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# Predictive model of postoperative hypoxaemia in general anaesthesia patients in the post-anesthesia care unit based on LASSO-logistic regression

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**Abstract: Objective** To construct a predictive model for postoperative hypoxaemia in general anaesthesia patients in the post-anesthesia care unit (PACU) using LASSO-logistic regression and to validate the efficacy. **Methods** The clinical data of 100 general anesthesia patients (modeling group) who were transferred to the PACU for observation after surgery in Zhongshan Hospital Affiliated to Xiamen University from December 2020 to December 2022 were retrospectively analyzed. According to whether hypoxaemia occurred in PACU, patients were divided into occurrence group and non-occurrence group. The clinical data of the two groups were collected, and LASSO regression were carried out for preliminary screening. Then the predictive variables were determined by multivariate logistic regression analysis to establish a prediction model of hypoxaemia. In addition, 30 patients with general anesthesia transferred to PACU after surgery in Zhongshan Hospital Affiliated to Xiamen University from January 2024 to June 2024 were prospectively selected as the verification group, and the predictive efficacy of the model was validated by using receiver operating characteristic (ROC) curves, calibration curves and decision curves. **Results** Among 100 patients,21 patients developed hypoxemia. Multivariate logistic regression analysis showed that age ≥70 years, preoperative peripheral, capillary oxygen saturation ($SpO_2$)<95%, thoracic surgery, and operation time ≥120 min were independent risk factors for hypoxaemia in PACU($P$<0.05). The C-index of the nomogram prediction model was 0.811, and the area under the ROC curve was 0.833(95%$CI$:0.758-0.892). The calibration curve was close to the ideal curve, and the decision curve showed that the model had high predictive net benefit. **Conclusion** Hypoxsaemia in PACU is closely related to age, and preoperative $SpO_2$, surgical site, operation time, and the nomogram model based on this has good prediction efficiency.

**Keywords**: Post-anesthesia care unit; Hypoxaemia; Oxygen saturation; LASSO-logistic regression model; Prediction model

Post-anesthesia care unit (PACU) is the location for postoperative recovery of patients who have undergone general anesthesia. It involves critical operations such as monitoring and supporting the respiratory and circulatory systems, as well as removing endotracheal tubes. Therefore, PACU is considered a high-risk area for the occurrence of postoperative hypoxemia [1]. According to clinical research reports, approximately 19.12% of patients experience postoperative hypoxemia during transfer from the operating room to the PACU. Within 30 minutes after transfer, up to 69.8% of patients develop hypoxemia. During the PACU recovery period, the risk of adult patients experiencing at least one episode of hypoxemia is 35%–55% [2-3]. Severe hypoxemia not only significantly prolongs the duration of mechanical ventilation for patients but may also lead to unstable blood pressure, as well as affect the circulatory system and postoperative recovery [4]. Therefore, timely identification and effective management of hypoxemia are crucial for the medical team. Potential risk factors for hypoxemia have been a focus of attention for many researchers. However, due to differences in the variables and subjects included in different studies, there are significant variations in the identified risk factors [5-6], and there is a lack of predictive models that can integrate multiple risk factors. This study conducted a detailed analysis of the clinical data of general anesthesia patients in the PACU, aiming to identify risk factors associated with the occurrence of hypoxemia and to establish a predictive model. This will enable more accurate prediction and management of hypoxemia in general anesthesia patients in the PACU, thereby improving the safety and efficiency of postoperative patient recovery.

## 1 Materials and Methods

### *1.1 General Data*

A retrospective analysis was performed on the clinical data of 100 general anesthesia patients who were transferred to the PACU for observation after surgery at Zhongshan Hospital Affiliated to Xiamen University from December 2020 to December 2022. Among them, there were 58 males and 42 females; age range was 36-78 years old. Additionally, 30 general anesthesia patients transferred to the PACU for observation after surgery from January 2024 to June 2024 were prospectively selected as the validation group.

Inclusion criteria: (1) Age ≥18 years; (2) General anesthesia, American Society of Anesthesiologists (ASA) physical status classification I-III; (3) Intraoperative controlled ventilation via endotracheal intubation or laryngeal mask airway; (4) Upon removal of the endotracheal tube or laryngeal mask postoperatively, the patient regained consciousness and was transferred to the PACU for observation and care.

Exclusion criteria: (1) History of surgery within one month preoperatively; (2) Combined with severe cardiopulmonary disease; (3) Presence of contraindications to anesthesia; (4) Presence of coagulation dysfunction or immune dysfunction; (5) During the anesthesia recovery period, the patient experienced drastic fluctuations in vital signs requiring transfer to the intensive care unit for treatment.

This study was approved by the Medical Ethics Committee of the Zhongshan Hospital Affiliated to Xiamen University (Ethics Filing No.: 2024-533).

### *1.2 Methods*

1.2.1 Collection of General Data

Patient general data, surgical data, anesthesia data, and postoperative data were obtained through the hospital electronic medical record system and the anesthesia recovery system. (1) General data: gender, age, body mass index (BMI), smoking history, alcohol history, hypertension, diabetes, ASA classification, preoperative heart rate, preoperative peripheral oxygen saturation ($SpO_2$), preoperative hemoglobin (Hb), preoperative albumin. (2) Surgical data: surgical site [thoracic (breast, lung), non-thoracic (brain, abdomen, thyroid, soft tissue, spine)], surgical position (prone, supine, lateral), operation time, intraoperative blood loss, intraoperative fluid infusion volume. (3) Ventilation mode (endotracheal intubation, laryngeal mask), sufentanil dosage, equivalent rocuronium dosage, Bispectral Index (BIS) at extubation. (4) Postoperative data: use of patient controlled intravenous analgesia (PCIA), body temperature upon PACU admission.

1.2.2 Grouping Method

Hypoxemia was defined as an oxygen index below 300 within 30 minutes after successful removal of the endotracheal tube or laryngeal mask. Patients were divided into an occurrence group and a non-occurrence group based on whether hypoxemia occurred in the PACU [7].

### *1.3 Statistical Methods*

Data analysis was performed using SPSS 26.0 and R 4.0.4 statistical software. Measurement data conforming to a normal distribution are described by $\bar{x} \pm s$, and independent samples *t*-test was used. Enumeration data are described by number (%), and Chi-square test was used; logistic regression model and least absolute shrinkage and selection operator (LASSO) regression were used to screen influencing factors, based on which a nomogram was constructed; Receiver operating characteristic (ROC) curve and calibration curve were plotted to evaluate the model's predictive performance. $P<0.05$ was considered statistically significant.

