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ORIGINAL RESEARCH

# A Risk Prediction Nomogram Model for Postoperative Pulmonary Complications in Children Aged 0-6 years

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**Background:** Postoperative pulmonary complications (PPCs) in children are common. However, few models tailored specifically for children are available to identify risk factors for PPCs and enable preoperative interventions. This study aimed to identify independent risk factors for PPCs in children and establish a risk prediction model.

**Methods:** The clinical data of pediatric patients aged 0–6 years with an American Society of Anesthesiologists (ASA) physical status of I or II, and had undergone surgery with mechanical ventilation at Henan Provincial People's Hospital between January 2020 and December 2021 were retrospectively reviewed. Univariate and multivariate logistic regression analyses were employed to identify risk factors for PPCs. The corresponding nomogram prediction model was constructed based on the regression coefficients. The receiver operating characteristic curve and calibration curve were used respectively to evaluate the discriminant validity and calibration of the prediction model.

**Results:** Among 1545 patients included, 211 (13.4%) developed PPCs (156 of 1082 patients in the discovery cohort and 55 of 463 patients in the test cohort). In the multivariate logistic regression analysis, age (odds ratio [OR] 0.87, 95% confidence interval [CI] 0.79–0.96, $P$=0.007), mechanical ventilation time (OR 1.36, 95% CI 1.20–1.55, $P$<0.001), airway device (OR 1.67, 95% CI 1.04–2.68, $P$=0.033), ASA physical status (OR 1.96, 95% CI 1.34–2.88, $P$=0.001), and type of surgery (the total effect, $P$=0.004) were identified as the independent risk factors for PPCs in the discovery cohort. The prediction model showed good discrimination and calibration performance in both the discovery and test cohorts. The corresponding area under the curve was 0.762 (95% CI: 0.722, 0.803) and 0.818 (95% CI: 0.760, 0.875), respectively.

**Conclusion:** We identified age, ventilation device and duration, ASA physical status, and surgical site as independent risk factors for PPCs in children aged 0–6 years. The predictive model performed well and demonstrated a certain capability in predicting the risk of PPCs.

**Keywords:** postoperative pulmonary complications, children, risk factors, prediction model

## Introduction

Postoperative pulmonary complications (PPCs) are common in children undergoing surgery, with an incidence ranging from 2% to 80%, depending on definitions, especially in the first week after surgery.[1,2] The development of PPCs can result in prolonged hospital stays and increased medical costs and mortality.[1–4] Intraoperative lung protective ventilation strategies have been developed to reduce the risk of PPCs.[5,6] Due to the limited oxygen reserve function, children typically have lower functional residual capacity and higher closed volume than adults, rendering them less tolerant to hypoxia. Consequently, children are more susceptible to ventilator-induced lung injury and PPCs following mechanical ventilation when compared with adults according to a previous study by Lee et al.[7]



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Early identification of risk factors for PPCs and taking preventive measures can reduce the incidence of PPCs. Two predictive scoring systems, "Assess Respiratory Risk in Surgical Patients in Catalonia"[3] and "the surgical lung injury prediction model",[8,9] have been developed to assess the probability of PPCs. Canet et al constructed a risk index for PPCs through a prospective multicenter study in Catalonia, Spain (n=2464).[3] Seven independent predictors were identified via logistic regression: low preoperative $SpO_2$, recent respiratory infection, age, anemia, upper abdominal/intrathoracic surgery, surgery duration, and emergency procedure. Kor et al developed the Surgical Lung Injury Prediction (SLIP) model through a secondary analysis of a prospective cohort study (n=4366), utilizing multivariate logistic regression to integrate five preoperative variables: high-risk cardiac, aortic vascular, or thoracic surgery; diabetes mellitus; chronic obstructive pulmonary disease; gastroesophageal reflux disease; and alcohol abuse.[8] Kor et al developed the SLIP-2 risk score model based on a multicenter cohort study (n=1562), utilizing logistic regression to integrate nine independent predictors, including patient characteristics (eg, sepsis, cirrhosis, admission from non-home locations), procedure-related features (eg, high-risk cardiac surgery, high-risk aortic vascular surgery, emergency surgery), and early physiologic markers (increased respiratory rate, $FiO_2$ >35%, $SpO_2$ <95%).[9] Neto et al developed a preoperative prediction score model (LAS VEGAS) for PPCs based on a multicenter cohort study (n=6063), utilizing logistic regression to integrate 13 variables, including patient characteristics, procedure-related features, and intraoperative events.[10] The intraoperative events considered include ventilation parameters (such as tidal volume and positive end-expiratory pressure [PEEP]), cardiovascular events (such as an aortic balloon catheter insertion, cardiopulmonary bypass duration, extracorporeal membrane oxygenation, substantial vasoactive agents use, and red blood cells transfusion), and fluid administrations. Incorporating these factors into a prediction model can enhance its predictive power.[11–14] However, pediatric patients were generally excluded from the studies. Although the developed risk prediction models/tools can identify key factors highly correlated with PPCs and enable preoperative interventions,[10,15] there are few models tailored specifically for children. Therefore, it is necessary to establish a risk prediction model for pediatric PPCs to provide clinical evidence for PPCs prevention.

We aimed to identify risk factors for PPCs in pediatric patients, with the goal of establishing a risk prediction model for PPC prevention in children.

# Materials and Methods

## Study Design and Patients

Pediatric patients who had undergone surgery at Henan Provincial People's Hospital between January 2020 and December 2021 were retrospectively reviewed. This study complied with the Declaration of Helsinki and was approved by the Medical Ethics Committee of Henan Provincial People's Hospital ((2024) No. 39). Since this study is a retrospective study, which only makes use of existing medical records or data, does not involve the identities or privacy of the subjects, and does not cause any risks or harm to the subjects, the informed consent was waived by the institutional ethics committee.

## Inclusion Criteria

Eligible patients were aged 0–6 years, with an American Society of Anesthesiologists (ASA) physical status of I-II, and undergoing surgery under general anesthesia.

## Exclusion Criteria

Patients under general anesthesia without intubation or laryngeal mask and those with incomplete clinical data were excluded. Types of surgery in which PPCs rarely occur were also excluded (eg, Ophthalmic, daytime, surface and other minor surgery).

## Sample Size

When developing prediction models for binary or time-to-event outcomes, a well-known rule of thumb for the required sample size is to ensure at least 10 events for each predictor parameter.[16] In this research, there were 14 variables included in univariate analysis, the event number should be 140 at least. The number of PPCs in our research was 156 in the discovery cohort, and 211 in the total sample, which is higher than 140.

## Anesthesia Protocol

All patients received routine monitoring of electrocardiography, blood pressure, and pulse oximetry upon entering the operating room. All patients received routine anesthesia induction, and intraoperative anesthesia maintenance included total intravenous anesthesia and intravenous inhalation combined anesthesia. Mechanical ventilation parameters and anesthesia management during the surgery were determined by the attending anesthesiologist based on the child's age and intraoperative conditions. After surgery, the patients were transferred to the post-anesthesia care unit (PACU) for anesthesia recovery.

## Source of Data

Preoperative and postoperative data, including age, sex, pre-existing cardiovascular disease, ASA physical status, anemia status, occurrence of PPCs, and length of postoperative hospital stay, were collected from the electronic medical record system. Intraoperative data, such as elective or emergency surgery, surgical and anesthesia duration, airway device used, type of surgery, and intraoperative events, were collected from the MediTech Surgical Anesthesia System. Currently, the parameters of the anesthesia machine (such as tidal volume, PEEP, etc) are not linked to the MediTech Surgical Anesthesia System, so they cannot be collected.

