Am J Transl Res 2025;17(11):8633-8642
www.ajtr.org /ISSN:1943-8141/AJTR0168510

*Original Article*

# Risk factors for hypoxemia during pediatric anesthesia: a logistic regression analysis

Zhi Li[1*], Shuangyu Yang[1*], Ling Zhang[1], Juanjuan Yu[1], Liqiang Deng[2], Yong Rao[1], Hai Zhang[2], Weiyan Wang[2]

[1]*Department of Pediatrics, Pu'er People's Hospital, Pu'er 665000, Yunnan, China;* [2]*Department of Anesthesiology, Pu'er People's Hospital, Pu'er 665000, Yunnan, China.* [*]*Co-first authors.*

Received September 2, 2025; Accepted October 22, 2025; Epub November 15, 2025; Published November 30, 2025

**Abstract:** Objective: To identify risk factors for hypoxemia in anesthetized children, offering a basis for targeted clinical prevention to reduce its occurrence. Methods: A retrospective analysis was conducted on the clinical data from 342 children who underwent anesthesia in the Department of Anesthesiology, Pu'er People's Hospital, from January 2024 to June 2025. Based on the occurrence of hypoxemia, the patients were divided into a hypoxemia group (n=19) and a non-hypoxemia group (n=323). General clinical data, preoperative blood routine, surgery-related conditions, inflammatory indices, and operating room environmental factors were compared between the two groups. Logistic regression analysis was used to identify independent risk factors for hypoxemia during pediatric anesthesia. Scatter plots were drawn to illustrate correlations between each independent risk factor and hypoxemia occurrence. Receiver Operating Characteristic (ROC) curves, calibration curves, and Decision Curve Analysis (DCA) were applied to evaluate the predictive performance. Results: Multivariate logistic regression identified C-reactive Protein (CRP; *OR*=1.011, 95% *CI*=1.004-1.018) and anesthesia duration (*OR*=1.029, 95% *CI*=1.017-1.042) as independent risk factors for hypoxemia during pediatric anesthesia. ROC analysis showed that CRP (AUC=0.799) and anesthesia duration (AUC=0.849) had good predictive performance for hypoxemia occurrence during pediatric anesthesia. The calibration and DCA demonstrated satisfactory model performance. Conclusion: Elevated CRP levels and prolonged anesthesia duration are independent risk factors for hypoxemia in children undergoing anesthesia.

**Keywords:** Anesthesia, hypoxemia, pediatric anesthesia, inflammatory factors

## Introduction

Pediatric patients are at a high risk of developing complications during general anesthesia, among which hypoxemia is among the most common [1]. Hypoxemia is defined as a decrease in arterial oxygen levels below the normal range, typically reflected by marked reductions in blood oxygen saturation and partial pressure of oxygen, and it also represents a major clinical manifestation of respiratory failure [2]. The occurrence of hypoxemia during pediatric anesthesia not only hinders the smooth progression of surgery but also impairs postoperative respiratory and circulatory recovery. Consequently, it leads to prolonged intubation duration and hospital stay, increases medical costs and resource use, and may even elevate postoperative mortality rates [3].

According to previous studies, the incidence of hypoxemia during anesthesia is approximately 31.31% (ranging from 0.32% to 55% across studies) [4]. Factors such as inadequate intraoperative oxygen supplementation, improper intraoperative fluid management, surgical type, and preexisting comorbidities can all adversely affect oxygen delivery during anesthesia, resulting in intraoperative hypoxia and subsequent hypoxemia [5]. Compared to adults, children are more susceptible to hypoxemia due to immature pulmonary development and lower oxygen reserves [6]. Despite advances in anesthetic techniques and monitoring, perioperative adverse events in pediatric anesthesia remain frequent [7].

Preoperative risk assessment of hypoxemia is crucial for early identification of high-risk pedi-

https://doi.org/10.62347/SLAQ8531

atric patients and the implementation of intervention measures. Previous studies have mostly examined specific populations or surgical categories. For example, Gu et al. [8] reported that among adult patients with acute cerebral infarction undergoing endovascular interventional, those with a body mass index (BMI) ≥24 kg/m$^3$ were more prone to developing hypoxemia due to poor pulmonary compliance. Similarly, Sun et al. [9] demonstrated that among pediatric patients with congenital heart disease undergoing corrective surgery with cardiopulmonary bypass, younger age, preoperative right-to-left intracardiac shunt, and intraoperative pleural cavity entry were associated with an increased risk of hypoxemia. However, these studies predominantly focused on specific populations or particular surgical types, limiting the generalizability of their conclusions to routine pediatric anesthesia.

Therefore, the present study retrospectively analyzed clinical data from children undergoing anesthesia and surgery at Pu'er People's Hospital to identify independent risk factors associated with hypoxemia during pediatric anesthesia. Our study aims to enhance perioperative safety and provide a reference for early intervention for patients at risk.

## Materials and methods

### *Sample estimation*

This was a single-center, retrospective cohort study. The sample size was calculated using the formula: N=(α×5)/b, where α represents the number of independent variables and b the expected incidence of hypoxemia. A total of 22 independent variables were planned (α=22). Based on hospital records indicating an incidence of hypoxemia of 34.49% (349 out of 1, 012 cases, b=0.3449), the estimated sample size was approximately 319. Considering a 10% attrition rate, the minimum required sample size was 351.

