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ARTICLE

Predictive Value of IPI for PACU Hypoxemia in Elderly Patients After General Anesthesia: A Retrospective Study

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Abstract

Aims/Background Elderly patients are at increased risk of hypoxemia in the post-anesthesia care unit (PACU) after general anesthesia. The Integrated Pulmonary Index (IPI) may have predictive value in identifying these patients. This study aimed to investigate the predictive value of the IPI for PACU hypoxemia in elderly patients after general anesthesia.

Methods A retrospective analysis was conducted on 276 patients who underwent general anesthesia surgeries at Zhongshan Hospital, Fudan University, between December 2021 and December 2024. Patients were divided into a PACU hypoxemia group (n = 96) and a non-PACU hypoxemia group (n = 180). Univariate and binary logistic regression analyses were used to determine influencing factors, and a receiver operating characteristic (ROC) curve analysis was conducted to evaluate the predictive value of IPI for PACU hypoxemia in elderly patients after general anesthesia.

Results Binary logistic regression analysis revealed that IPI was an independent influencing factor of PACU hypoxemia in elderly patients ($p < 0.05$). ROC analysis showed that IPI had an area under the curve of 0.843 (95% confidence interval [CI]: 0.799–0.887, $p = 0.002$), with a standard error of 0.023, a Youden index of 0.58, sensitivity of 85.42%, specificity of 72.22%, and an optimal cut-off value of 7.5. The discharge rate of patients with IPI >7.5 was significantly higher than that of patients with IPI ≤7.5 ($p < 0.05$).

Conclusion IPI demonstrates a certain predictive value of PACU hypoxemia in elderly patients after general anesthesia.

Key words: hypoxia; anesthesia; post-anesthesia; pulmonary; prediction methods

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Introduction

The combination of the population's rapidly accelerating aging process and ongoing progress in medical technology has resulted in a growing number of elderly patients receiving surgeries with general anesthesia. General anesthesia, as the primary method for elderly patients undergoing surgical procedures, provides significant intraoperative support (Jamilian et al., 2024; Liu et al., 2024); however, the prevention and control of postoperative complications remain a key clinical concern (Adıgüzel et al., 2023; Conway et al., 2022). Among these complications, hypoxemia in the post-anesthesia care unit (PACU) is both common and serious, with an incidence rate of around 40% in the elderly population and an even higher rate in individuals aged 70 years and above. Hypoxemia is closely associated with poor patient outcomes, and severe cases can lead to end-organ damage, posing a

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significant threat to patient life (Thammaiah et al., 2023; Xu et al., 2021). Although research has examined risk factors for postoperative hypoxemia both domestically and internationally, studies focusing on predicting the risk of PACU hypoxemia in elderly patients after general anesthesia remain limited. Existing research results vary, and no effective personalised predictive model has yet been established (Celik et al., 2024; Perez-Viloria et al., 2022). Therefore, accurate prediction of PACU hypoxemia risk in elderly patients is crucial for timely intervention in high-risk populations, reducing incidence rates, and improving patient outcomes. The Integrated Pulmonary Index (IPI) is a comprehensive indicator of pulmonary function that integrates four parameters: oxygen saturation, end-tidal carbon dioxide partial pressure, respiratory rate, and pulse rate. By condensing these complex respiratory data into a simplified value ranging from 1 to 10, IPI provides a practical reflection of both oxygenation and ventilation. Given these characteristics, IPI may have predictive value for the occurrence of hypoxemia in PACU among elderly patients after general anesthesia. This study aims to explore the predictive role of IPI in PACU hypoxemia in elderly patients after general anesthesia through retrospective analysis. Thus, it offers fresh benchmarks for clinical risk evaluation and the formulation of specific intervention measures.