## 2 Results

### *2.1 Comparison of Clinical Data Between Two Groups*

Hypoxemia occurred in 21 cases and did not occur in 79 cases within the PACU. Differences in age, preoperative $SpO_2$, surgical site, operation time, and intraoperative blood loss between the two groups were statistically significant ($P<0.05$). See **Table 1**.

**Tab.1** Comparison of clinical data between two groups [case(%)]

| Indicators | Occurrence group ($n$=21) | Non-occurrence group ($n$=79) | $\chi^2$ value | $P$ value |
|---|---|---|---|---|
| **Gender** | | | | |
| **Male** | 13(61.90) | 45(56.96) | 0.166 | 0.683 |
| **Female** | 8(38.10) | 34(43.04) | | |
| **Age** | | | | |
| **≥70 years** | 15(71.43) | 27(34.18) | 9.450 | 0.002 |
| **<70 years** | 6(28.57) | 52(65.82) | | |
| **BMI** | | | | |
| **≥25 kg/m²** | 9(42.86) | 22(27.85) | 1.747 | 0.186 |
| **<25 kg/m²** | 12(57.14) | 57(72.15) | | |
| **Smoking history** | 15(71.43) | 64(81.01) | 0.919 | 0.388 |
| **Drinking history** | 13(61.90) | 59(74.68) | 1.344 | 0.246 |
| **Hypertension** | 11(52.38) | 27(34.18) | 2.333 | 0.127 |
| **Diabetes** | 6(28.57) | 15(18.99) | 0.919 | 0.338 |
| **ASA classification** | | | | |
| **I** | 8(38.10) | 44(55.70) | 2.800 | 0.247 |
| **II** | 9(42.86) | 28(35.44) | | |
| **III** | 4(19.05) | 7(8.86) | | |
| **Preoperative heart rate (beats/min)** [a] | 76.62±12.25 | 74.58±11.36 | 0.720 | 0.474 |
| **Preoperative $SpO_2$** | | | | |
| **<95%** | 8(38.10) | 7(8.86) | 8.946 | 0.003 |
| **≥95%** | 13(61.90) | 72(91.14) | | |
| **Preoperative Hb (g/L)** | 125.23±21.17 | 128.84±16.68 | 0.831 | 0.408 |
| **Preoperative albumin (g/L)** [a] | 36.11±3.56 | 37.69±4.11 | 1.607 | 0.111 |
| **Surgical site** | | | | |
| **Thoracic** | 15(71.43) | 31(39.24) | 6.920 | 0.009 |
| **Non-thoracic** | 6(28.57) | 48(60.76) | | |
| **Surgical position** | | | | |
| **Prone position** | 14(66.67) | 35(44.30) | 3.320 | 0.068 |
| **Non prone position** | 7(33.33) | 45(55.70) | | |
| **Surgical time** | | | | |
| **≥120 min** | 16(76.19) | 29(36.71) | 10.449 | 0.001 |
| **<120 min** | 5(23.81) | 50(63.29) | | |
| **Intraoperative blood loss** | | | | |
| **≥120 mL** | 11(52.38) | 22(27.85) | 4.516 | 0.034 |
| **<120 mL** | 10(47.62) | 57(72.15) | | |
| **Intraoperative infusion volume (mL)** [a] | 1425.19±152.13 | 1369.47±145.53 | 1.545 | 0.126 |
| **Ventilation mode** | | | | |
| **Endotracheal intubation** | 15(71.43) | 62(78.48) | 0.466 | 0.495 |
| **Laryngeal mask** | 6(28.57) | 17(21.52) | | |
| **Dosage of sufentanil (μg)** [a] | 30.24±3.28 | 28.89±3.18 | 1.718 | 0.089 |
| **Equivalent dosage of rocuronium bromide (mg)** [a] | 50.26±5.53 | 49.95±6.12 | 0.210 | 0.834 |
| **Pull out BIS value** [a] | 89.95±4.13 | 91.56±3.35 | 1.861 | 0.066 |
| **Postoperative use of PCIA** | 16(76.19) | 54(68.35) | 0.485 | 0.486 |
| **Postoperative PACU body temperature** | | | | |
| **<36.0 ℃** | 3(14.29) | 4(5.06) | 0.857 | 0.355 |
| **≥36.0 ℃** | 18(85.71) | 75(94.94) | | |

Note: [a] meant the data was performed in the form of $\bar{x} \pm s$.

### *2.2 Analysis of Influencing Factors for Hypoxemia in General Anesthesia Patients Transferred to PACU for Observation*

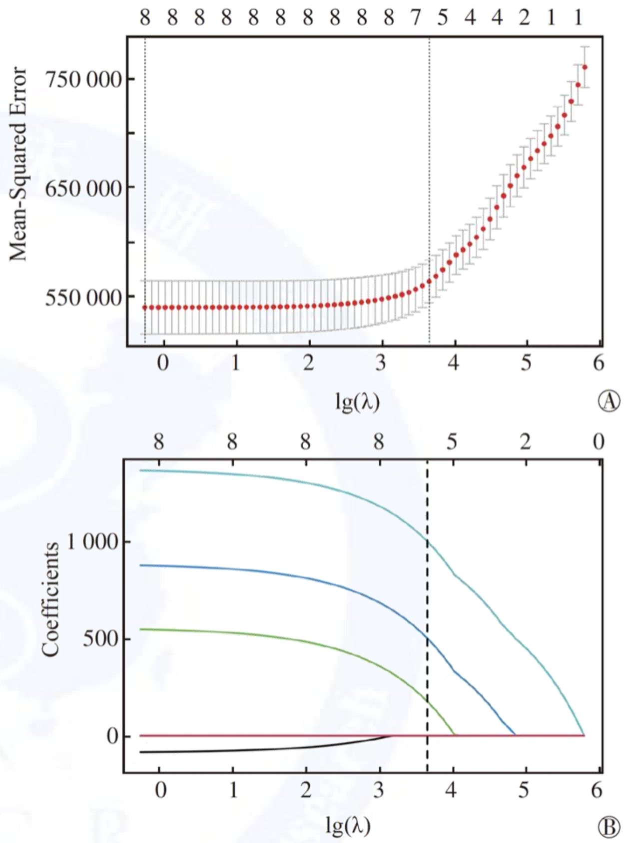
Using the occurrence of hypoxemia (no=0, yes=1) as the dependent variable, and the factors with statistically significant differences in Table 1 (age, preoperative $SpO_2$, surgical site, operation time, intraoperative blood loss) as independent variables, univariate logistic regression analysis was performed. The results showed that age, preoperative $SpO_2$, surgical site, and surgical time were influencing factors for hypoxemia ($P<0.05$). See **Table 2**. Considering the impact of correlations between independent variables on the model, variables with statistically significant differences in the univariate logistic regression analysis and the occurrence of hypoxemia were subjected to LASSO regression analysis. The screening of variables in the LASSO-logistic regression model with changing $\lambda$ values is shown in **Figure 1**. The results of the LASSO regression model showed that 4 non-zero coefficient hypoxemia-related indicators were screened by the optimal $\lambda$ value: age, preoperative $SpO_2$, surgical site, surgical time ≥120 min. Multivariate logistic regression analysis was performed. After adjusting for confounding factors, the main risk factors for hypoxemia in general anesthesia patients transferred to the PACU were finally identified as age ≥70 years, preoperative $SpO_2$ <95%, thoracic surgery, and surgical time ≥120 min ($P<0.05$). See **Table 3**.