### *Patient selection*

Diagnostic criteria: According to the *Noninvasive Respiratory Support in the Hypoxaemic Peri-operative/Periprocedural Patient: A Joint ESA/ESICM Guideline* [10], hypoxemia during anesthesia is diagnosed when the peripheral oxygen saturation ($SpO_2$) falls below 90% or the oxygenation index (Partial Pressure of Oxygen in Arterial Blood/Fraction of inspiration $O_2$, $PaO_2/FiO_2$) is ≤40 kPa (300 mmHg; 1 mmHg =0.133 kPa).

Inclusion criteria: (1) Children aged ≤14 years; (2) Children who underwent surgery under general anesthesia; (3) Patients transferred to the post-anesthesia care unit (PACU) after surgery; (4) Patients with an American Society of Anesthesiologists (ASA) physical status classification of I-III (ASA I: healthy; ASA II: mild systemic disease; ASA III: severe systemic disease); (5) Complete anesthesia and surgical records available. Exclusion criteria: (1) Coagulation dysfunction; (2) Preexisting respiratory conditions, including bronchial foreign bodies, bronchopulmonary dysplasia, or airway malformations; (3) Autoimmune diseases, tumors, or immunodeficiency disorders; (4) Severe cardiac, hepatic, or renal dysfunction; (5) Palliative surgical procedures; (6) Incomplete clinical data.

A total of 353 children who met the inclusion criteria and underwent anesthesia in the Department of Anesthesiology at Pu'er People's Hospital between January 2024 and June 2025 were initially screened. According to exclusions criteria, 2 patients were excluded due to severe cardiac, hepatic, or renal diseases, 1 patient due to abnormal pulmonary function, and 8 patients due to incomplete medical records. Ultimately, 342 valid cases were included (19 children developed hypoxemia, and 323 did not), meeting the minimum sample size requirement. This study was approved by the Ethics Committee of Pu'er People's Hospital (Approval No.: 2025-016-Thesis-01). Since this study only collected anonymized clinical data of pediatric patients and posed no impact on the health and rights of the pediatric patients, written informed consent was waived.

### *Anesthesia*

All anesthesia procedures were performed by the same anesthesiology team. All children underwent routine preoperative fasting and water deprivation, followed by either non-intubated or endotracheal intubation general anesthesia. Atropine (0.01 mg/kg) was administered 30 minutes before surgery. An intravenous line was established 20 minutes before anesthesia induction, and active warming was initiated to maintain an operating room temperature of approximately 22°C. Anesthesia induction was achieved using midazolam (0.1 mg/kg), sufentanil (1 μg/kg), atracurium (0.3 mg/kg), and propofol (2 mg/kg). Anesthesia was maintained using sufentanil (1 μg/kg), atracurium (0.3 mg/kg), and propofol (initial dose: 12 mg/kg, adjusted every 20 minutes to 12, 10, or 8 mg/kg).

*Observation indicators*

Hypoxemia determination: During anesthesia, hypoxemia was diagnosed if $SpO_2$ fell below 90% on more than one occasion for ≥15 seconds (excluding episodes due to probe detachment, motion artifacts, or technical failures). The diagnosis was further confirmed by an oxygenation index ≤300 mmHg or abnormal arterial blood gas results.

Data collection: Potential factors associated with hypoxemia were identified through literature review and expert consultation. Corresponding clinical data were retrieved from the hospital's electronic medical record system. Cases were rigorously screened based on predefined inclusion and exclusion criteria to ensure study eligibility. All collected data were organized using Microsoft Excel and verified through double-check to ensure accuracy and completeness. Records containing missing values, outliers, or inconsistent data identified during quality control were subsequently excluded from the final analysis to maintain data integrity.

Data variables: The collected data included: (1) General information: sex, age, weight, BMI, height, and blood type; (2) Preoperative blood tests: serum creatinine (Scr), white blood cell count (WBC), neutrophil percentage (NEUT), C-reactive protein (CRP), red blood cell count (RBC), hemoglobin concentration (Hb), and prothrombin time (PT); (3) Surgical details: duration of surgery and anesthesia, anesthesia type, and surgical site; (4) Inflammatory markers: interleukin-2 (IL-2), IL-6, IL-10, and tumor necrosis factor-α (TNF-α); (5) Operating room environment: cleanliness class.

*Statistical analysis*

Data normality was assessed using the Shapiro-Wilk test. Normally distributed continuous variables were expressed as mean ± standard deviation ($\bar{x}$±s) and compared using independent samples t-tests. Non-normally distributed variables were presented as median (interquartile range) [M ($Q_{25}$, $Q_{75}$)] and analyzed using the Mann-Whitney U test. Categorical data were reported as frequencies (percentages) [n (%)] and tested using the chi-square test ($\chi^2$ test).

To identify factors associated with hypoxemia during anesthesia, univariate and multivariate logistic regression analyses were performed. Correlations between independent risk factors and hypoxemia incidence were evaluated using Spearman's rank correlation, and significant associations were visualized with scatter plots. Significance was set at $p<0.05$.

Model discrimination was assessed through the receiver operating characteristic (ROC) curve, where a higher area under the curve (AUC) indicated superior discrimination. Internal validation of the prediction model was conducted using calibration curves (generated via the "rms" package in RStudio version 4.3.3) and decision curve analysis (DCA; implemented using the "rmda" package).

## Results

*Comparison of general information between the two groups*

Preoperative general information of the two groups is summarized in **Table 1**. No significant differences were found in sex, age, weight, BMI, height, or blood type between the hypoxemia and non-hypoxemia groups ($P>0.05$).