Methods

Research Objects

This study was designed as a retrospective analysis. The sample size was calculated using the overall proportional formula, $N = Z^2_{\alpha/2}\pi(1-\pi)/\delta^2$, with π set at 37.4% (Luo et al., 2025), a significance level (α) of 0.05, and an allowable error (δ) of 0.06. The calculated sample size was at least 254 cases. Data from 300 cases were collected in this study. After screening, 276 patients who underwent general anesthesia surgeries in the Zhongshan Hospital, Fudan University, between December 2021 and December 2024 were included in the final analysis. Patients were divided into two groups based on the occurrence of PACU hypoxemia: the PACU hypoxemia group (n = 96) and the non-PACU hypoxemia group (n = 180). Fig. 1 illustrates a flowchart depicting the patient selection procedure. The criteria for PACU hypoxemia were based on the study by Aust et al. (2012). Within 30 minutes after tracheal tube or laryngeal mask removal in the care unit, while the patient was breathing ambient air, hypoxemia was defined as an arterial oxygen partial pressure (PaO_2) $<$60 mmHg or pulse oxygen saturation (SpO_2) $<$90%. The inclusion criteria were as follows: (1) patients met the surgical indications for general anesthesia surgery; (2) age $\geq$60; (3) ventilation was controlled with tracheal intubation or laryngeal mask during the operation. After removal of the airway management device, patients regained consciousness and were transferred to the PACU for continuous observation; (4) complete clinical data; (5) good patient compliance; (6) normal communication and cognitive skills. The exclusion criteria were: (1) history of surgery within one month before surgery; (2) anesthesia-related emergencies requiring treatment during the procedure; (3) presence of infectious disease; (4) patients transferred to other facilities intraoperatively; (5) severe cardiopulmonary

disease. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Ethics Committee of Zhongshan Hospital, Fudan University (B2025-305). All patients provided written informed consent.

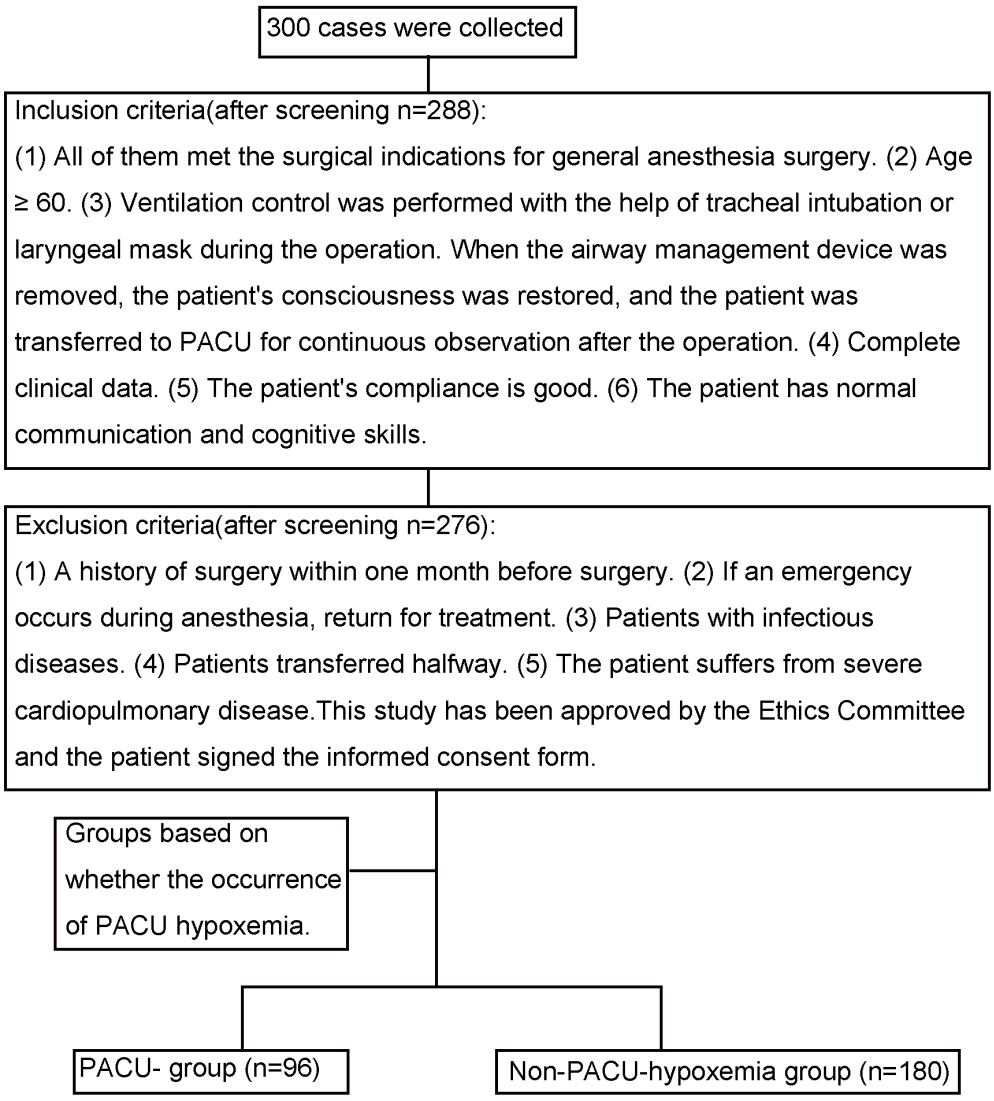

Fig. 1. Flow chart of the patient selection process. PACU, post-anesthesia care unit.