## Definition of Outcomes

The primary outcome of this study was the occurrence of PPCs within the first 7 days postoperatively. PPCs were defined as any of the following: bronchospasm, pneumonia, respiratory failure, acute respiratory distress syndrome (ARDS), atelectasis, pneumothorax, pleural effusion, respiratory infection and aspiration pneumonia, based on pre-defined criteria (Table 1).[17,18] PPCs were identified by manual review of medical records to identify events meeting any PPC definition and ultimately determined by the principal investigator.

**Table 1** Definitions for Postoperative Pulmonary Complications

| Outcome Measure | Definition and Diagnostic Criteria |
|---|---|
| **Bronchospasm** | Newly detected expiratory wheeze treated with bronchodilators. |
| **Pneumonia** | CXR showing at least one of the following: infiltrate, consolidation, cavitation; plus at least one of the following: fever >38 °C with no other cause, white cell count <4 or >12 × $10^9$ litre$^{-1}$, >70 years of age with altered mental status with no other cause; plus at least two of the following: new purulent/changed sputum, increased secretions/suctioning, new/worse cough/dyspnoea/tachypnoea, rales/bronchial breath sounds, worsening gas exchange. |
| **Respiratory Failure** | Postoperative $PaO_2$ <8 kPa (60 mm Hg) on room air, a $PaO_2$: $FiO_2$ ratio <40 kPa (300 mm Hg), or arterial oxyhaemoglobin saturation <90% measured by pulse oximetry and requiring oxygen therapy. |
| **ARDS** | Ventilated, bilateral infiltrates on CXR, $PaO_2$: $FiO_2$ ≤ 300, and minimal evidence of left atrial fluid overload within 7 days of surgery. |
| **Pleural Effusion** | CXR showing blunting of the costophrenic angle, loss of sharp silhouette of the ipsilateral hemidiaphragm in upright position, displacement of adjacent anatomical structures, or (in supine position) hazy opacity in one hemithorax with preserved vascular shadows. |
| **Atelectasis** | Lung opacification with mediastinal shift, hilum or hemidiaphragm shift towards the affected area, with compensatory hyperinflation in adjacent non-atelectatic lung. |
| **Pneumothorax** | Air in the pleural space without vascular bed surrounding the visceral pleura. |
| **Respiratory Infection** | Antibiotics for suspected infection with one or more of the following: new or changed sputum, new or changed lung opacities, fever, white blood cell count >12 × $10^9$ litre$^{-1}$. |
| **Aspiration Pneumonitis** | Acute lung injury following the inhalation of regurgitated gastric contents. |

**Abbreviations**: ARDS, acute respiratory distress syndrome; CXR, chest radiograph; $FiO_2$, fraction of inspired oxygen; $PaO_2$, partial pressure of oxygen in arterial blood.


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## Statistical Analysis

All statistical analyses were conducted using the IBM SPSS Statistics 24 software (IBM Corporation, Armonk, NY, USA). Categorical variables were expressed as percentages (n(%)), and the chi-square test was used for inter-group comparisons. Continuous variables were expressed as mean ± standard deviation or median (interquartile ranges [IQRs]) depending on whether a normal distribution was followed. Since the units of operation, anesthesia, and mechanical ventilation duration were minutes, and the significance of the effect of each minute was small, the three variables were discretized by dividing them every 30 minutes.

Eligible patients were randomly divided into the discovery and test cohorts in a 7:3 ratio. The discovery cohort was used to construct the model, and the test cohort was used to confirm the discriminatory ability of the model. Univariate logistic regression was used to identify potential risk factors for PPCs based on patient characteristics and perioperative data including age, sex (male vs female), pre-existing cardiovascular disease (Yes vs No), ASA physical status (I vs II), anemia status (Yes vs No), surgery (Emergency surgery vs Elective surgery), Airway device (Laryngeal mask vs Intubation), operation time, anesthesia time, mechanical ventilation time, surgical positions, and type of surgery (Urological surgery or Abdominal surgery or Surface-related surgery or Head, neck and maxillofacial surgery or Thoracic surgery vs Orthopedic surgery). Variables with $P < 0.1$ in the univariate analysis were included in the multivariate logistic regression model, and the stepwise method was used to screen the variables ($P_{in} = 0.05$, $P_{out} = 0.10$). The variables retained in the equation were used to construct the prediction model and draw a nomogram for visual prediction. The receiver operating characteristic (ROC) curve and calibration curve were used to evaluate the predictive performance of the model. Decision curve analysis (DCA) was used to analyze the clinical utility of the risk prediction model. By visualizing the net benefit, it allows for a more informed decision about whether the benefits of using the model outweigh the potential harms and costs associated with false positives and false negatives. $P < 0.05$ was considered statistically significant unless otherwise specified.

The term "clinical utility" refers to the benefit of a risk prediction model for patients in clinical practice. Its primary aim is to ascertain whether the advantages of employing the model to provide decision-making information in clinical practice outweigh the disadvantages and to complement the model's clinical effectiveness. Its clinical application is primarily appraised through DCA. The greater the distance the curve reaches from the two extremities, the higher the clinical utility of the nomogram.

# Results

From January 2020 to December 2021, 6181 patients who met the inclusion criteria were identified, and 4636 were excluded based on the exclusion criteria. Finally, 1545 patients were included for analysis (1082 in the discovery cohort and 463 in the test cohort) (Figure 1). The baseline characteristics of the study population were well-balanced between the discovery and test cohorts, as shown in Table 2.

Overall, 211 (13.7%) patients experienced PPCs, including 156 (14.4%) in the discovery cohort and 55 (11.9%) in the test cohort. Most patients had one pulmonary complication (157, 10.2%), while 54 (3.5%) had two or more events. Bronchospasm was the most common PPC (189, 12.2%). Other complications included pneumonia in 52 (3.4%), respiratory failure in 29 (1.9%), ARDS in 16 (1.0%), pleural effusion in 14 (0.9%), atelectasis in 7 (0.5%), and pneumothorax in 5 (0.3%). No respiratory infections and aspiration pneumonia were observed. We stratified the duration of operation, anesthesia, and mechanical ventilation of the patients by taking 30 minutes as the boundary. There was no statistically significant difference between the discovery and test cohorts (Table 3).

Univariate logistic regression analysis showed that age, sex, operation time, anesthesia time, mechanical ventilation time, airway device, ASA physical status, anemia, surgical position and type of surgery were significantly associated with the risk of PPCs. After including these factors in a multivariate analysis, age (OR 0.87, 95% CI 0.79–0.96, $P$=0.007), mechanical ventilation time (OR 1.36, 95% CI 1.20–1.55, $P$=0.000), airway device (OR 1.67, 95% CI 1.04–2.68, $P$=0.033), ASA physical status (OR 1.96, 95% CI 1.34–2.88, $P$=0.001), and type of surgery (the total effect, $P$=0.004) were identified as the independent risk factors for PPCs in pediatric patients (Table 4).