*Comparisons of preoperative hematological indices between the two groups*

As shown in **Table 2**, the hypoxemia group exhibited significantly higher levels of WBC, NEUT, CRP, and PT, and significantly lower Hb levels compared to the non-hypoxemia group ($P<0.05$). No significant differences were observed in SCr or RBC levels between the groups ($P>0.05$).

*Comparisons of intraoperative variables between the two groups*

As shown in **Table 3**, the hypoxemia group had significantly longer surgical and anesthesia

**Table 1.** Comparison of general information between two groups of patients

| Variable | Hypoxemia group (n=19) | Non-Hypoxemia group (n=323) | $Z/\chi^2$ | *P* |
|---|---|---|---|---|
| Gender (n, %) | | | 3.564 | 0.059 |
| Male | 15 (78.95) | 184 (56.97) | | |
| Female | 4 (21.05) | 139 (43.03) | | |
| Age distribution (n, %) | | | 0.288 | 0.741 |
| <1 month | 1 (5.26) | 11 (3.41) | | |
| 1-12 months | 2 (10.53) | 28 (8.67) | | |
| 1-3 years | 3 (15.79) | 50 (15.48) | | |
| 3-14 years | 13 (68.42) | 234 (72.44) | | |
| Weight [kg, M ($Q_{25}$, $Q_{75}$)] | 18.50 (13.50, 21.75) | 20.00 (13.15, 26.60) | -0.935 | 0.353 |
| BMI [kg/m$^2$, M ($Q_{25}$, $Q_{75}$)] | 15.99 (14.34, 17.65) | 15.40 (14.11, 17.13) | -0.298 | 0.768 |
| Height [cm, M ($Q_{25}$, $Q_{75}$)] | 109.00 (87.50, 123.50) | 114.00 (96.00, 130.00) | -0.894 | 0.374 |
| Blood type (n, %) | | | 1.308 | 0.735 |
| Type A | 4 (21.05) | 101 (31.27) | | |
| Type B | 7 (36.84) | 86 (26.63) | | |
| Type O | 6 (31.58) | 104 (32.20) | | |
| Type AB | 2 (10.53) | 32 (9.91) | | |

Note: BMI: Body Mass Index.

**Table 2.** Comparison of preoperative blood routine indicators between the two groups of patients [M ($Q_{25}$, $Q_{75}$)]

| Variable | Hypoxemia group (n=19) | Non-Hypoxemia group (n=323) | *Z* | *P* |
|---|---|---|---|---|
| SCr (μmol/L) | 38.00 (34.00, 49.00) | 39.00 (31.00, 49.00) | -0.568 | 0.573 |
| WBC (×10$^9$/L) | 14.66 (9.48, 17.59) | 8.23 (6.43, 11.50) | -3.062 | 0.002 |
| NEUT (%) | 74.80 (65.75, 81.10) | 55.10 (43.45, 67.00) | -4.163 | 0.000 |
| CRP (mg/L) | 33.79 (20.56, 128.02) | 5.50 (5.00, 16.85) | -4.484 | 0.000 |
| RBC (×10$^9$/L) | 4.47 (4.04, 4.90) | 4.60 (4.31, 4.94) | -0.947 | 0.347 |
| Hb (g/L) | 119.00 (103.50, 127.50) | 127.00 (118.00, 135.00) | -2.397 | 0.016 |
| PT (s) | 13.20 (12.60, 13.70) | 12.50 (11.85, 13.20) | -2.487 | 0.012 |

Note: SCr: serum creatinine; WBC: white blood cell count; NEUT: neutrophil percentage; CRP: C-reactive protein; RBC: red blood cell count; Hb: hemoglobin concentration; PT: prothrombin time.

**Table 3.** Comparison of surgery-related parameters between the two groups of patients

| Variable | Hypoxemia group (n=19) | Non-Hypoxemia group (n=323) | $Z/\chi^2$ | *P* |
|---|---|---|---|---|
| Duration of surgery [min, M ($Q_{25}$, $Q_{75}$)] | 70.00 (43.00, 96.50) | 20.00 (15.00, 29.00) | -5.233 | 0.000 |
| Duration of anesthesia [min, M ($Q_{25}$, $Q_{75}$)] | 90.00 (50.00, 110.00) | 30.00 (25.00, 40.00) | -5.192 | 0.000 |
| Type of anesthesia (n, %) | | | 24.047 | 0.000 |
| Non-intubated general anesthesia | 9 (47.37) | 284 (87.93) | | |
| Endotracheal intubated general anesthesia | 10 (52.63) | 39 (12.07) | | |
| Surgical site (n, %) | | | 6.256 | 0.199 |
| Thoracic and abdominal regions | 17 (89.47) | 310 (95.98) | | |
| Perineal region | 0 (0.00) | 2 (0.62) | | |
| Cervical region | 0 (0.00) | 2 (0.62) | | |
| Upper limbs | 1 (5.26) | 3 (0.93) | | |
| Craniofacial region | 1 (5.26) | 3 (0.93) | | |
| Lower limbs | 0 (0.00) | 3 (0.93) | | |

**Table 4.** Comparison of blood inflammatory marker levels between the two groups of patients [M ($Q_{25}$, $Q_{75}$)]

| Variable | Hypoxemia group (n=19) | Non-Hypoxemia group (n=323) | *Z* | *P* |
|---|---|---|---|---|
| IL-2 (ng/L) | 3.15 (1.66, 6.21) | 2.62 (1.46, 3.73) | -1.485 | 0.139 |
| IL-6 (ng/L) | 67.29 (44.51, 759.24) | 23.81 (10.74, 53.23) | -4.489 | <0.0001 |
| IL-10 (ng/L) | 19.49 (10.14, 28.87) | 12.25 (7.21, 18.27) | -2.207 | 0.027 |
| TNF-α (μg/L) | 1.99 (1.30, 3.67) | 2.21 (1.06, 3.53) | -0.127 | 0.901 |

Note: IL-2: interleukin-2; IL-6: interleukin-6; IL-10: interleukin-10; TNF-α: tumor necrosis factor-α.

