/FVC (%)	80.62 [76.42, 85.06]	79.19 [75.44, 82.80]	82.27 [77.52, 86.44]	< 0.001[2]
Exercise Tolerance				0.032[1]
> 6MET	168	55	113	
3-6MET	222	88	134	
< 3MET	8	6	2	
Pulmonary Disease				0.460[1]
No	46	20	26	
Yes	352	129	223	
Pleural effusion				0.829[1]
No	6	3	3	
Yes	392	146	246	
History of Respiratory Infections				0.344[1]
No	67	29	38	

Table 1 (continued)

Variables	*Total(n = 398)*	*Hypoxemia(n = 149)*	Non-hypoxemia(*n* = 249)	*p*
Yes	331	120	211	
Preoperative Hemoglobin (g/L)	132.89 (14.47)	133.26 (14.82)	132.67 (14.28)	0.696[3]

Note: [1] χ^2 value; [2] Z value; [3] t value

Table 2 Comparison of surgical and anesthesia conditions between the two groups of patients

Variables	*Total (n = 398)*	*Hypoxemia (n = 149)*	Non-hypoxemia*(n = 249)*	*p*
SpO_2 upon entering OR(%)	97.00 [96.00, 98.00]	97.00 [96.00, 98.00]	98.00 [96.00, 99.00]	0.0052
HR (beats/min)	78.50 [71.00, 88.00]	80.00 [71.00, 87.00]	78.00 [71.00, 88.00]	0.7642
Respiratory rate	18.00 [16.00, 20.00]	19.00 [16.00, 20.00]	18.00 [16.00, 20.00]	0.6402
Propofol (mg)	80.00 [70.00, 100.00]	80.00 [70.00, 110.00]	80.00 [70.00, 100.00]	0.6762
Sufentanil (ug)	25.00 [22.50, 30.00]	25.00 [22.50, 30.00]	25.00 [22.50, 30.00]	0.9732
Remifentanil (ug)	744.60 [554.88, 968.80]	785.00 [602.00, 995.60]	732.60 [534.30, 960.00]	0.0522
cis-Atracurium (mg)	13.00 [12.00, 15.00]	14.00 [12.00, 15.00]	13.00 [11.00, 15.00]	0.3242
Intraoperative Fluid Volume (ml)	400.00 [300.00, 500.00]	400.00 [300.00, 500.00]	350.00 [300.00, 500.00]	0.1332
Intraoperative Blood Loss (ml)	10.00 [5.00, 10.00]	10.00 [5.00, 10.00]	10.00 [5.00, 10.00]	0.1762
Duration of Anesthesia (min)	122.00 [97.00, 151.75]	125.00 [101.00, 154.00]	120.00 [96.00, 150.00]	0.3512
Surgical Duration (min)	79.50 [57.00, 107.00]	81.00 [58.00, 109.00]	79.00 [56.00, 104.00]	0.3732
Duration of Single-Lung Ventilation (min)	77.00 [57.25, 105.00]	78.00 [65.00, 110.00]	77.00 [55.00, 104.00]	0.173
Surgical Position				0.2941
Supine position	14 (3.5)	8 (5.4)	6 (2.4)	
Left Lateral Position	226 (56.8)	82 (55.0)	144 (57.8)	
Right lateral position	158 (39.7)	59 (39.6)	99 (39.8)	
Ventilation Mode				1.0001
Single-lumen tracheal intubation	2 (0.5)	1 (0.7)	1 (0.4)	
Double-lumen tracheal intubation	396 (99.5)	148 (99.3)	248 (99.6)	
Surgical Site				0.6921
Left	172 (43.2)	62 (41.6)	110 (44.2)	
Right	226 (56.8)	87 (58.4)	139 (55.8)	
Type of Surgery				0.1091
Wedge Resection	203 (51.0)	73 (49.0)	130 (52.2)	
Segmentectomy	74 (18.6)	22 (14.8)	52 (20.9)	
Lobar Resection	120 (30.2)	53 (35.6)	67 (26.9)	
Pneumonectomy	1 (0.3)	1 (0.7)	0 (0.0)	
Pain at 30 min entering PACU	2.00 [0.00, 3.00]	2.00 [0.00, 3.00]	2.00 [0.00, 3.00]	0.0522
Immediate pain upon extubation	1.00 [1.00, 2.00]	2.00 [1.00, 2.00]	1.00 [1.00, 2.00]	0.5922
Nausea				1.0001
Yes	8	3	5	
No	390	146	244	
Vomiting				0.9981
Yes	4	2	2	
No	394	147	247	
Chills				1.0001
Yes	21	8	13	
No	377	141	236	
Agitation				1.0001
Yes	11	4	7	
No	387	145	242	
Delayed Awakening				<0.001[1]
Yes	8	8	0	
No	390	249	141	
Time to extubation (min)	13.00 [10.00, 18.00]	14.00 [10.00, 19.00]	13.00 [10.00, 17.00]	0.3092
Duration of PACU stay (min)	69.0 (58.0, 79.0)	80.0 (66.0, 98.0)	69.50 (58.0, 79.75)	< 0.001[2]