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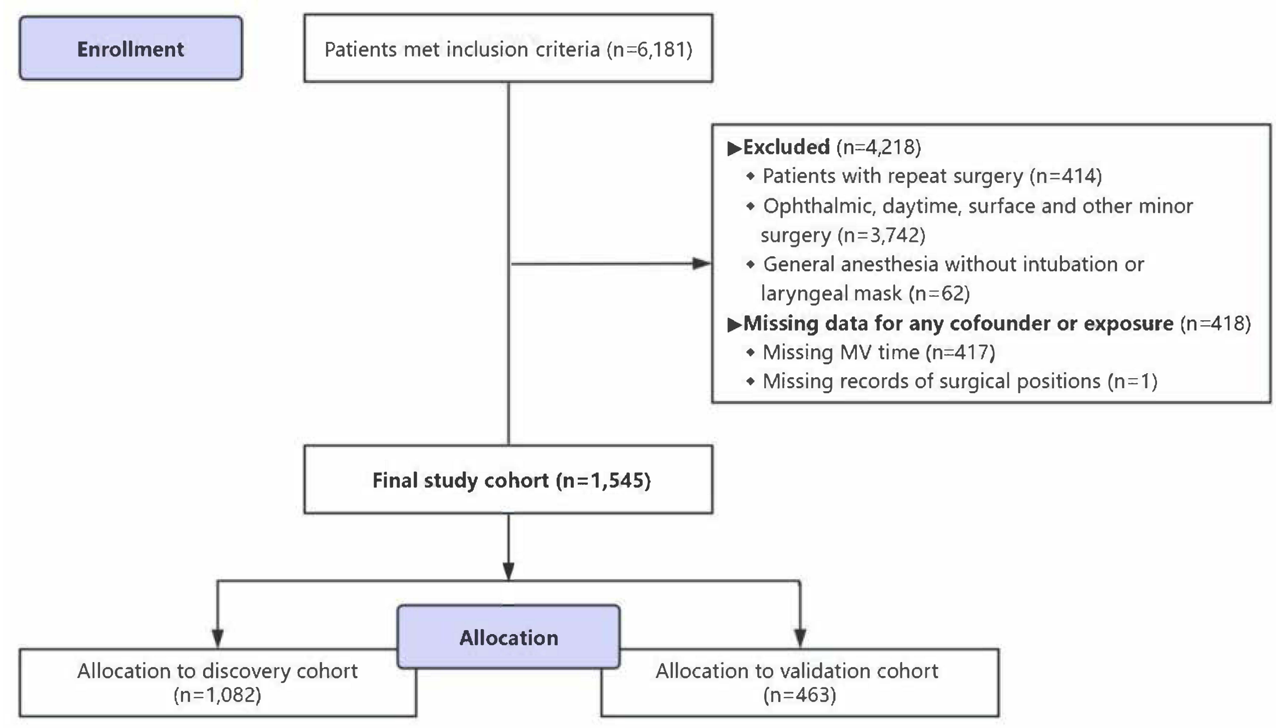


**Figure 1** Study flow diagram.

An individualized nomogram predictive model was established based on the five independent risk factors (Figure 2). The younger age, prolonged mechanical ventilation, endotracheal intubation, higher ASA physical status, and thoracic surgery were associated with an increased probability of PPCs.

**Table 2** Baseline Characteristics of the Study Population (n=1545)

| Variables | Discovery Cohort (n=1082) | Test Cohort (n=463) | *P* |
|---|---|---|---|
| **Age, M (IQR), years** | 2 (1, 4) | 2 (1, 4) | 0.707 |
| **Sex, n (%)** | | | 0.973 |
| Female | 289 (26.7) | 127 (27.4) | |
| Male | 793 (73.3) | 336 (72.6) | |
| **Cardiovascular disease, n (%)** | | | |
| No | 1074 (99.3) | 456 (98.5) | 0.572 |
| Yes | 8 (0.7) | 7 (1.5) | |
| **ASA physical status, n (%)** | | | |
| I | 716 (66.2) | 290 (62.6) | 0.865 |
| II | 366 (33.8) | 173 (37.4) | |
| **Surgery, n (%)** | | | |
| Elective surgery | 824 (76.2) | 362 (78.2) | 0.981 |
| Emergency surgery | 258 (23.8) | 101 (21.8) | |
| **Anemia, n (%)** | | | |
| No | 900 (83.2) | 386 (83.4) | 0.474 |
| Yes | 182 (16.8) | 77 (16.6) | |

(*Continued*)

**Table 2** (Continued).

| Variables | Discovery Cohort (n=1082) | Test Cohort (n=463) | *P* |
|---|---|---|---|
| **Airway device, n (%)** | | | |
| Laryngeal mask | 587 (54.3) | 235 (50.8) | 0.459 |
| Intubation | 495 (45.7) | 228 (49.2) | |
| **Operation time, M (range), mins** | 40 (20, 75) | 42 (25, 80) | 0.228 |
| **Anesthesia time, M (range), mins** | 46 (29, 81) | 50 (30, 90) | 0.277 |
| **MV time, M (range), mins** | 77 (55, 120) | 81 (53, 125) | 0.735 |
| **Type of surgery, n (%)** | | | |
| Orthopedic surgery | 86 (7.9) | 41 (8.9) | 0.309 |
| Urological surgery | 347 (32.1) | 144 (31.1) | |
| Abdominal surgery | 381 (35.2) | 172 (37.1) | |
| Surface-related surgery | 85 (7.9) | 37 (8) | |
| Head, neck and maxillofacial surgery | 164 (15.2) | 60 (13) | |
| Thoracic surgery | 19 (1.8) | 9 (1.9) | |
| **Surgical positions, n (%)** | | | |
| Supine position | 985 (91) | 421 (90.9) | 0.269 |
| Lithotomy position | 47 (4.3) | 18 (3.9) | |
| Lateral position | 30 (2.8) | 16 (3.5) | |
| Prone position | 20 (1.8) | 8 (1.7) | |
| **PPCs, n (%)** | | | |
| No | 926 (85.6) | 408 (88.1) | 0.720 |
| Yes | 156 (14.4) | 55 (11.9) | |

**Notes**: We found that 91% of the patients were in the supine position during surgery, with fewer patients in other positions, resulting in a large intergroup difference. Therefore, in the data processing, we combined other positions' surgeries with those of the supine position, except for the supine position surgeries.
**Abbreviations**: M, median; ASA, American Society of Anesthesiologists; mins, minutes; MV, mechanical ventilation; PPCs, Postoperative pulmonary complications.