**Table 5.** Comparison of operating room cleanliness class between the two groups of patients (n, %)

| Variable | Hypoxemia group (n=19) | Non-Hypoxemia group (n=323) | $\chi^2$ | *P* |
|---|---|---|---|---|
| Operating room cleanliness class | | | 12.646 | 0.002 |
| ≥0.5 μM (Class 10 000) | 11 (57.89) | 282 (87.31) | | |
| ≥0.5 μM (Class 100) | 8 (42.11) | 41 (12.69) | | |

durations and a higher proportion of endotracheal general anesthesia compared with the non-hypoxemia group (*P*<0.05). No significant difference in surgical site distribution was observed between the groups (*P*>0.05).

*Comparisons of serum inflammatory marker levels between the two groups*

Serum inflammatory marker levels in the two groups are presented in **Table 4**. The hypoxemia group demonstrated significantly higher IL-6 and IL-10 levels compared to the non-hypoxemia group (*P*<0.05). No significant differences were observed in IL-2 or TNF-α levels between the groups (*P*>0.05).

*Comparisons of operating room environmental cleanliness class between the two groups*

Operating room environmental cleanliness levels of the two groups are detailed in **Table 5**. The hypoxemia group had a significantly higher proportion of cases conducted in rooms meeting Class 100 cleanliness standards (particle size ≥0.5 μm) compared with the non-hypoxemia group (*P*<0.05).

*Univariate logistic regression analysis of hypoxemia in children during anesthesia*

The findings of the univariate logistic regression analysis are summarized in **Table 6**. Univariate logistic regression was performed with hypoxemia occurrence as the dependent variable (0= no hypoxemia, 1= hypoxemia), and all potential predictors as independent variables. Univariate analysis revealed that WBC (*OR*=1.079, 95% *CI*: 1.016-1.146), NEUT (*OR*=1.071, 95% *CI*: 1.035-1.108), CRP (*OR*=1.015, 95% *CI*: 1.007-1.022), Hb (*OR*=0.965, 95% *CI*: 0.938-0.993), PT (*OR*=1.322, 95% *CI*: 1.011-1.728), duration of surgery (*OR*=1.035, 95% *CI*: 1.022-1.048), anesthesia duration (*OR*=1.033, 95% *CI*: 1.021-1.046), type of anesthesia (*OR*=8.091, 95% *CI*: 3.096-21.147), IL-2 (*OR*=1.355, 95% *CI*: 1.059-1.734), IL-10 (*OR*=1.009, 95% *CI*: 1.001-1.017), and operating room cleanliness (*OR*=5.002, 95% *CI*: 1.900-13.167) were significantly associated with pediatric hypoxemia during anesthesia (*P*<0.05).

*Multivariate logistic regression analysis of hypoxemia in children during anesthesia*

The results of the multivariate logistic regression analysis are presented in **Table 7**. Variables with statistical significance in the univariate analysis (WBC, NEUT, CRP, Hb, PT, surgery duration, anesthesia duration, anesthesia type, IL-2, IL-10, and operating room cleanliness) were included in the multivariate model. The analysis identified CRP and anesthesia duration as independent risk factors for pediatric hypoxemia in children undergoing anesthesia (*P*<0.05). As shown in **Figure 1**, forest plot visualization indicated that both CRP and anesthesia duration were positively associated with hypoxemia risk, with 95% CIs not crossing unity (*P*<0.05). Conversely, IL-10 demonstrated no significant association with pediatric hypoxemia, as its 95% CI included unity (*P*>0.05).