### *2.3 Construction of a Nomogram Model for Predicting Hypoxemia Risk in General Anesthesia Patients Transferred to PACU for Observation*

A nomogram model for predicting the risk of hypoxemia in PACU patients was constructed based on the risk factors screened in **Table 3** (**Figure 2**). Based on each risk factor of the patient, projecting upwards to the small scale gives the score for each item. Summing the individual scores gives the total score. The higher the total score, the greater the patient's risk of developing hypoxemia.

### *2.4 Validation of the Nomogram Model for Predicting Hypoxemia Risk in General Anesthesia Patients Transferred to PACU for Observation*

The model validation results showed a C-index of 0.811, and the area under the ROC curve (AUC) was 0.833 (95%*CI*: 0.758-0.892), indicating good discriminative ability of the model (**Figure 3A**); the calibration curve was close to the ideal curve, indicating good predictive performance of the model (**Figure 3B**); the decision curve indicated that the model had a high net benefit value (**Figure 3C**).




**Note:** A represents the cross-validation curve; B represents the regression coefficient path plot.

**Fig.1** LASSO regression variable screening

**Tab.2** Logistic regression analysis of hypoxemia in general anesthesia patients transferred to PACU observation

| Independent variable | *β* | *SE* | Wald $\chi^2$ | *OR* value | 95%*CI* | *P* value |
|---|---|---|---|---|---|---|
| Age | 1.572 | 0.538 | 8.530 | 4.815 | 1.677~13.825 | 0.003 |
| Preoperative $SpO_2$ | 1.845 | 0.599 | 9.493 | 6.330 | 1.957~20.472 | 0.002 |
| Surgical site | 1.354 | 0.535 | 6.396 | 3.871 | 1.356~11.050 | 0.011 |
| Surgical time | 1.708 | 0.563 | 9.202 | 5.517 | 1.830~16.633 | 0.002 |

**Tab.3** Multivariate logistic regression analysis of hypoxemia in general anesthesia patients transferred to PACU observation

| Independent variable | *β* | *SE* | Wald $\chi^2$ | *OR* value | 95%*CI* | *P* value |
|---|---|---|---|---|---|---|
| Age≥70 years | 1.310 | 0.614 | 4.544 | 3.706 | 1.111~12.357 | 0.033 |
| Preoperative $SpO_2$<95% | 1.788 | 0.760 | 5.531 | 5.979 | 1.347~26.535 | 0.019 |
| Surgical site (Thoracic) | 1.295 | 0.611 | 4.497 | 3.651 | 1.103~12.083 | 0.034 |
| Surgical time≥120 min | 1.345 | 0.638 | 4.439 | 3.838 | 1.098~13.412 | 0.035 |

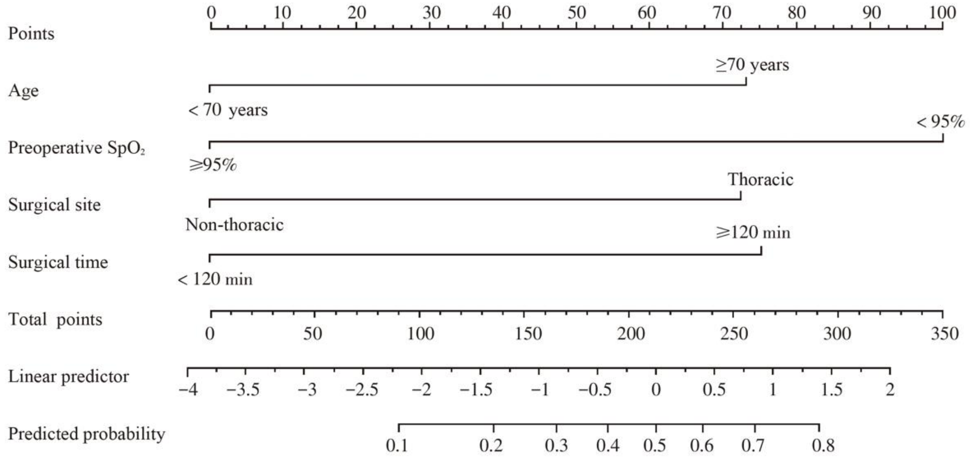
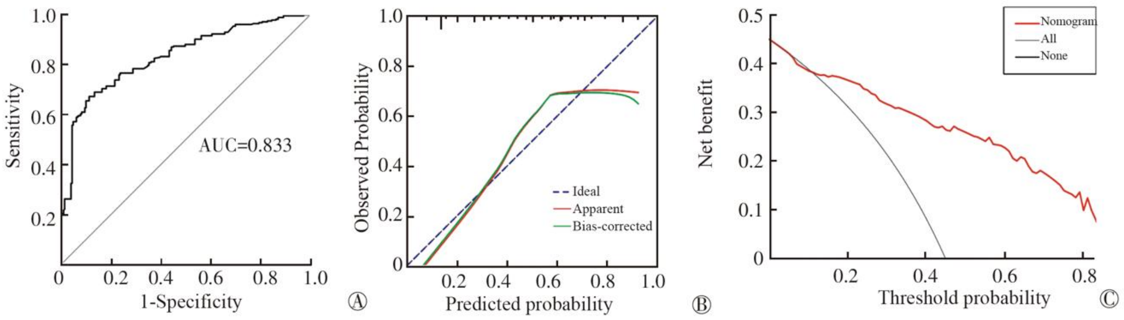



**Fig.2** A nomogram model for predicting the risk of hypoxemia in general anesthesia patients transferred to PACU




**Note:** A, ROC curve; B, calibration curve; C, decision curve.

**Fig.3** ROC curve，calibration curve and decision curve of the prediction model for the risk of hypoxeamia in general anesthesiapatients transferred to PACU

## 3 Discussion

This study showed that the incidence of hypoxemia in general anesthesia patients transferred to the PACU for observation was 21%, which is basically consistent with the 21.79% incidence reported by Chen *et al* [8], indicating a high incidence of hypoxemia in the PACU. The LASSO-logistic regression model in this study suggested that the occurrence of hypoxemia in the PACU is associated with age, preoperative $SpO_2$, surgical site, and surgical time.