**Table 3** Discretization Results of Operation Time, Anesthesia Time, and MV Time

| Variables | Discovery Cohort (n=1082) | Test Cohort (n=463) | *P* |
|---|---|---|---|
| **Operation time, n (%)** | | | 0.903 |
| <30 mins | 153 (33) | 382 (35.3) | |
| 30 mins~ | 131 (28.3) | 320 (29.6) | |
| 60 mins~ | 85 (18.4) | 173 (16) | |
| 90 mins~ | 38 (8.2) | 85 (7.9) | |
| 120 mins~ | 26 (5.6) | 57 (5.3) | |
| 150 mins~ | 12 (2.6) | 29 (2.7) | |
| ≥180 mins | 18 (3.9) | 36 (3.3) | |
| **Anesthesia time, n (%)** | | | 0.579 |
| <30 mins | 113 (24.4) | 284 (26.2) | |
| 30 mins~ | 148 (32) | 358 (33.1) | |
| 60 mins~ | 83 (17.9) | 202 (18.7) | |
| 90 mins~ | 50 (10.8) | 88 (8.1) | |
| 120 mins~ | 32 (6.9) | 65 (6) | |
| 150 mins~ | 12 (2.6) | 36 (3.3) | |
| ≥180 mins | 25 (5.4) | 49 (4.5) | |

(*Continued*)

**Table 3** (Continued).

| Variables | Discovery Cohort (n=1082) | Test Cohort (n=463) | *P* |
|---|---|---|---|
| **MV time, n (%)** | | | 0.263 |
| <30 mins | 6 (1.3) | 36 (3.3) | |
| 30 mins~ | 134 (28.9) | 283 (26.2) | |
| 60 mins~ | 123 (26.6) | 312 (28.8) | |
| 90 mins~ | 78 (16.8) | 179 (16.5) | |
| 120 mins~ | 39 (8.4) | 92 (8.5) | |
| 150 mins~ | 34 (7.3) | 63 (5.8) | |
| ≥180 mins | 49 (10.6) | 117 (10.8) | |

**Abbreviation**: MV, mechanical ventilation.

**Table 4** Logistic Regression Analysis in the Discovery Cohort

| Variables | Univariate Analysis | | Multivariate Analysis | |
|---|---|---|---|---|
| | **OR (95% CI)** | ***P*** | **OR (95% CI)** | ***P*** |
| **Age** | 0.81 (0.73, 0.89) | **<0.001** | 0.87 (0.79, 0.96) | **0.007** |
| **Sex** (Male vs female) | 0.69 (0.48, 0.99) | **0.044** | | |
| **Cardiovascular disease** (Yes vs No) | 1.99 (0.40, 9.96) | 0.402 | | |
| **ASA physical status** (II vs I) | 2.92 (2.07, 4.13) | **<0.001** | 1.96 (1.34, 2.88) | **0.001** |
| **Emergency surgery** (Yes vs No) | 0.76 (0.50, 1.16) | 0.209 | | |
| **Anemia** (Yes vs No) | 1.53 (1.01, 2.32) | **0.044** | | |
| **Operation time** | 1.37 (1.24, 1.51) | **<0.001** | | |
| **Anesthesia time** | 1.38 (1.26, 1.52) | **<0.001** | | |
| **MV time** | 1.52 (1.38, 1.68) | **<0.001** | 1.36 (1.20, 1.55) | **0.000** |
| **Airway device (**Laryngeal mask vs Intubation) | 3.88 (2.66, 5.66) | **<0.001** | 1.67 (1.04, 2.68) | **0.033** |
| **Surgical position** | 2.12 (1.29, 3.49) | **0.003** | | |
| **Type of surgery** | | **<0.001** | | **0.004** |
| Orthopedics | 1 | | 1 | |
| Urological surgery | 1.05 (0.49, 2.27) | 0.897 | 1.41 (0.63, 3.17) | 0.401 |
| Abdomen surgery | 1.47 (0.70, 3.11) | 0.308 | 2.39 (1.08, 5.30) | **0.032** |
| Surface-related surgery | 2.63 (1.12, 6.18) | **0.026** | 3.68 (1.47, 9.20) | **0.005** |
| Head, neck and maxillofacial surgery | 1.47 (0.65, 3.31) | 0.357 | 2.65 (1.06, 6.61) | **0.037** |
| Thoracic surgery | 7.70 (2.48, 23.95) | **<0.001** | 5.19 (1.60, 16.86) | **0.006** |

**Note**: P values in bold indicate statistical significance (≤0.05).
**Abbreviations**: OR, odds ratio; MV, mechanical ventilation; ASA, American Society of Anesthesiologists.

The discriminatory ability and calibration performance of the prediction model were then tested in the discovery and test cohorts. The area under the curve (AUC) of ROC curve was 0.762 (95% CI 0.722, 0.803) and 0.818 (95% CI 0.760, 0.875) in the discovery and test cohorts, respectively (Figure 3A and B). The corresponding calibration curves are shown in Figure 4A and B. The predicted probabilities of the model were consistent with the actual probabilities.

The DCA for the prediction model in the discovery and test cohorts was illustrated in Figure 5A and B. The DCA curves obtained from the two cohorts were both above the extreme line, indicating that our risk prediction model has good clinical effectiveness.

## Discussion

Mechanical ventilation can provide adequate ventilation and preserve arterial oxygen saturation in pediatric patients undergoing general anesthesia, although it carries the potential risk of inducing pulmonary injury.[19–21] As a distinct demographic, children exhibit different physiological and anatomical characteristics from adults, making them more

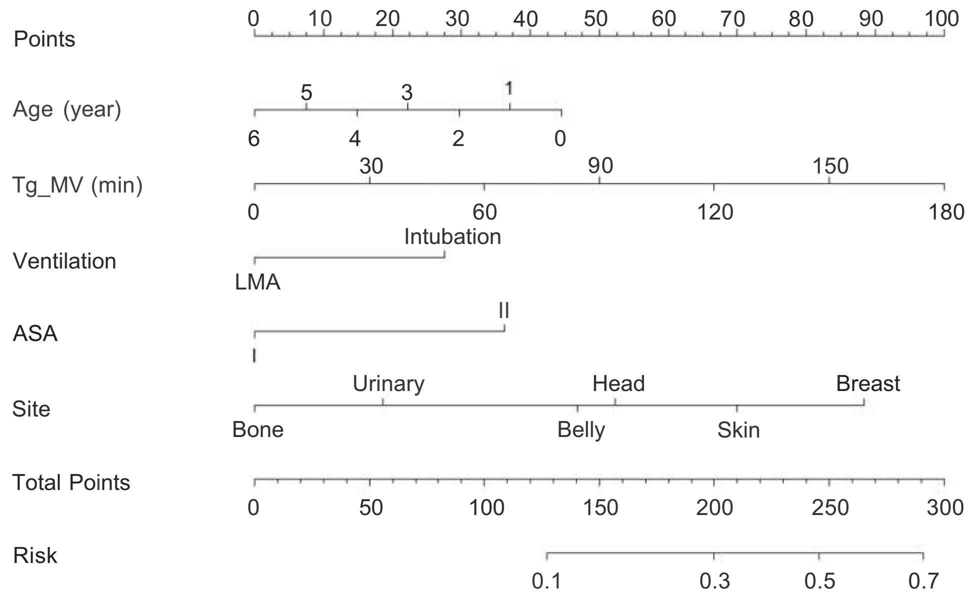


**Figure 2** Nomogram for predicting the risk of postoperative pulmonary complications. Points: Score scale. The variable in each risk factor corresponds to the score on the scale, and each variable corresponds to the score on the scale, representing the risk degree of the variable.
**Abbreviations**: ASA, American Society of Anesthesiologists physical status; MV, mechanical ventilation, LMA, laryngeal mask.