Note: [1] χ^2 value; [2] Z value; [3] t value

Table 3 Multivariate analysis of hypoxemia in PACU after thoracoscopic lung surgery

Variables	β value	Standard Error	Wald χ^2value	*P* value	OR value	95% CI
Age	0.036	0.011	11.017	0.001	1.037	1.015 ~ 1.059
BMI	0.124	0.042	8.510	0.004	1.132	1.041 ~ 1.230
SPO_2 upon entering OR	-0.125	0.061	4.298	0.038	0.882	0.783 ~ 0.993
Immediate pain upon extubation	0.320	0.108	8.829	0.003	1.377	1.115 ~ 1.700
Preoperative SpO_2	-0.107	0.062	3.033	0.082	0.898	0.796 ~ 1.014
FEV1/FVC	-0.030	0.017	2.96	0.085	0.971	0.939 ~ 1.004
Duration of PACU stay	0.037	0.006	33.98	0.001	1.036	1.022 ~ 1.049
Constants	6.600	6.489	1.035	0.309	-	-

Note: "-" has no clinical significance and is included solely for model construction

al. for postoperative hypoxemia following similar procedures [20]. This finding underscores hypoxemia as a prevalent complication, posing challenges to recovery and increasing the workload in the PACU. Our analysis highlights that age, BMI, immediate post-extubation pain, and prolonged PACU stay independently contribute to the risk of hypoxemia, whereas higher preoperative SpO_2 serves as a protective factor.

Age emerged as a significant risk factor, corroborating prior studies [21]. With advancing age, patients experience systemic degenerative changes, diminished organ reserve, and reduced pulmonary compliance, all of which heighten susceptibility to hypoxemia during recovery [22]. Additionally, age-related comorbidities, such as hypertension and diabetes, further amplify this risk [23]. Strategies to address these risks include optimizing preoperative preparation, meticulous anesthetic management, and enhanced intraoperative monitoring. However, it is critical to consider that age alone does not dictate outcomes, emphasizing the multifactorial nature of postoperative recovery.

BMI was identified as another key risk factor for hypoxemia. Obesity impairs pulmonary mechanics by increasing airway resistance and decreasing lung compliance, thereby compromising gas exchange. Obese patients often present with comorbidities such as obstructive sleep apnea, exacerbating the risk. These findings align with the conclusions of Campos and Feider regarding perioperative respiratory risks in obese individuals [24–26]. Preoperative weight management and customized anesthetic plans are essential to mitigate these risks. Obesity is a well-documented risk factor for perioperative hypoxemia [27], and thus, preoperative weight control, comprehensive pulmonary function testing, and thorough risk assessments are critical for reducing the likelihood of PACU hypoxemia [28]. Postoperative management of obese patients should include enhanced monitoring of respiratory function and supplemental oxygen therapy to further minimize the risk of hypoxemia. Additionally, the use of muscle relaxants during anesthesia in obese patients can significantly reduce functional residual capacity and lung compliance, resulting in airway collapse and ventilation-perfusion mismatch, contributing to postoperative hypoxemia [29].

Immediate post-extubation pain significantly influenced hypoxemia risk, likely due to its adverse effects on effective ventilation and coughing, which are vital for maintaining oxygenation [30]. Pain-induced sympathetic activation may lead to tachycardia, hypertension, and additional stress on the cardiovascular system, which can further compromise cardiopulmonary function, as noted by Kehlet et al. [31]. Additionally, inadequate pain management can inhibit effective coughing, increasing the risk of atelectasis and pulmonary infections, which further contribute to hypoxemia [32]. Research shows that patients with well-managed postoperative pain are more likely to engage in early ambulation and deep breathing exercises, significantly reducing the risk of pulmonary complications [33]. While opioids are effective for pain relief, their potential to depress the respiratory center may exacerbate the risk of hypoxemia [34]. Conversely, insufficient pain control can lead to atelectasis and compromised pulmonary function, further increasing the likelihood of hypoxemia. Multimodal analgesia, incorporating regional techniques and nerve blocks, provides effective pain relief while minimizing the risk of respiratory depression [35]. A balanced approach is essential to ensure optimal pain management without exacerbating hypoxemia.