**Table 6.** Univariate logistic regression analysis of hypoxemia during anesthesia in pediatric patients

| Variable | | B | S.E. | Wald $\chi^2$ | *P* | OR | 95% *CI* |
|---|---|---|---|---|---|---|---|
| Sex | | 1.041 | 0.574 | 3.293 | 0.07 | 2.833 | 0.920-8.723 |
| Age distribution | <1 month | | | 0.285 | 0.963 | | |
| | 1-12 months | -0.241 | 1.275 | 0.036 | 0.850 | 0.786 | 0.065-9.569 |
| | 1-3 years | -0.416 | 1.202 | 0.120 | 0.730 | 0.660 | 0.063-6.958 |
| | 3-14 years | -0.492 | 1.083 | 0.207 | 0.649 | 0.611 | 0.073-5.101 |
| Weight (kg) | | -0.024 | 0.023 | 1.133 | 0.287 | 0.976 | 0.934-1.021 |
| BMI (kg/m$^2$) | | 0.007 | 0.076 | 0.008 | 0.930 | 1.007 | 0.867-1.169 |
| Height (cm) | | -0.008 | 0.008 | 0.845 | 0.358 | 0.992 | 0.977-1.009 |
| Blood type | Type A | | | 1.275 | 0.735 | | |
| | Type B | 0.720 | 0.644 | 1.252 | 0.263 | 2.055 | 0.582-7.258 |
| | Type O | 0.376 | 0.660 | 0.324 | 0.569 | 1.457 | 0.399-5.316 |
| | Type AB | 0.456 | 0.889 | 0.263 | 0.608 | 1.578 | 0.276-9.021 |
| SCr (μmol/L) | | 0.001 | 0.005 | 0.018 | 0.893 | 1.001 | 0.991-1.011 |
| WBC (×10$^9$/L) | | 0.076 | 0.031 | 6.182 | 0.013 | 1.079 | 1.016-1.146 |
| NEUT (%) | | 0.068 | 0.017 | 15.541 | 0.000 | 1.071 | 1.035-1.108 |
| CRP (mg/L) | | 0.015 | 0.004 | 15.031 | 0.000 | 1.015 | 1.007-1.022 |
| RBC (×10$^9$/L) | | -0.603 | 0.414 | 2.122 | 0.145 | 0.547 | 0.243-1.232 |
| Hb (g/L) | | -0.035 | 0.015 | 5.889 | 0.015 | 0.965 | 0.938-0.993 |
| PT (s) | | 0.279 | 0.137 | 4.163 | 0.041 | 1.322 | 1.011-1.728 |
| Duration of surgery (min) | | 0.034 | 0.006 | 27.921 | 0.000 | 1.035 | 1.022-1.048 |
| Duration of anesthesia (min) | | 0.033 | 0.006 | 28.575 | 0.000 | 1.033 | 1.021-1.046 |
| Type of anesthesia | | 2.091 | 0.490 | 18.193 | 0.000 | 8.091 | 3.096-21.147 |
| Surgical site | Thoracic and abdominal regions | | | 4.470 | 0.484 | | |
| | Perineal region | -18.300 | 28420.722 | 0.000 | 0.999 | 0.000 | 0.000 |
| | Cervical region | -18.300 | 28420.722 | 0.000 | 0.999 | 0.000 | 0.000 |
| | Upper limbs | 1.805 | 1.181 | 2.334 | 0.127 | 6.078 | 0.600-61.558 |
| | Craniofacial region | 1.805 | 1.181 | 2.334 | 0.127 | 6.078 | 0.600-61.558 |
| | Lower limbs | -18.300 | 23205.422 | 0.000 | 0.999 | 0.000 | 0.000 |
| IL-2 (ng/mL) | | 0.304 | 0.126 | 5.816 | 0.016 | 1.355 | 1.059-1.734 |
| IL-6 (ng/mL) | | 0.000 | 0.000 | 6.842 | 0.009 | 1.000 | 1.000-1.001 |
| IL-10 (ng/mL) | | 0.009 | 0.004 | 4.940 | 0.026 | 1.009 | 1.001-1.017 |
| TNF-α (μg/mL) | | 0.080 | 0.126 | 0.408 | 0.523 | 1.084 | 0.847-1.386 |
| Operating room cleanliness class | | 1.610 | 0.494 | 10.629 | 0.001 | 5.002 | 1.900-13.167 |

Note: SCr: serum creatinine; WBC: white blood cell count; NEUT: neutrophil percentage; CRP: C-reactive protein; RBC: red blood cell count; Hb: hemoglobin concentration; PT: prothrombin time; IL-2: interleukin-2; IL-6: interleukin-6; IL-10: interleukin-10; TNF-α: tumor necrosis factor-α.

**Table 7.** Multivariate logistic regression analysis of hypoxemia during anesthesia in pediatric patients

| Variable | B | S.E | Wald $\chi^2$ | *P* | *OR* | 95% *CI* |
|---|---|---|---|---|---|---|
| CRP (mg/L) | 0.011 | 0.004 | 9.768 | 0.002 | 1.011 | 1.004-1.018 |
| Duration of anesthesia (min) | 0.029 | 0.006 | 21.247 | 0.000 | 1.029 | 1.017-1.042 |
| IL-10 (ng/mL) | 0.007 | 0.004 | 3.339 | 0.068 | 1.007 | 1.000-1.014 |

Note: CRP: C-reactive protein; IL-10: interleukin-10.

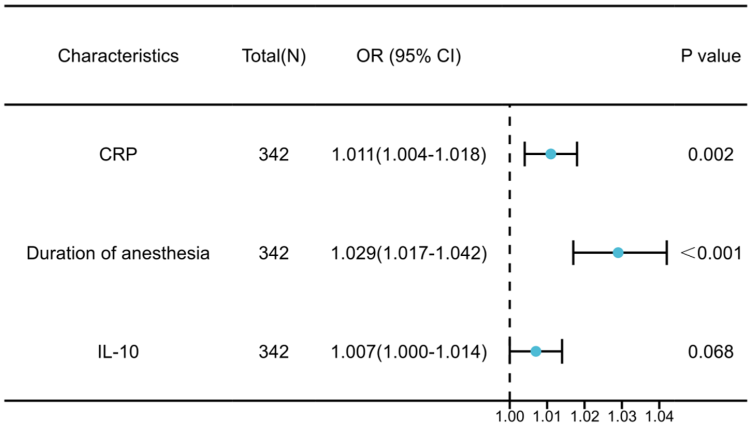


**Figure 1.** Forest plot of risk factors for hypoxemia in pediatric anesthesia. Note: CRP: C-reactive protein.

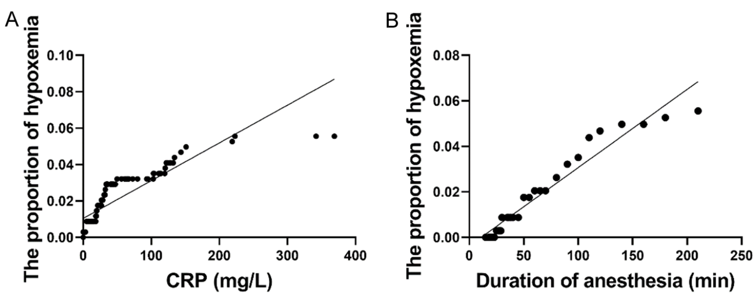


**Figure 2.** Correlation between independent risk factors and hypoxemia risk. A. Scatter plot of the correlation between CRP and hypoxemia risk; B. Scatter plot of the correlation between anesthesia duration and hypoxemia risk.