With increasing age, the balance of the individual's renin-angiotensin system becomes dysregulated, leading to an exacerbated inflammatory response and degree of lung injury. This imbalance may be related to various physiological and biochemical changes, including decreased lung elasticity and enhanced alveolar closing capacity. These changes may lead to alveolar collapse, thereby affecting alveolar ventilation function and ultimately resulting in the occurrence of hypoxemia [9]. A Meta-analysis showed that age is an independent risk factor for postoperative hypoxemia [10]. The study by Huang *et al* [11] showed that the incidence of hypoxemia after general anesthesia in elderly patients was 40.1%, significantly higher than that in general patients. This study further defined "age ≥ 70 years" as a specific risk threshold, providing a clear quantitative indicator for clinically screening high-risk elderly patients.

Patients with preoperative $SpO_2$ below 95% have a probability of postoperative hypoxia that is 4 fold that of patients with normal $SpO_2$, and the probability of postoperative hypoxemia is also 3 times that of patients with normal $SpO_2$ [12]. This study showed that the risk of hypoxemia was significantly increased in patients with preoperative $SpO_2$<95%. However, some patients did not develop hypoxemia, which might be related to the lung protective strategies implemented during surgery (such as low tidal volume ventilation, application of positive end-expiratory pressure, etc.). This suggests that targeted intraoperative interventions can reduce postoperative risk in patients with insufficient preoperative oxygen reserve, providing a feasible approach for the "preemptive prevention and control" of hypoxemia.

The surgical site has a significant impact on postoperative respiratory function. Thoracic surgery, because it directly involves the lung tissue, pleura, and thoracic structure within the chest cavity, and surgical maneuvers (such as lobectomy, thoracic retraction, etc.) directly limit lung expansion and interfere with respiratory muscle movement, leading to reduced effective ventilation area, ventilation-perfusion mismatch, thereby increasing the risk of hypoxemia. Studies have found that patients undergoing combined thoracoabdominal surgery and upper abdominal surgery have a higher probability of postoperative hypoxemia compared to patients undergoing surgery at other sites [13], indicating that the choice of surgical site may have an important impact on the patient's postoperative oxygenation status. Combined thoracoabdominal surgery and upper abdominal surgery may have a greater impact on the patient's respiratory function, thereby increasing the risk of hypoxemia. The possible mechanism is that thoracic surgery interferes with respiratory function more directly and persistently – for example, thoracotomy destroys the negative pressure environment of the pleural cavity and has a higher probability of delayed lung re-expansion postoperatively. This suggests that clinical management should prioritize enhanced respiratory support (such as non-invasive ventilation, nebulization, etc.) and oxygenation monitoring in the PACU for patients after thoracic surgery.

Reports indicate that the occurrence of hypoxemia is positively correlated with surgical time, meaning that the longer the operation time, the higher the risk of hypoxemia [14]. Increased surgical time exerts a more prolonged stimulatory effect on the patient's body, activating a series of inflammatory responses, leading to neutrophil aggregation on the alveolar surface, further causing damage to pulmonary endothelial factors, and ultimately damaging the blood-gas barrier, affecting the effective exchange of oxygen, and leading to the occurrence of hypoxemia. Furthermore, prolonged surgical time is accompanied by accumulation of anesthetic drugs, increased duration of respiratory muscle inhibition, and delayed recovery of postoperative respiratory function, further aggravating oxygenation impairment. In addition, prolonged surgery may indirectly increase problems such as intraoperative hypothermia and difficulty in fluid management, collectively elevating the risk of hypoxemia. This suggests that clinically, postoperative risk can be reduced by optimizing surgical procedures and shortening operation time (e.g., adopting minimally invasive surgical techniques).

The nomogram model constructed in this study based on the above risk factors, using a concise and intuitive image, clearly demonstrates the predictive effect of various risk factors on the risk of hypoxemia, showing significant advantages in clinical practice. Furthermore, during the model validation process, this study adopted a more comprehensive approach. Unlike the study by Lin *et al* [15], this study did not rely solely on the ROC curve as an evaluation tool. On the contrary, the validation work in this study integrated multiple evaluation indicators, including the C-index, calibration curve, ROC curve, and decision curve, to comprehensively verify the model's accuracy and discriminative ability. This multi-dimensional validation method not only enhanced our confidence in the model's performance but also improved the rigor and credibility of the entire research results. Through these comprehensive evaluation means, this study ensured that the model's validity and applicability were fully verified and guaranteed.

This study still has some limitations: (1) The sample size is relatively small. The number of hypoxemia cases in the modeling group was only 21, and the validation group sample size was only 30, and it was a single-center study. This resulted in wide 95%*CI*s for some risk factors (such as preoperative $SpO_2$ <95%, age ≥70 years, etc.) in the multivariate logistic regression analysis, reflecting insufficient precision and stability of the effect estimates, which may affect the model's accuracy; (2) The study used a design combining retrospective analysis with prospective small-sample validation. The retrospective part has potential for selection bias and information bias, and the validation group did not undergo multi-center, large-sample validation, limiting the model's generalizability and universality; (3) More factors that might affect hypoxemia (such as details of anesthesia methods, postoperative analgesia regimen, follow-up, etc.) were not included, which might lead to omitted factors and have a certain impact on the model's comprehensiveness.

In the future, it is necessary to expand the sample size, include anesthesia-related factors, conduct long-term prognostic follow-up of patients, use standardized data collection tools to collect data, reduce data bias, and further improve the model's predictive ability and applicability.