In this study, preoperative SpO_2 refers to peripheral oxygen saturation measured upon entering the operating room, rather than arterial blood gas parameters obtained at rest, such as PaO_2 or the alveolar-arterial oxygen gradient (PA–a gradient), which are standard indicators for assessing pulmonary reserve or oxygenation capacity. Although preoperative SpO_2 was statistically associated with a reduced risk of postoperative hypoxemia ($OR < 1$, $P = 0.038$), labeling it as a "protective factor" may be an oversimplification from a physiological and anesthetic standpoint. Instead, preoperative SpO_2 more likely reflects baseline pulmonary function, the presence of chronic hypoxic conditions (e.g., pulmonary disease or anemia), and may serve as a surrogate predictor of limited oxygenation reserve [36]. Therefore, although

preoperative SpO_2 should not be interpreted as a direct protective factor, it may serve as a practical and accessible indicator for evaluating preoperative oxygenation status and predicting postoperative respiratory outcomes.

Although the duration of PACU stay was included in the multivariate logistic regression analysis and demonstrated a significant association with hypoxemia, it must be interpreted with caution. Given that PACU duration is recorded after the occurrence of hypoxemia, it may be better regarded as a consequence or marker of clinical deterioration rather than a true predisposing factor. Nevertheless, it was retained in the model to reflect the downstream clinical impact of hypoxemia and to capture the recovery burden [37]. Future prospective studies with time-sequenced variable collection are needed to clarify the temporal and causal relationship between PACU stay duration and hypoxemia.

The prolonged duration of PACU stay observed in the hypoxemia group suggests that hypoxemia extends the postoperative recovery period, potentially leading to increased healthcare resource utilization. Patients experiencing hypoxemia may require prolonged monitoring, additional oxygen therapy, or unplanned interventions, thereby increasing the burden on healthcare systems [38]. This highlights the need for early identification of at-risk patients and targeted interventions to minimize hypoxemia episodes, ultimately improving recovery efficiency and reducing resource consumption.

This study has several limitations that warrant discussion. First, the sample was derived from a single center, which may limit the generalizability of the findings to other populations or healthcare settings. Differences in surgical protocols, anesthesia practices, and patient demographics across institutions could influence the risk factors and incidence of hypoxemia in PACU settings. Second, although we identified several independent risk factors through logistic regression, residual confounding cannot be entirely ruled out. The observational nature of this study necessitates cautious interpretation, as external factors such as surgical techniques or perioperative practices may also influence results. In addition, unmeasured variables such as specific anesthetic techniques or variations in postoperative management may have impacted the outcomes but were not included in the analysis. Finally, this study was observational in design, which precludes establishing causal relationships between the identified risk factors and hypoxemia. Future studies incorporating randomized interventions targeting modifiable risk factors, such as BMI or immediate post-extubation pain, are needed to confirm these associations and inform clinical guidelines.

In conclusion, this study emphasizes the need for proactive measures to reduce hypoxemia incidence in the PACU following thoracoscopic lung surgery. Focused interventions targeting elderly and obese patients, coupled with effective pain management and careful monitoring of preoperative SpO_2, can significantly enhance recovery. The prolonged PACU stay associated with hypoxemia further underscores the clinical and economic burden of this complication. Future research should explore perioperative interventions aimed at reducing hypoxemia incidence and optimizing postoperative recovery in this patient population.

Abbreviations

PACU	The post-anesthetic care unit
FEV1	Forced Expiratory Volume at 1 s
FVC	Forced Vital Capacity
SpO2	Pulse Oximetry Oxygen Saturation
PaO<	Subscript>2</Subscript> Arterial oxygen partial pressure
VAS	Visual analog scale pain scores

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12871-025-03043-9.

Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

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Author contributions

Xi Luo: conducted the experiments, analyzed the data, and wrote the original draft. Yanmei Ying and Lu Yin: data collection, validation and data curation; Pan Chang: conceptualization, methodology, resources, supervision, writing – review & editing, funding acquisition. All authors reviewed the manuscript.

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Data availability

All data that support the findings of this study are included within the article (and any supplementary files).

Declarations

Human ethics and consent to participate

Prior to the recruitment of participants, this study received approval from the Ethics Committee of West China Hospital, Sichuan University (2024 – 611), and was registered on the Chinese Clinical Trial Registry (ChiCTR2400083595). The study design strictly adhered to the declaration of Helsinki and the STROBE statement. All participants signed a written informed consent form before enrolment.

Consent for publication

Not Applicable.

Competing interests

The authors declare no competing interests.

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