*Correlation between independent risk factors and hypoxemia occurrence*

**Figure 2** shows scatter plots depicting the correlation between CRP, anesthesia duration, and the hypoxemia incidence. A strong positive correlation was observed between CRP levels and hypoxemia risk (*r*=0.9372, *P*<0.001, **Figure 2A**) and between anesthesia duration and hypoxemia risk (*r*=0.9912, *P*<0.001, **Figure 2B**). These findings indicate that CRP and anesthesia duration were strongly positively correlated with the occurrence of hypoxemia in pediatric patients undergoing anesthesia.

*Validation of the prediction model for hypoxemia during anesthesia in children*

The predictive performance of the hypoxemia risk model is presented in **Figure 3**. A predictive model was developed using independent predictors identified in multivariate logistic regression analysis. The ROC analysis demonstrated an AUC of 0.914 for the combined predictive ability of CRP and anesthesia duration (**Figure 3A**). The calibration curve showed good agreement between predicted and observed hypoxemia probabilities, with a Brier score of 0.042 (**Figure 3B**). DCA demonstrated a favorable net benefit across threshold probabilities of 0.05-0.65, outperforming both “treat none” and “treat all” strategies (**Figure 3C**).

## Discussion

Hypoxemia represents one of the common adverse events during pediatric anesthesia, and its epidemiologic characteristics and pathological mechanisms have attracted considerable attention in the field of pediatric anesthesia [11]. Previous studies have indicated that the mortality rate within 48 hours after hypoxemia onset in children can reach 3.8% [12]. During anesthesia, the combined effects of surgical stress, anesthetic agents, and the unique physiologic characteristics of children, along with the involvement of inflammatory factors, may elevate the risk of hypoxemia [13, 14]. The present study identified CRP levels and anesthesia duration as independent risk factors for hypoxemia in children during anes-

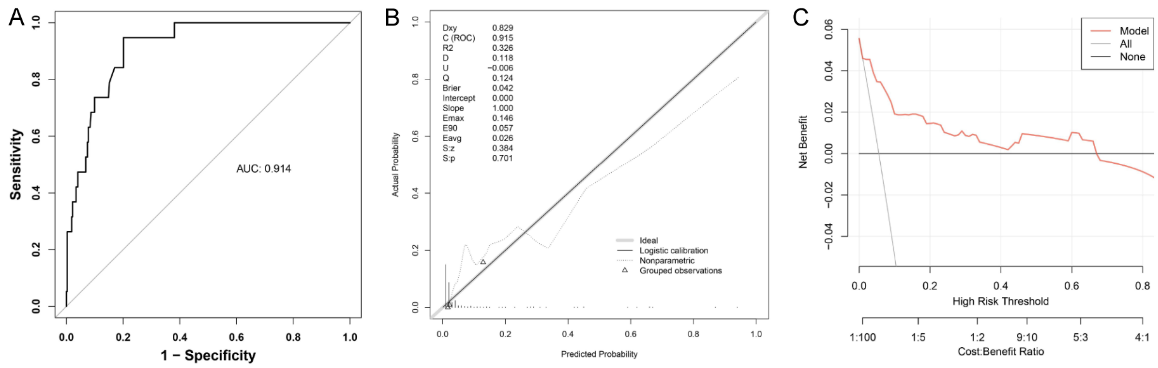


**Figure 3.** Predictive performance of the risk prediction model for hypoxemia during pediatric anesthesia. A. ROC (Receiver Operating Characteristic) curve; B. Calibration curve; C. DCA (Decision Curve Analysis).

thesia. This underscores the importance of monitoring preoperative inflammatory status and carefully controlling anesthesia duration in clinical practice to mitigate the incidence of hypoxemia and enhance perioperative safety in pediatric patients.

As a pivotal acute-phase reactant protein, CRP levels increase rapidly in response to infection, inflammation, trauma, or surgical stimuli [15]. The findings of this study identified CRP as an independent risk factor for hypoxemia in children during anesthesia, suggesting it may contribute to the occurrence of hypoxemia through two primary mechanisms. First, CRP can directly bind to vascular endothelial cell receptors, thereby downregulating the expression and biological activity of endothelial nitric oxide synthase (eNOS), reducing the nitric oxide (NO) production, and promoting the release of vasoconstrictors and adhesion molecules [16]. This cascade disrupts pulmonary vascular endothelial barrier integrity and may lead to impaired oxygen exchange and subsequent hypoxemia [17]. Second, CRP serves as a well-recognized biomarker for systemic inflammation and cardiovascular risk. Following surgical trauma, CRP recruits immune cells, including neutrophils and macrophages, to accumulate in the lungs [18-20]. The reactive oxygen species (ROS) and enzymes (e.g., matrix metalloproteinases) released by these activated cells further damage alveolar epithelial and capillary endothelial structures, reducing lung compliance and facilitating the occurrence of hypoxemia [21, 22].