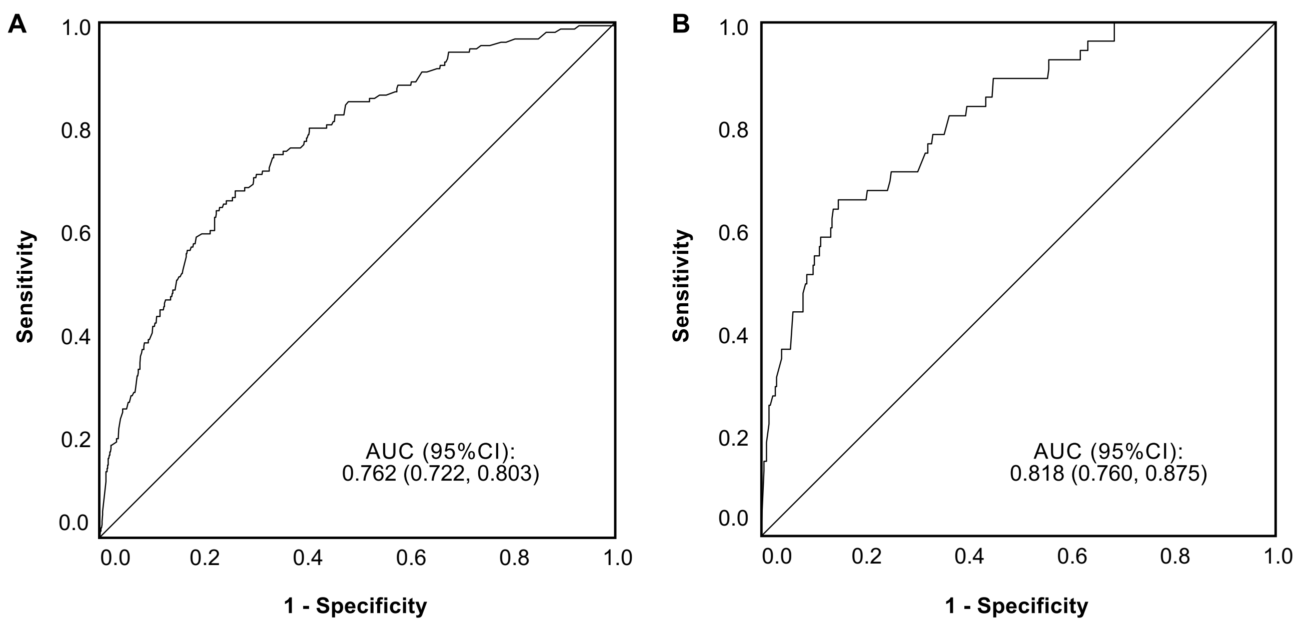


**Figure 3** Receiver operating characteristic (ROC) curve of the prediction model for predicting Postoperative Pulmonary Complications in the discovery cohort (**A**) and test cohort (**B**).

susceptible to perioperative pulmonary injury and PPCs.[7] The management of PPCs presents a significant challenge in pediatric anesthesia and surgery. A comprehensive understanding of the contributing risk factors is imperative for perioperative care and optimizing patient outcomes. Current research on pediatric PPC risk factors has been predominantly focused on intensive care units and cardio-thoracic surgery. There is less research on patients undergoing other types of surgery, and there are few studies related to risk prediction models. Risk prediction models are more precise in predicting outcomes than simple risk factors and can provide more powerful support for earlier scientific clinical diagnosis and prevention and treatment decisions. Our advantage is not only predicting the risk factors for PPCs in

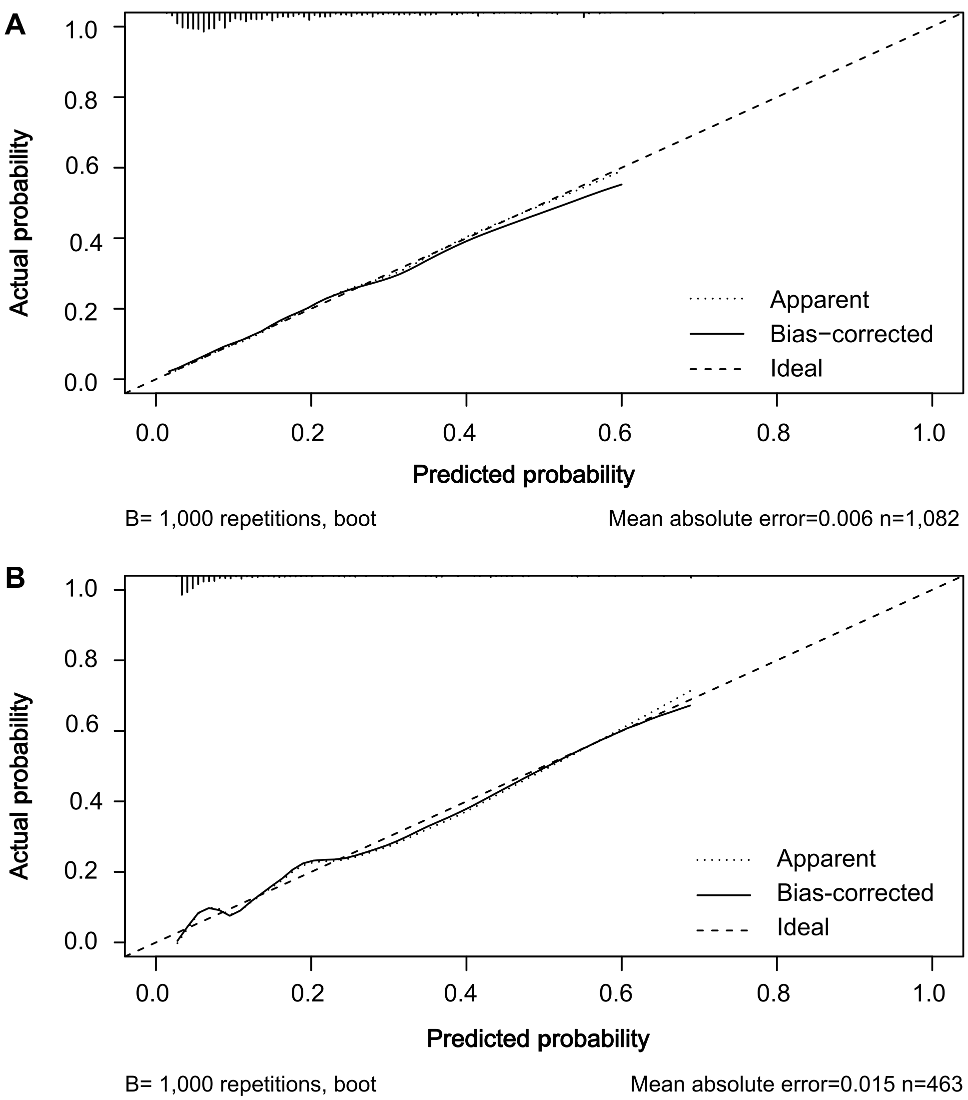


**Figure 4** Calibration Curve of the Prediction Model in the discovery cohort (**A**) and test cohort (**B**).

children aged 0–6 under general anesthesia through retrospective analysis of information from all surgical pediatric patients, but also established a risk model based on risk factors and verifying the clinical value of the model.