**Conflict of Interest** None

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·论　著·

# 基于LASSO-logistic回归建立麻醉复苏室全身麻醉患者术后低氧血症的预测模型

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**摘要：目的**　运用LASSO-logistic回归构建麻醉复苏室（PACU）全身麻醉患者术后低氧血症的预测模型并进行效果验证。**方法**　回顾性分析2020年12月至2022年12月厦门大学附属中山医院术后转入PACU观察的100例全身麻醉患者（建模组）的临床资料，根据患者PACU内是否发生低氧血症将其分为发生组和未发生组，收集两组患者临床资料，进行LASSO回归初步筛选，再经多因素logistic回归分析确定预测变量，建立低氧血症预测模型。另前瞻性选取2024年1月至2024年6月厦门大学附属中山医院术后转入PACU观察的30例全身麻醉患者作为验证组，采用受试者工作特征（ROC）曲线、校准曲线和决策曲线对模型的预测效能进行验证。**结果**　100例患者中，共有21例出现低氧血症。通过多因素logistic回归分析确定年龄≥70岁、术前血氧饱和度（$SpO_2$）< 95%、胸部手术、手术时间≥120 min是PACU患者发生低氧血症的独立危险因素（$P$<0.05）。基于以上4个因素构建列线图风险预测模型，C-index为0.811，ROC曲线下面积为0.833（95%$CI$：0.758~0.892），校准曲线与理想曲线较为接近，决策曲线表明模型具有较高的预测净获益值。**结论**　PACU低氧血症的发生与年龄、术前$SpO_2$、手术部位、手术时间等因素密切相关，据此构建的列线图模型具有良好的预测效能。

**关键词：** 麻醉复苏室；低氧血症；血氧饱和度；LASSO-logistic回归模型；预测模型
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## Predictive model of postoperative hypoxaemia in patients undergoing general anaesthesia in the post-anesthesia care unit based on LASSO-logistic regression

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**Abstract：Objective**　To construct a predictive model for postoperative hypoxaemia in general anesthesia patients in the post-anesthesia care unit（PACU）using LASSO-logistic regression and to validate the efficacy. **Methods**　The clinical data of 100 general anesthesia patients（modeling group）who were transferred to the PACU for observation after surgery in Zhongshan Hospital Affiliated to Xiamen University from December 2020 to December 2022 were retrospectively analyzed. According to whether hypoxaemia occurred in PACU，patients were divided into occurrence group and non-occurrence group. The clinical data of the two groups were collected，and LASSO regression were carried out for preliminary screening. Then the predictive variables were determined by multivariate logistic regression analysis to establish a prediction model of hypoxaemia. In addition，30 patients transferred to PACU undergoing general anesthesia after surgery in Zhongshan Hospital Affiliated to Xiamen University from January 2024 to June 2024 were prospectively selected as the verification group，and the predictive efficacy of the model was validated by using receiver operating characteristic（ROC）curves，calibration curves and decision curves. **Results**　Among 100 patients，21 patients developed hypoxaemia. Multivariate logistic regression analysis showed that age ≥70 years，preoperative peripheral, capillary oxygen saturation（$SpO_2$）< 95%，thoracic surgery，and operation time ≥120 min were independent

QR code for English version

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risk factors for hypoxaemia in PACU (*P*<0.05). The C-index of the nomogram prediction model was 0.811, and the area under the ROC curve was 0.833 (95%*CI*: 0.758–0.892). The calibration curve was close to the ideal curve, and the decision curve showed that the model had high predictive net benefit. **Conclusion**　Hypoxaemia in PACU is closely related to age, and preoperative $SpO_2$, surgical site, operation time, and the nomogram model based on this has good prediction efficiency.

**Keywords**: Post-anesthesia care unit; Hypoxaemia; Oxygen saturation; LASSO-logistic regression model; Prediction model

麻醉复苏室(post-anesthesia care unit，PACU)为接受全身麻醉(全麻)的患者进行术后复苏的地点，包括呼吸、循环系统的监测与支持，以及拔除气管插管等关键操作，因此该区域被认为是术后低氧血症发生的高风险区域[1]。根据临床研究报告，从手术室转移到PACU的过程中，约有19.12%的患者出现术后低氧血症，在转运后30 min内，高达69.8%的患者出现低氧血症，在PACU恢复期间，成人患者至少经历一次低氧血症的风险为35%~55%[2-3]。严重的低氧血症，不仅会显著延长患者的机械通气时间，还可能导致血压不稳定，影响循环系统，阻碍术后恢复[4]。因此，对于医疗团队来说，及时识别和有效地管理低氧血症至关重要。在国内外学术界，低氧血症的潜在危险因素一直是众多研究者关注的焦点，但由于研究过程中纳入的变量和研究对象不尽相同，导致危险因素之间存在较大差异[5-6]，且缺乏能够综合多个危险因素的预测模型。本研究对PACU全麻患者的临床数据进行详尽分析，旨在识别与低氧血症发生相关的危险因素，并建立预测模型，以便更准确地预测和处理全麻患者PACU中的低氧血症，提高患者术后恢复的安全性和效率。

## 1　资料与方法

1.1　*一般资料*　回顾性分析2020年12月至2022年12月厦门大学附属中山医院术后转入PACU观察的100例全麻患者的临床资料，其中男58例，女42例；年龄36~78岁。另前瞻性选取2024年1月至2024年6月术后转入PACU观察的30例全麻患者作为验证组。纳入标准：(1) 年龄≥18岁；(2) 全麻，美国麻醉医师协会(American Society of Anesthesiologists，ASA)分级Ⅰ~Ⅲ级；(3) 术中采用气管插管或喉罩控制通气；(4)术后拔除气管插管或喉罩时患者意识恢复，转入PACU观察和照护。排除标准：(1) 术前1个月有手术史；(2) 合并严重心肺疾病；(3) 存在麻醉禁忌证；(4) 存在凝血功能障碍或免疫功能障碍；(5) 麻醉恢复期间出现生命体征剧烈波动，需转入重症监护室治疗。本研究经厦门大学附属中山医院医学伦理委员会审核批准(伦理备案号:2024-533)。

1.2　*方法*

1.2.1　一般资料采集　通过医院电子病历系统和麻醉复苏系统获取患者的一般资料、手术资料、麻醉资料和术后资料。(1) 一般资料：性别、年龄、身体质量指数(BMI)、吸烟史、饮酒史、高血压、糖尿病、ASA分级、术前心率、术前脉搏血氧饱和度($SpO_2$)、术前血红蛋白(Hb)、术前白蛋白。(2) 手术资料：手术部位[胸部(乳腺、肺)、非胸部(脑、腹部、甲状腺、软组织、脊椎)]、手术体位(俯卧位、仰卧位、侧卧位)、手术时间、术中出血量、术中输液量。(3) 控制通气方式(气管插管、喉罩)、舒芬太尼用量、等效罗库溴铵用量、拔管脑电双频指数(BIS)。(4) 术后资料：术后使用自控镇痛泵(PCIA)、术后入PACU时体温。