In addition, prolonged anesthesia duration was also identified as an independent risk factor for hypoxemia, aligning with previous finding that an extended anesthesia duration is significantly correlated with an elevated incidence of surgical complications [23]. Extended exposure to anesthetic agents such as propofol and sufentanil can result in drug accumulation, suppressing the medullary respiratory center and gradually reducing respiratory rate [24, 25]. Concurrently, the muscle relaxant effects of atracurium may cause respiratory muscle relaxation, retention of airway secretions, and inadequate alveolar ventilation, further increasing hypoxemia risk [26]. Scatter plots revealed strong positive correlations between both CRP levels and anesthesia duration with the occurrence of hypoxemia.

A predictive model incorporating CRP levels and anesthesia duration was constructed and evaluated using ROC curves, calibration curves, and DCA. The model achieved an AUC value of 0.914, indicating excellent discrimination between pediatric patients who developed hypoxemia and those who did not. The calibration curve demonstrated close alignment between predicted and observed probabilities, confirming the model's good calibration. Furthermore, DCA showed a clear net clinical benefit within threshold probabilities of 0.05-0.65, outperforming both "treat-all" and "treat-none" strategies.

Collectively, these results demonstrate that the predictive model based on CRP and anesthesia duration possesses high discrimination, calibration, and clinical applicability. Therefore, monitoring preoperative CRP levels and optimizing anesthesia duration may facilitate early identification and timely intervention for children at high risk of developing hypoxemia during anesthesia.

This study has several limitations. First, the data were retrospectively collected from a single center, potentially leading to selection bias. Second, the limited sample size compromises the generalizability of the findings, warranting further validation through multi-center studies. Third, intraoperative blood concentrations of anesthetic agents were not dynamically monitored, making it difficult to precisely assess the dose-effect relationship between drug accumulation and hypoxemia. In addition, potential confounding variables, such as preoperative pulmonary function and airway management during anesthesia, were not fully controlled, which may have influenced the mechanistic analysis. Future multi-center, prospective studies incorporating real-time drug concentration monitoring and multi-dimensional indicators are needed to refine the hypoxemia risk assessment model.

## Conclusion

CRP levels and anesthesia duration were identified as independent risk factors for hypoxemia in pediatric patients undergoing anesthesia. The predictive model derived from these factors demonstrated excellent performance and may serve as a practical tool for early clinical screening and intervention. These findings underscore the importance of monitoring CRP and optimizing anesthesia duration to reduce the risk of intraoperative hypoxemia, thereby offering a theoretical basis for improving perioperative management and safety in pediatric anesthesia.

## Disclosure of conflict of interest

None.

**Address correspondence to:** Weiyan Wang, Department of Anesthesiology, Pu'er People's Hospital, Pu'er 665000, Yunnan, China. E-mail: 15125518005@163.com; pesrmyykjb@126.com

## References

[1] Li H, Zhang Y, Cai J, Wang H and Wei R. Risk factors of hypoxemia in the postanesthesia care unit after general anesthesia in children. J Perianesth Nurs 2023; 38: 799-803.
[2] Gangaram-Panday NH, Poppe JA, Tintu AN, Poets CF, Reiss IKM, van Weteringen W and Simons SHP. Towards standardized and clinically relevant definitions of hypoxemia and hyperoxemia in preterm infants: a systematic review. Paediatr Respir Rev 2025; [Epub ahead of print].
[3] Kim EH, Park JB, Kang P, Ji SH, Jang YE, Lee JH, Kim HS and Kim JT. Oxygen reserve index versus conventional peripheral oxygen saturation for prevention of hypoxaemia: a randomised controlled trial. Eur J Anaesthesiol 2024; 41: 687-694.
[4] Qin YJ, Yang YX, Li JX and Guan J. Risk factors for hypoxemia in children with severe mycoplasma pneumoniae pneumonia. Zhongguo Dang Dai Er Ke Za Zhi 2025; 27: 192-198.
[5] Xiong N, Nong Y and Yi Y. Meta-analysis of risk factors associated with postoperative hypoxemia in the postanesthesia care unit. Am J Transl Res 2024; 16: 5787-5796.
[6] Bizuneh YB, Zeleke ME, Gebru AM, Teshome DF, Mekonnen FA, Angaw DA and Getahun AB. Global prevalence of postoperative hypoxemia among adult and pediatric surgical patients: a systematic review and meta-analysis. BMC Anesthesiol 2025; 25: 284.
[7] Gao Y, Wang B, Wang S, Jiang Y, Wang D, Lin Q, Liu K, Zhang S, Cheng Y and Xu J. LncRNA MALAT1 serves as a risk factor in perioperative respiratory adverse events in children under general anesthesia. Toxicol Res (Camb) 2025; 14: tfaf068.
[8] Gu Z, Yin A, Lu L, Lu Y, Jiang B and Yin L. Risk factors for intraprocedural hypoxemia in patients with acute cerebral ischemia treated with vascular intervention and its impact on prognosis: a retrospective cohort study. Brain Circ 2024; 10: 42-50.
[9] Sun Y, Deng XM, Cai Y, Shen SE and Dong LY. Post-cardiopulmonary bypass hypoxaemia in paediatric patients undergoing congenital heart disease surgery: risk factors, features, and postoperative pulmonary complications. BMC Cardiovasc Disord 2022; 22: 430.
[10] Leone M, Einav S, Chiumello D, Constantin JM, De Robertis E, Abreu MG, Gregoretti C, Jaber S, Maggiore SM, Pelosi P, Sorbello M and Afshari A. Noninvasive respiratory support in the hypoxaemic peri-operative/periprocedural patient: a joint ESA/ESICM guideline. Eur J Anaesthesiol 2020; 37: 265-279.
[11] Park JB, Lee HJ, Yang HL, Kim EH, Lee HC, Jung CW and Kim HS. Machine learning-based prediction of intraoperative hypoxemia for pediatric patients. PLoS One 2023; 18: e0282303.
[12] Conradi N, Opoka RO, Mian Q, Conroy AL, Hermann LL, Charles O, Amone J, Nabwire J, Lee BE, Saleh A, Mandhane P, Namasopo S and