According to the research, the incidence of PPCs in adults ranges from 2% to 80%.[1,2] In our hospital, the incidence of PPCs in pediatric patients was 13.7%, consistent with previous research findings.[22] Key risk factors identified encompass age, duration of mechanical ventilation, airway device, ASA physical status, and type of surgery. A nomogram was created based on the results of the multivariate logistic regression analysis to simplify multiple statistical prediction models into digital estimates of the occurrence probability. Based on this nomogram, clinical healthcare professionals can sum up the scores corresponding to each risk factor to obtain a total score, and predict the probability of the child developing PPCs through the total score. This can enable early decision-making on the next step of clinical management, including close monitoring of clinical symptoms, imaging and laboratory results, make sure adequate preparation for surgery, and enhanced airway management during surgery. The nomogram is easy to use and has significant clinical utility. Based on the 5 risk factors obtained by logistic regression analysis, a prediction model was established. An internal test cohort consisting of 463 patients was constructed to validate the model. The results showed that the ROC AUC for the discovery cohort and test cohort were 0.762 and 0.818, respectively, both of which were greater than 0.75. Thus, it indicates strong predictive capability regarding PPCs development in patients. The calibration curve for both

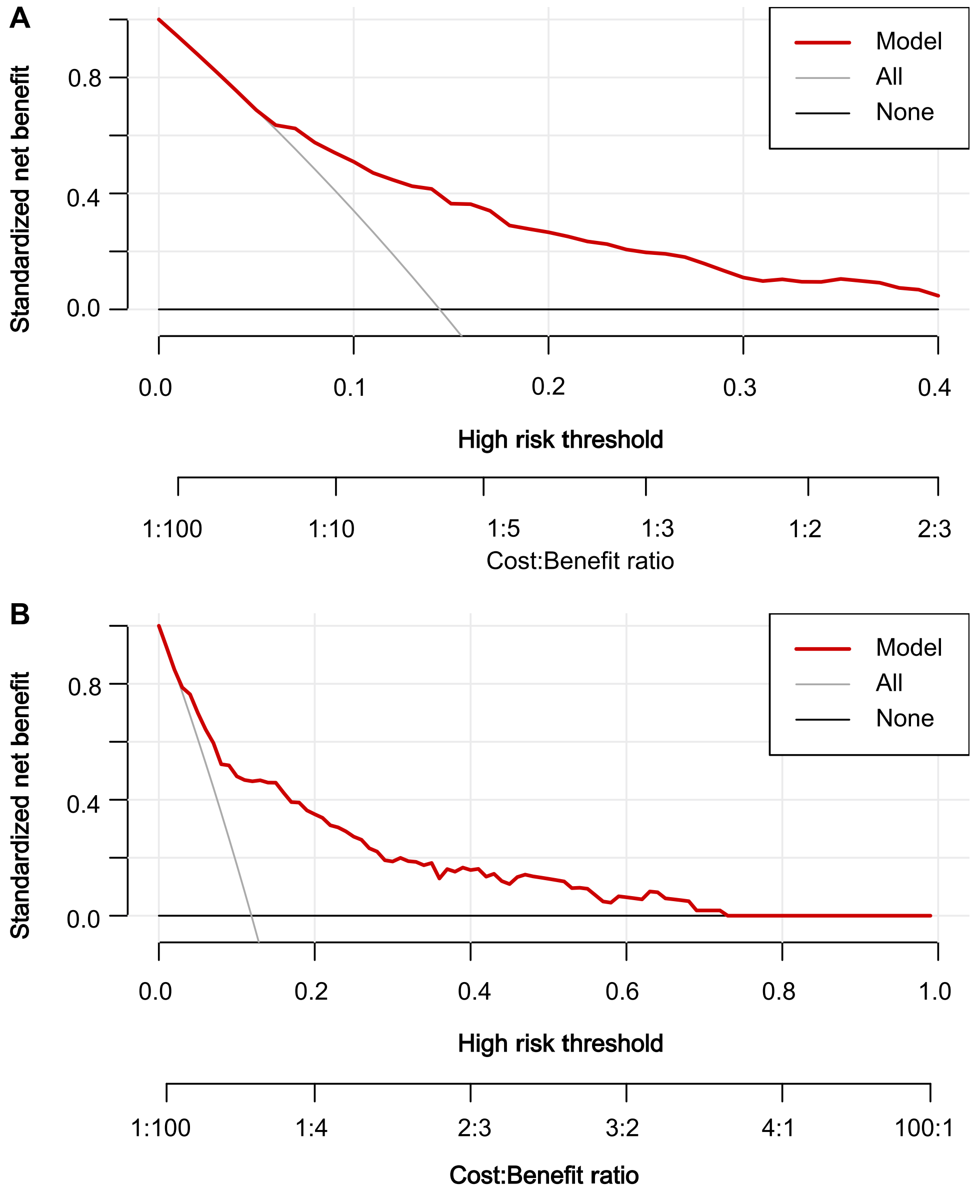


**Figure 5** Decision curve analysis (DCA) for the prediction model in the discovery cohort (**A**) and test cohort (**B**).

groups shows good consistency between the predicted and actual results. In summary, we believe that this model can help clinical healthcare professionals to predict the risk of PPCs in patients early on.

The age of patients is identified as a significant risk factor for PPCs.[23–25] Our research findings indicate that younger age is associated with an increased susceptibility to developing PPCs. Bronchospasm emerged as the predominant PPC, potentially linked to preexisting upper respiratory infections in pediatric patients. Notably, most patients had a history of COVID-19 infection during the past three years of pandemic. Even after testing negative, some patients exhibited heightened airway sensitivity, possibly contributing to the elevated incidence of bronchospasm in this study. Moreover, the majority of pediatric patients opted for tracheal intubation, which has a greater stimulation effect on the trachea compared to the laryngeal mask, making it more likely for children to experience laryngospasm. Age-related studies indicated an 11% reduction in relative risk for bronchospasm.[24] The incidence of airway spasms was 12.2% in our study, representing the highest rate among PPCs. Pulmonary atelectasis was identified as the most prevalent type of PPCs following surgery.[26–28] The incidence of atelectasis was relatively low in our study, possibly attributed to the postoperative PACU admission of our patients, with some undergoing continuous positive airway pressure lung alveolar recruitment prior to extubation. Literature suggests that a majority of patients can spontaneously recover from atelectasis within 24 hours after surgery.[29] Our data collection focused on the postoperative ward, indicating potential disparity from immediate postoperative atelectasis incidence.

The type and complexity of surgery affect the likelihood of PPCs in children. Upper abdominal and thoracic surgeries, as well as longer operation times, are associated with a high risk of PPCs.[7,30–32] In this study, the highest risk of PPCs was observed in pediatric patients undergoing thoracic surgery, followed by those undergoing surface-related surgery. Factors contributing to the increased incidence of PPCs include the need for unilateral lung ventilation during surgery, delayed recovery of lung function postoperatively due to pain or other causes, and pre-existing lung diseases or respiratory dysfunction in patients undergoing thoracic surgery.[33,34] Surgical procedures, such as opening the chest cavity leading to loss of negative pressure, imbalance in ventilation/blood flow ratio, unilateral lung ventilation causing atelectasis, surgical manipulation resulting in pulmonary edema and injury, and pleural incision with intercostal dissection inducing inflammation and pain-related physiological responses, can all increase the likelihood of and exacerbate PPCs occurrence. Many studies recommend that adequate pain management and postoperative respiratory care are crucial for mitigating these risks.[35,36]

The ASA physical status offers valuable insights into a child's overall health status and perioperative risk. Higher ASA physical status are associated with poorer overall health, decreased tolerance, and an increased risk of PPCs, underscoring the importance of preoperative assessment and risk stratification. Nonetheless, the subjectivity inherent in ASA physical status prompted a meta-analysis to establish two thresholds (ASA ≥ II and ASA ≥ III) for investigating the relationship between ASA physical status and PPCs. In both scenarios, PPC incidence rates were positively correlated with ASA physical status.[37] Our findings revealed that among patients with an ASA physical status of II, 123 (58.3%) experienced PPCs, while among those with an ASA physical status of I, 88 (41.7%) developed PPCs ($P$ <0.001). In our study, children with ASA physical status above 2 were not included considered their more severe conditions and difficulty in accurately calculating the duration of mechanical ventilation due to prolonged mechanical ventilation before and after surgery. In pediatric patients, prolonged mechanical ventilation is linked to an elevated risk of PPCs. The recognition of lung injury induced by mechanical ventilation has been growing. Factors such as tidal volume, PEEP, and ventilation device can impact lung function and increase the risk of complications. The comprehension and implementation of tailored lung-protective ventilation strategies for pediatric patients are pivotal in reducing the incidence of PPCs.[7] Our study showed that the longer the duration of mechanical ventilation, the higher the risk of PPCs in children. However, we failed to obtain the relevant data on mechanical ventilation setting parameters in this study. Future studies are needed to investigate whether protective ventilation strategies could reduce PPCs.