1.2.2　分组方法　低氧血症定义为患者成功拔除气管导管或喉罩之后的30 min内，其氧合指数低于300。根据患者PACU内是否发生低氧血症将其分为发生组和未发生组[7]。

1.3　*统计学方法*　数据分析采用SPSS 26.0和R 4.0.4统计软件。符合正态分布的计量资料以 $\bar{x}\pm s$ 描述，行独立样本*t*检验；计数资料以例(%)描述，行$\chi^2$检验和校正$\chi^2$检验；采用logistic回归模型和LASSO回归模型筛选影响因素，据此构建列线图风险预测模型；绘制受试者工作特征(ROC)曲线及校准度曲线评价模型预测效能。$P<0.05$为差异有统计学意义。

## 2　结　果

2.1　*两组患者临床资料比较*　PACU内发生低氧血症21例，未发生79例。两组患者年龄、术前$SpO_2$、手术部位、手术时间、术中出血量差异有统计学意义($P<0.05$)。见表1。

2.2　*转入PACU观察的全麻患者发生低氧血症的影响因素分析*　以是否发生低氧血症(未发生=0，发生=1)为因变量，以表1中差异有统计学意义的因素(年龄、术前$SpO_2$、手术部位、手术时间、术中出血量)为自变量进行单因素logistic回归分析，结果显示，年龄、术前$SpO_2$、手术部位、手术时间为患者发生低氧

血症的影响因素（$P<0.05$）。见表2。考虑到自变量之间的相关关系对模型的影响，将单因素logistic回归分析中差异有统计学意义的变量与是否发生低氧血症进行LASSO回归分析，LASSO-logistic回归模型中变量随λ值变化的筛选情况见图1。LASSO回归模型结果显示，由最优λ值筛选出4个非零系数的低氧血症相关指标：年龄、术前$SpO_2$、手术部位、手术时间≥120 min，进行多因素logistic回归分析，调整混杂因素后，最终筛选出转入PACU观察的全麻患者发生低氧血症主要危险因素是年龄≥70岁、术前$SpO_2<95\%$、胸部手术、手术时间≥120 min（$P<0.05$）。见表3。

**表1　两组患者临床资料比较　［例（%）］**

**Tab.1　Comparison of clinical data between two groups ［case（%）］**

| 项目 | | 发生组（$n$=21） | 未发生组（$n$=79） | $\chi^2$值 | $P$值 |
|---|---|---|---|---|---|
| 性别 | 男 | 13（61.90） | 45（56.96） | 0.166 | 0.683 |
| | 女 | 8（38.10） | 34（43.04） | | |
| 年龄 | ≥70岁 | 15（71.43） | 27（34.18） | 9.450 | 0.002 |
| | ＜70岁 | 6（28.57） | 52（65.82） | | |
| BMI | ≥25 kg/m² | 9（42.86） | 22（27.85） | 1.747 | 0.186 |
| | ＜25 kg/m² | 12（57.14） | 57（72.15） | | |
| 吸烟史 | | 15（71.43） | 64（81.01） | 0.919 | 0.388 |
| 饮酒史 | | 13（61.90） | 59（74.68） | 1.344 | 0.246 |
| 高血压 | | 11（52.38） | 27（34.18） | 2.333 | 0.127 |
| 糖尿病 | | 6（28.57） | 15（18.99） | 0.919 | 0.338 |
| ASA分级 | Ⅰ级 | 8（38.10） | 44（55.70） | 2.800 | 0.247 |
| | Ⅱ级 | 9（42.86） | 28（35.44） | | |
| | Ⅲ级 | 4（19.05） | 7（8.86） | | |
| 术前心率（次/min，$\bar{x}\pm s$） | | 76.62±12.25 | 74.58±11.36 | 0.720 | 0.474 |
| 术前$SpO_2$ | ＜95% | 8（38.10） | 7（8.86） | 8.946 | 0.003 |
| | ≥95% | 13（61.90） | 72（91.14） | | |
| 术前Hb（g/L，$\bar{x}\pm s$） | | 125.23±21.17 | 128.84±16.68 | 0.831 | 0.408 |
| 术前白蛋白（g/L，$\bar{x}\pm s$） | | 36.11±3.56 | 37.69±4.11 | 1.607 | 0.111 |
| 手术部位 | 胸部 | 15（71.43） | 31（39.24） | 6.920 | 0.009 |
| | 非胸部 | 6（28.57） | 48（60.76） | | |
| 手术体位 | 俯卧位 | 14（66.67） | 35（44.30） | 3.320 | 0.068 |
| | 非俯卧位 | 7（33.33） | 45（55.70） | | |
| 手术时间 | ≥120 min | 16（76.19） | 29（36.71） | 10.449 | 0.001 |
| | ＜120 min | 5（23.81） | 50（63.29） | | |
| 术中出血量 | ≥120 mL | 11（52.38） | 22（27.85） | 4.516 | 0.034 |
| | ＜120 mL | 10（47.62） | 57（72.15） | | |
| 术中输液量（mL，$\bar{x}\pm s$） | | 1 425.19±152.13 | 1 369.47±145.53 | 1.545 | 0.126 |
| 控制通气方式 | 气管插管 | 15（71.43） | 62（78.48） | 0.466 | 0.495 |
| | 喉罩 | 6（28.57） | 17（21.52） | | |
| 舒芬太尼用量（μg，$\bar{x}\pm s$） | | 30.24±3.28 | 28.89±3.18 | 1.718 | 0.089 |
| 等效罗库溴铵用量（mg，$\bar{x}\pm s$） | | 50.26±5.53 | 49.95±6.12 | 0.210 | 0.834 |
| 拔管BIS值（$\bar{x}\pm s$） | | 89.95±4.13 | 91.56±3.35 | 1.861 | 0.066 |
| 术后使用PCIA | | 16（76.19） | 54（68.35） | 0.485 | 0.486 |
| 术后入PACU时体温 | | | | | |
| | ＜36.0 ℃ | 3（14.29） | 4（5.06） | 0.857 | 0.355 |
| | ≥36.0 ℃ | 18（85.71） | 75（94.94） | | |