Hawkes MT. Solar-powered O(2) delivery for the treatment of children with hypoxaemia in Uganda: a stepped-wedge, cluster randomised controlled trial. Lancet 2024; 403: 756-765.
[13] Zhang SJ, Lin MY, Zhou M, Dan YZ, Gu HB and Lu GL. Hypoxaemia risk in pediatric flexible bronchoscopy for foreign body removal: a retrospective study. BMC Pediatr 2024; 24: 359.
[14] Pita-Martínez C, Goez-Sanz C, Virseda-Berdices A, Gonzalez-Praetorius A, Mazario-Martín E, Rodriguez-Mesa M, Quero-Delgado M, Matías V, Martínez I and Resino S. Reduced antiviral gene expression and elevated CXCL8 expression in peripheral blood are associated with severe hypoxemia in RSV-infected children. Front Immunol 2024; 15: 1438630.
[15] Potempa M, Hart PC, Rajab IM and Potempa LA. Redefining CRP in tissue injury and repair: more than an acute pro-inflammatory mediator. Front Immunol 2025; 16: 1564607.
[16] Ling C, Cook MD, Grimm H, Aldokhayyil M, Gomez D and Brown M. The effect of race and shear stress on CRP-induced responses in endothelial cells. Mediators Inflamm 2021; 2021: 6687250.
[17] Cuesta-López L, Arias-de la Rosa I, Martín-Salazar JE, Barranco AM, Ladehesa-Pineda L, Ruiz-Ponce M, Puche Larrubia MÁ, Pérez-Sánchez C, Seguí P, Ortega R, Calvo J, Ábalos-Aguilera MC, Ruiz-Vilchez D, Moreno-Caño E, Ortiz-Buitrago P, Lopez-Pedrera C, Escudero-Contreras A, Collantes E, López-Medina C and Barbarroja N. Molecular insights into the relationship between sustained CRP elevation and endothelial dysfunction in axial spondyloarthritis. RMD Open 2025; 11: e005746.
[18] Sibianu M and Slevin M. The pathogenic role of C-reactive protein in diabetes-linked unstable atherosclerosis. Int J Mol Sci 2025; 26: 6855.
[19] Newling M, Sritharan L, van der Ham AJ, Hoepel W, Fiechter RH, de Boer L, Zaat SAJ, Bisoendial RJ, Baeten DLP, Everts B and den Dunnen J. C-reactive protein promotes inflammation through FcγR-induced glycolytic reprogramming of human macrophages. J Immunol 2019; 203: 225-235.
[20] Karasu E, Halbgebauer R, Schütte L, Greven J, Bläsius FM, Zeller J, Winninger O, Braig D, Messerer DAC, Berger B, Feuerstein H, Schultze A, Peter K, Knippschild U, Horst K, Hildebrand F, Eisenhardt SU and Huber-Lang M. A conformational change of C-reactive protein drives neutrophil extracellular trap formation in inflammation. BMC Biol 2025; 23: 4.
[21] Ali YM, Abd El-Aziz AM, Mabrook M, Shabaan AA, Sim RB and Hassan R. Recombinant chemotaxis inhibitory protein of Staphylococcus aureus (CHIPS) protects against LPS-induced lung injury in mice. Clin Immunol 2018; 197: 27-33.
[22] Liang CC, Zhao J, Zhang YQ, Chen J and Wang Y. Research progress on the effect of neutrophil elastase and its inhibitors in respiratory diseases. J Int Med Res 2025; 53: 3000605251352789.
[23] Brady JS, Desai SV, Crippen MM, Eloy JA, Gubenko Y, Baredes S and Park RCW. Association of anesthesia duration with complications after microvascular reconstruction of the head and neck. JAMA Facial Plast Surg 2018; 20: 188-195.
[24] Zhang C, Luo J, Liao Y, Cao H, Wu X, Huang X, Lan H, Lin Y, Chen H and Guan X. Respiratory depression in women receiving propofol/esketamine versus propofol/fentanyl for abortion surgery or curettage: a randomized clinical trial. Ann Med 2025; 57: 2483981.
[25] Liu C, Wang Y, Yin Y, Wang P, Ji X, Sun J, Zhao S, Jia Y, Liu S and Zhou Z. Comparative efficacy of esketamine vs sufentanil with propofol for sedation in EUS: a randomized, controlled study. J Pain Res 2025; 18: 205-215.
[26] Karimi M, Ghaheri A, Saleh K, Cheraghi Z and Farahanchi A. Effect of atracurium versus cisatracurium on QT interval changes in patients undergoing cataract surgery: a randomized clinical trial. BMC Anesthesiol 2024; 24: 431.