Previous studies reported a higher incidence of PPCs in emergency surgery patients than in elective surgery patients.[37,38] However, in our study, emergency surgery did not increase the risk of PPCs in children, contrary to the conventional understanding. This may be due to the different definitions of emergency surgery in our hospital. Some patients who were in a basic non-emergency state before surgery, without severe diseases, had undergone preoperative preparation and laboratory tests, and had normal examination results before entering the operating room were classified as emergency surgery in our hospital. Therefore, these may lead to bias in the results and should be considered carefully.

The construction strategies for PPCs risk prediction models demonstrate significant variations across populations.[3,8–10] Based on predictor selection frameworks, existing models can be categorized into two types: 1) Integrated models (eg, LAS VEGAS, SLIP/SLIP-2, and the pediatric model from our study),[3,8–10] which incorporate both preoperative baseline characteristics (ASA physical status, age) and intraoperative management parameters (PEEP settings, vasopressor use); and 2) Preoperative-focused models[3] (eg, the ARISCAT model),[3] which emphasize modifiable preoperative factors such as preoperative oxygenation status ($SpO_2$) and recent infections. Notably, while all models universally include surgical type, duration, and baseline physiological status as core predictors, the differential weighting of intraoperative factors reflects population-specific demands: for high-risk surgical cohorts, the inclusion of intraoperative parameters significantly enhances discriminative performance[9,10] (eg, SLIP-2 AUC 0.84 vs LAS VEGAS AUC 0.72) (Supplementary Table 1).

Our pediatric model uniquely highlights physiological vulnerabilities inherent to children: younger age (reflecting airway immaturity) and prolonged mechanical ventilation (indicating respiratory fragility) emerge as independent risk factors. This contrasts sharply with adult-oriented models, where predictors such as oxygenation deficits or chronic diseases dominate, underscoring the need for model development to align closely with the anatomical and physiological traits of target populations.[3] Clinically, these models facilitate risk stratification to guide precision interventions, including protective ventilation strategies (eg, dynamic PEEP titration) and preoperative respiratory optimization. Our study aimed to predict the risk of PPCs in pediatric patients. Although the results provide valuable information, the study still has some limitations. First, this is a retrospective study, all the data are from the same hospital and lack external validation. It is unknown whether the conclusion can be extrapolated to a wider range. Second, the intraoperative information was collected from the Medtronic anesthesia system, some important parameters such as tidal volume and PEEP were not collected due to system setup issues. Third, potential confounding factors such as preoperative oxygenation status and postoperative analgesic effects were not considered. Forth, the study was conducted during the COVID-19 pandemic, which may have direct or indirect effects on the cohort and outcomes, thus impacting the generalization of the results. Fifth, patients with incomplete data were excluded, which may also introduce potential bias. Future studies can further validate and improve our risk prediction model by increasing the sample size, conducting multicenter studies, and introducing more potential factors. In addition, applying the research findings to clinical practice and conducting intervention studies to improve the perioperative management of pediatric patients are important directions for future research.

## Conclusion

This study investigated the risk factors and predictive modeling for PPCs in pediatric patients undergoing general anesthesia. The incidence of PPCs in the studied pediatric cohort was found to be 13.7%, with key risk factors including age, duration of mechanical ventilation, type of airway device, ASA physical status, and the nature of surgical procedures. A nomogram was developed from these factors to facilitate clinical predictions regarding the likelihood of PPCs, with a ROC AUC of 0.762 and 0.818 in the discovery and test cohorts, respectively, indicating robust predictive capability.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Disclosure

The authors declare that they have no conflicts of interest.

## References


1. Fernandez-Bustamante A, Frendl G, Sprung J, et al. Postoperative pulmonary complications, early mortality, and hospital stay following noncardiothoracic surgery: a multicenter study by the perioperative research network investigators. *JAMA Surg*. 2017;152(2):157–166. doi:10.1001/jamasurg.2016.4065
2. O'Gara B, Talmor D. Perioperative lung protective ventilation. *BMJ*. 2018;362:k3030. doi:10.1136/bmj.k3030
3. Canet J, Gallart L, Gomar C, et al. Prediction of postoperative pulmonary complications in a population-based surgical cohort. *Anesthesiology*. 2010;113(6):1338–1350. doi:10.1097/ALN.0b013e3181fc6e0a
4. Shander A, Fleisher LA, Barie PS, Bigatello LM, Sladen RN, Watson CB. Clinical and economic burden of postoperative pulmonary complications: patient safety summit on definition, risk-reducing interventions, and preventive strategies. *Crit Care Med*. 2011;39(9):2163–2172. doi:10.1097/CCM.0b013e31821f0522
5. Ladha K, Vidal Melo MF, McLean DJ, et al. Intraoperative protective mechanical ventilation and risk of postoperative respiratory complications: hospital based registry study. *BMJ*. 2015;351:h3646. doi:10.1136/bmj.h3646
6. Güldner A, Kiss T, Serpa Neto A, et al. Intraoperative protective mechanical ventilation for prevention of postoperative pulmonary complications: a comprehensive review of the role of tidal volume, positive end-expiratory pressure, and lung recruitment maneuvers. *Anesthesiology*. 2015;123(3):692–713. doi:10.1097/ALN.0000000000000754
7. Lee JH, Bae JI, Jang YE, Kim EH, Kim HS, Kim JT. Lung protective ventilation during pulmonary resection in children: a prospective, single-centre, randomised controlled trial. *Br J Anaesth*. 2019;122(5):692–701. doi:10.1016/j.bja.2019.02.013
8. Kor DJ, Warner DO, Alsara A, et al. Derivation and diagnostic accuracy of the surgical lung injury prediction model. *Anesthesiology*. 2011;115(1):117–128. doi:10.1097/ALN.0b013e31821b5839
9. Kor DJ, Lingineni RK, Gajic O, et al. Predicting risk of postoperative lung injury in high-risk surgical patients: a multicenter cohort study. *Anesthesiology*. 2014;120(5):1168–1181. doi:10.1097/ALN.0000000000000216
10. Neto AS, da Costa LGV, Hemmes SNT, et al. The Las Vegas risk score for prediction of postoperative pulmonary complications: an observational study. *Eur J Anaesthesiol*. 2018;35(9):691–701. doi:10.1097/EJA.0000000000000845
11. Silva JM, de Oliveira AM, Nogueira FA, et al. The effect of excess fluid balance on the mortality rate of surgical patients: a multicenter prospective study. *Crit Care*. 2013;17(6):R288. doi:10.1186/cc13151