**表2　转入PACU观察的全麻患者发生低氧血症的单因素logistic回归分析**

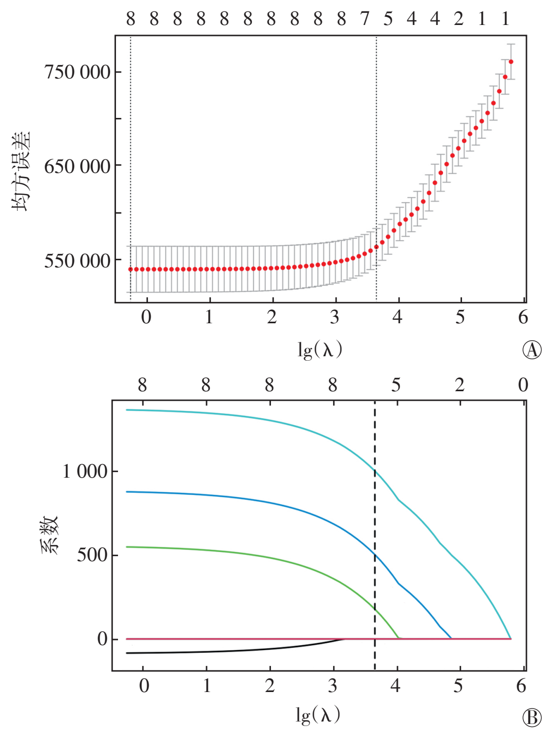
**Tab.2　Univariate logistic regression analysis of hypoxaemia in general anesthesia patients transferred to PACU observation**

| 因素 | $\beta$ | $SE$ | Wald $\chi^2$ | $OR$值 | 95%$CI$ | $P$值 |
|---|---|---|---|---|---|---|
| 年龄≥70岁 | 1.572 | 0.538 | 8.530 | 4.815 | 1.677~13.825 | 0.003 |
| 术前$SpO_2<95\%$ | 1.845 | 0.599 | 9.493 | 6.330 | 1.957~20.472 | 0.002 |
| 手术部位（胸部） | 1.354 | 0.535 | 6.396 | 3.871 | 1.356~11.050 | 0.011 |
| 手术时间≥120 min | 1.708 | 0.563 | 9.202 | 5.517 | 1.830~16.633 | 0.002 |

**表3　转入PACU观察的全麻患者发生低氧血症的多因素logistic回归分析**

**Tab.3　Multivariate logistic regression analysis of hypoxaemia in general anesthesia patients transferred to PACU observation**

| 因素 | $\beta$ | $SE$ | Wald $\chi^2$ | $OR$值 | 95%$CI$ | $P$值 |
|---|---|---|---|---|---|---|
| 年龄≥70岁 | 1.310 | 0.614 | 4.544 | 3.706 | 1.111~12.357 | 0.033 |
| 术前$SpO_2<95\%$ | 1.788 | 0.760 | 5.531 | 5.979 | 1.347~26.535 | 0.019 |
| 手术部位（胸部） | 1.295 | 0.611 | 4.497 | 3.651 | 1.103~12.083 | 0.034 |
| 手术时间≥120 min | 1.345 | 0.638 | 4.439 | 3.838 | 1.098~13.412 | 0.035 |




注：A表示交叉验证曲线；B表示回归系数路径图。

**图1　LASSO回归变量筛选**

**Fig.1　LASSO regression variable screening**

**2.3　转入PACU观察的全麻患者发生低氧血症风险预测列线图模型的构建**　根据表3中筛选出的危险因素构建PACU患者发生低氧血症风险预测列线图模型（图2），根据患者每一项危险因素，向上投射到小标尺即可得出该患者每一项的分值，将各项分值相加得到总分值，总分值越高，患者发生低氧血症的风险越大。

**2.4　转入PACU观察的全麻患者发生低氧血症风险预测列线图模型的验证**　模型验证结果显示，C-index为0.811，ROC曲线下面积（AUC）为0.833（95%$CI$：

0.758~0.892)，表明该模型区分度较好（图3A）；校准曲线与理想曲线较为接近，表明该模型具有良好的预测效能（图3B）；决策曲线表明模型具有较高的预测净获益（图3C）。

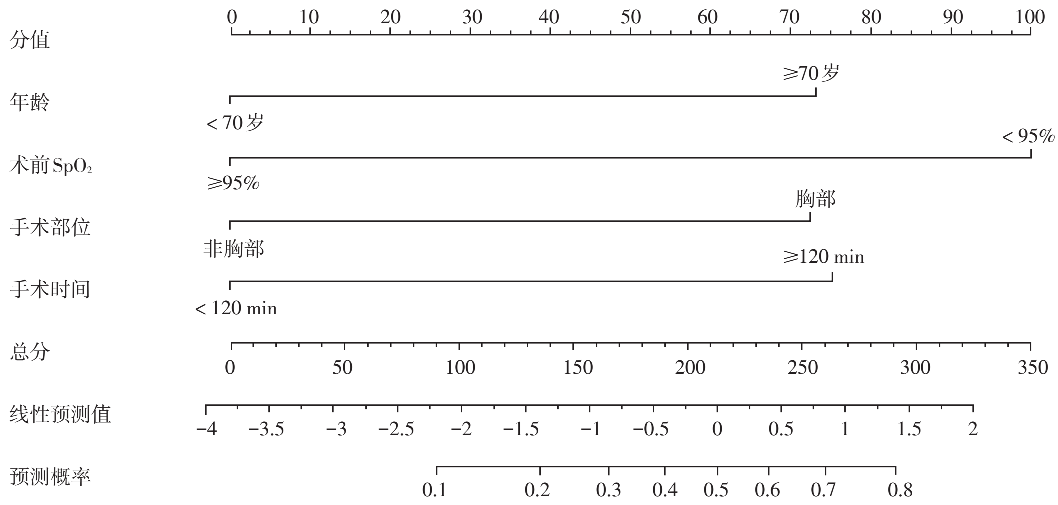
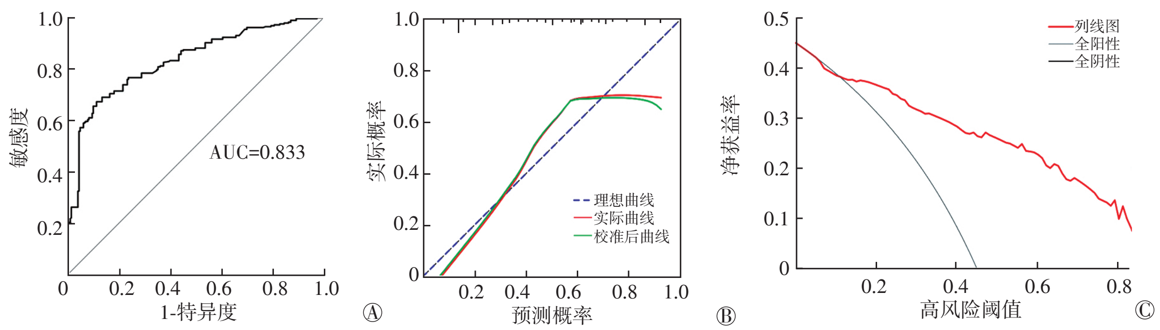