12. Lamarche Y, Elmi-Sarabi M, Ding L, Abel JG, Sirounis D, Denault AY. A score to estimate 30-day mortality after intensive care admission after cardiac surgery. *J Thorac Cardiovasc Surg*. 2017;153(5):1118–25.e4. doi:10.1016/j.jtcvs.2016.11.039
13. Riss S, Mittlböck M, Riss K, Chitsabesan P, Stift A. Intraoperative complications have a negative impact on postoperative outcomes after rectal cancer surgery. *Int J Surg*. 2014;12(8):833–836. doi:10.1016/j.ijsu.2014.07.003
14. Serpa Neto A, Hemmes SN, Barbas CS, et al. Protective versus conventional ventilation for surgery: a systematic review and individual patient data meta-analysis. *Anesthesiology*. 2015;123(1):66–78. doi:10.1097/ALN.0000000000000706
15. Gajic O, Dabbagh O, Park PK, et al. Early identification of patients at risk of acute lung injury: evaluation of lung injury prediction score in a multicenter cohort study. *Am J Respir Crit Care Med*. 2011;183(4):462–470. doi:10.1164/rccm.201004-0549OC
16. Riley RD, Ensor J, Snell KIE, et al. Calculating the sample size required for developing a clinical prediction model. *BMJ*. 2020;368:m441. doi:10.1136/bmj.m441
17. Jammer I, Wickboldt N, Sander M, et al. Standards for definitions and use of outcome measures for clinical effectiveness research in perioperative medicine: European Perioperative Clinical Outcome (EPCO) definitions: a statement from the ESA-ESICM joint taskforce on perioperative outcome measures. *Eur J Anaesthesiol*. 2015;32(2):88–105. doi:10.1097/EJA.0000000000000118
18. Miskovic A, Lumb AB. Postoperative pulmonary complications. *Br J Anaesth*. 2017;118(3):317–334. doi:10.1093/bja/aex002
19. Ball L, Almondo C, Pelosi P. Perioperative lung protection: general mechanisms and protective approaches. *Anesth Analg*. 2020;131(6):1789–1798. doi:10.1213/ANE.0000000000005246
20. Davidovich N, DiPaolo BC, Lawrence GG, Chhour P, Yehya N, Margulies SS. Cyclic stretch-induced oxidative stress increases pulmonary alveolar epithelial permeability. *Am J Respir Cell mol Biol*. 2013;49(1):156–164. doi:10.1165/rcmb.2012-0252OC
21. Slutsky AS, Ranieri VM. Ventilator-induced lung injury. *N Engl J Med*. 2013;369(22):2126–2136. doi:10.1056/NEJMra1208707
22. Egbuta C, Mason KP. Recognizing risks and optimizing perioperative care to reduce respiratory complications in the pediatric patient. *J Clin Med*. 2020;9(6):1942. doi:10.3390/jcm9061942
23. Subramanyam R, Yeramaneni S, Hossain MM, Anneken AM, Varughese AM. Perioperative respiratory adverse events in pediatric ambulatory anesthesia: development and validation of a risk prediction tool. *Anesth Analg*. 2016;122(5):1578–1585. doi:10.1213/ANE.0000000000001216
24. von Ungern-Sternberg BS, Boda K, Chambers NA, et al. Risk assessment for respiratory complications in paediatric anaesthesia: a prospective cohort study. *Lancet*. 2010;376(9743):773–783. doi:10.1016/S0140-6736(10)61193-2
25. Mamie C, Habre W, Delhumeau C, Argiroffo CB, Morabia A. Incidence and risk factors of perioperative respiratory adverse events in children undergoing elective surgery. *Paediatr Anaesth*. 2004;14(3):218–224. doi:10.1111/j.1460-9592.2004.01169.x
26. Li X, Liu H, Wang J, et al. Individualized positive end-expiratory pressure on postoperative atelectasis in patients with obesity: a randomized controlled clinical trial. *Anesthesiology*. 2023;139(3):262–273. doi:10.1097/ALN.0000000000004603
27. Jang YE, Ji SH, Kim EH, Lee JH, Kim JT, Kim HS. Effect of regular alveolar recruitment on intraoperative atelectasis in paediatric patients ventilated in the prone position: a randomised controlled trial. *Br J Anaesth*. 2020;124(5):648–655. doi:10.1016/j.bja.2020.01.022
28. Tusman G, Böhm SH, Tempra A, et al. Effects of recruitment maneuver on atelectasis in anesthetized children. *Anesthesiology*. 2003;98(1):14–22. doi:10.1097/00000542-200301000-00006
29. Zhu C, Zhang S, Dong J, Wei R. Effects of positive end-expiratory pressure/recruitment manoeuvres compared with zero end-expiratory pressure on atelectasis in children: a randomised clinical trial. *Eur J Anaesthesiol*. 2021;38(10):1026–1033. doi:10.1097/EJA.0000000000001451
30. Acosta CM, Sara T, Carpinella M, et al. Lung recruitment prevents collapse during laparoscopy in children: a randomised controlled trial. *Eur J Anaesthesiol*. 2018;35(8):573–580. doi:10.1097/EJA.0000000000000761
31. Choi ES, Oh AY, In CB, Ryu JH, Jeon YT, Kim HG. Effects of recruitment manoeuvre on perioperative pulmonary complications in patients undergoing robotic assisted radical prostatectomy: a randomised single-blinded trial. *PLoS One*. 2017;12(9):e0183311. doi:10.1371/journal.pone.0183311
32. Fernandez-Bustamante A, Sprung J, Parker RA, et al. Individualized PEEP to optimise respiratory mechanics during abdominal surgery: a pilot randomised controlled trial. *Br J Anaesth*. 2020;125(3):383–392. doi:10.1016/j.bja.2020.06.030
33. Semmelmann A, Baar W, Haude H, Moneke I, Loop T. Risk factors for postoperative pulmonary complications leading to increased morbidity and mortality in patients undergoing thoracic surgery for pleural empyema. *J Cardiothorac Vasc Anesth*. 2023;37(9):1659–1667. doi:10.1053/j.jvca.2023.04.017
34. Ávila AC, Fenili R. Incidence and risk factors for postoperative pulmonary complications in patients undergoing thoracic and abdominal surgeries. *Rev Col Bras Cir*. 2017;44(3):284–292. doi:10.1590/0100-69912017003011
35. Marshall K, McLaughlin K. Pain management in thoracic surgery. *Thorac Surg Clin*. 2020;30(3):339–346. doi:10.1016/j.thorsurg.2020.03.001
36. Abrams BA, Murray KA, Mahoney K, et al. Postdischarge pain management after thoracic surgery: a patient-centered approach. *Ann Thorac Surg*. 2020;110(5):1714–1721. doi:10.1016/j.athoracsur.2020.04.048
37. Smetana GW, Lawrence VA, Cornell JE. Preoperative pulmonary risk stratification for noncardiothoracic surgery: systematic review for the American College of Physicians. *Ann Intern Med*. 2006;144(8):581–595. doi:10.7326/0003-4819-144-8-200604180-00009
38. Kaw R, Chung F, Pasupuleti V, Mehta J, Gay PC, Hernandez AV. Meta-analysis of the association between obstructive sleep apnoea and postoperative outcome. *Br J Anaesth*. 2012;109(6):897–906. doi:10.1093/bja/aes308



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