**图2** 转入PACU观察的全麻患者发生低氧血症风险预测列线图模型

**Fig.2** A nomogram model for predicting the risk of hypoxemia in general anesthesia patients transferred to PACU




注：A为ROC曲线；B为校准曲线；C为决策曲线。

**图3** 转入PACU观察的全麻患者发生低氧血症风险列线图预测模型的ROC曲线、校准曲线和决策曲线

**Fig.3** ROC curve, calibration curve and decision curve of the prediction model for the risk of hypoxeamia in general anesthesia patients transferred to PACU

## 3 讨 论

本研究显示，转入PACU观察的全麻患者低氧血症的发生率为21%，与陈赟等[8]报道的21.79%发生率基本相符，说明患者在PACU低氧血症的发生率高。本研究LASSO-logistic回归模型提示，PACU低氧血症的发生与年龄、术前$SpO_2$、手术部位、手术时间有关。

随着年龄的增长，个体肾素-血管紧张素系统的平衡失调，导致炎症反应和肺损伤程度加剧，这种失衡可能与多种生理和生物化学变化有关，其中包括肺弹性的下降和肺泡闭合能力的增强，这些改变可能会导致肺泡塌陷，从而影响肺泡通气功能，最终导致低氧血症的发生[9]。一项meta分析显示，年龄是术后低氧血症的独立危险因素[10]。黄秋瑞等[11]研究显示，老年患者全麻后低氧血症的发生率为40.1%，明显高于普通患者。本研究进一步将"年龄≥70岁"界定为具体风险阈值，为临床筛选高风险老年患者提供了明确的量化指标。

术前$SpO_2$低于95%的患者，在手术后出现缺氧的概率是$SpO_2$正常患者的4倍，术后低氧血症概率也是$SpO_2$正常患者的3倍[12]。本研究显示，术前$SpO_2$<95%的患者低氧血症发生风险明显升高。但部分患者并未发生低氧血症，这可能与手术中实施的肺保护性策略（如小潮气量通气、呼气末正压应用等）有关，这提示临床可通过术中针对性干预，降低术前氧合储备不足患者的术后风险，为低氧血症的"前置防控"提供了可行思路。

手术部位对术后呼吸功能的影响显著，胸部手术因直接涉及胸腔内肺组织、胸膜及胸廓结构，手术操作（如肺叶切除、开胸牵拉等）会直接限制肺扩张、干扰呼吸肌运动，导致有效通气面积减少、通气-血流比例失衡，进而增加低氧血症风险。研究发现，胸

腹联合手术和上腹部手术患者术后出现低氧血症的概率高于其他部位手术患者[13]，说明手术部位的选择可能对患者的术后氧合状态产生重要影响，胸腹联合手术和上腹部手术可能对患者的呼吸功能产生更大的影响，从而增加低氧血症的风险。可能机制是：胸部手术对呼吸功能的干扰更直接、更持久，例如开胸手术会破坏胸腔负压环境，术后肺复张延迟概率更高，提示临床对胸部手术患者术后需优先加强 PACU 内呼吸支持（如无创通气、雾化吸入等）与氧合监测。

报道显示，低氧血症的发生与手术时间呈正相关，即手术时间越长，低氧血症发生风险越高[14]。手术时间增加会对患者机体产生更持久的刺激作用，激活一系列炎症反应，导致肺泡表面中性粒细胞聚集，进一步引发肺内皮因子损害，并最终对血气屏障造成破坏，影响氧气的有效交换，导致低氧血症的发生。另外，手术时间延长会伴随麻醉药物蓄积、呼吸肌抑制时间增加，术后呼吸功能恢复延迟，进一步加重氧合障碍。此外，长时间手术还可能间接增加术中体温下降、液体管理难度等问题，共同升高低氧血症风险，提示临床可通过优化手术流程、缩短手术时间（如采用微创手术技术），降低术后风险。

本研究基于上述危险因素构建的风险列线图模型，利用简洁且直观的图像，清晰展示了各种危险因素对低氧血症风险的预测效果，在临床实际操作中展现出显著优势。此外，在模型的验证过程中，本研究采取了更为全面的方法，与 Lin 等[15]的研究不同，本研究并未仅仅依赖于 ROC 曲线作为一种评估工具。相反，本研究的验证工作融合了多种评价指标，包括 C-index、校正曲线、ROC 曲线以及决策曲线，以此来全面验证模型的准确性和区分能力。这种多维度的验证方法不仅增强了本研究对模型性能的信心，也提高了整个研究结果的严谨性和可信度。通过这些综合评价手段，本研究确保模型的有效性和适用性得到充分的验证和保障。

本研究仍存在一定局限性：(1) 样本量相对较小，建模组中发生低氧血症的病例数仅 21 例，验证组样本量也仅 30 例，且为单中心研究，这使得多因素 logistic 回归分析中部分危险因素（如术前 $SpO_2$<95%、年龄≥70 岁等）的 95%*CI* 范围较宽，反映出效应估计的精度与稳定性不足，可能对模型的准确性产生影响；(2) 研究采用回顾性分析结合前瞻性小样本验证的设计，回顾性部分存在选择偏倚、信息偏倚的潜在可能，且验证组未开展多中心大样本验证，限制了模型的外推性与普适性；(3) 未纳入更多可能影响低氧血症的因素（如麻醉方式细节、术后镇痛方案、随访等），可能存在因素遗漏，对模型的全面性有一定影响。今后需扩大样本量，纳入麻醉相关因素，对患者进行长期预后随访，使用标准化的数据收集工具收集数据，减少数据偏差，进一步提高模型的预测能力与适用性。

综上所述，PACU 低氧血症的发生主要与年龄、术前 $SpO_2$、手术部位、手术时间有关，以此构建的列线图模型具有良好区分度和预测效能。

**利益冲突** 无

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