Indicator Testing and Definition

General Information

Patient general information was collected using the electronic medical record system. The variables included age, gender, body mass index (BMI), American Society of Aneshesiologists (ASA) physical status classification system classification, hypertension, drinking history, smoking history, diabetes history, obstructive sleep apnea syndrome, body temperature <36.0 °C after admission to PACU, blood oxygen saturation before induction of anesthesia, preoperative hemoglobin, surgery time, intraoperative blood loss, intraoperative infusion volume, Positive End-Expiratory Pressure (PEEP), surgery type, and surgical position.

IPI Algorithm

Oxygen was administered using a nasal cannula with an oral sampling port, enabling continuous collection and measurement of carbon dioxide in the patient's inhaled and exhaled gases during spontaneous breathing. The sampling line was connected to a portable bedside monitor that displayed real-time carbon dioxide waveforms, Postapneic End-Tidal Carbon Dioxide Pressure ($PETCO_2$), respiratory rate (RR), pulse rate (PR), IPI, and SpO_2. Preoperative IPI values were recorded 30 minutes before surgery. The IPI is represented by a single index value ranging from 1 to 10, where values of 7–10 indicate nearly normal ventilation, $4 <$ values ≤ 6 suggest that potential intervention may be required, and values ≤ 4 indicate that intervention is necessary (Ronen et al., 2017).

Anesthetic Drugs

The assignment is based on the distribution of anesthesia methods in the included cases. Since the number of cases with other combinations is small, the classification is based on this. The usage of anesthetic drugs in the study subjects was recorded. The combination of propofol + remifentanil + sufentanil + hydromorphone was assigned a value of option 1, propofol + remifentanil + sufentanil was assigned a value of option 2, and other combinations were assigned a value of option 3.

Discharge Rate

Postoperative outcomes were recorded after surgery. This study is divided into transferred to the Intensive Care Unit (ICU) for continued treatment or discharge.

Statistical Analysis

All collected data underwent analysis via SPSS 27.0 (International Business Machines Corporation, Armonk, NY, USA). The Shapiro-Wilk test was utilised to evaluate data normality. In cases where variables exhibited non-normal distributions, data were reported as median quartiles (Q1, Q3), with comparisons conducted using the Mann-Whitney U test. Categorical data were presented as frequencies and analysed using the χ^2 test or Fisher's exact test. Variables found to be significant in univariate analysis were included in the binary logistic regression model to identify independent influencing factors. Tolerance and variance inflation factor (VIF) values were used to assess collinearity. The predictive value of IPI for PACU hypoxemia in elderly patients after general anesthesia was evaluated using receiver operating characteristic (ROC) curve analysis. A p-value of less than 0.05 was deemed statistically significant throughout the study.

Results

Univariate Analysis of Factors Influencing PACU Hypoxemia in Elderly Patients After General Anesthesia

No statistically significant differences were observed with respect to age, gender, BMI, hypertension, alcohol-drinking history, smoking history, diabetes, obstructive sleep apnea syndrome, postoperative PACU temperature <36.0 °C, pre-

Table 1. Univariate analysis of factors influencing PACU hypoxemia in elderly patients after general anesthesia.

Indicator	PACU hypoxemia group (n = 96)	Non-PACU hypoxemia group (n = 180)	Z/χ^2	p
Age (years)	68.00 (62.00, 76.00)	70.00 (63.00, 74.00)	–0.788	0.430
Gender			0.079	0.779
Male	57	110		
Female	39	70		
BMI (kg/m^2)	23.46 (20.52, 27.35)	22.78 (19.92, 25.29)	–1.814	0.070
ASA classification (level)			6.045	0.014
2	84	172		
3	12	8		
Hypertension			0.454	0.500
Yes	17	38		
No	79	142		
Alcohol-drinking history			0.279	0.598
Yes	11	17		
No	85	163		
Smoking history			0.584	0.445
Yes	23	36		
No	73	144		
History of diabetes			0.199	0.655
Yes	10	22		
No	86	158		
Obstructive sleep apnea syndrome			0.478	0.490
Yes	5	5		
No	91	175		
PACU <36.0 °C			-	1.000
Yes	1	1		
No	95	179		
Pre-induction SaO_2 (%)	96.00 (94.00, 98.00)	97.00 (95.00, 98.00)	–1.251	0.211
Preoperative hemoglobin (g/L)	122.70 (109.05, 137.00)	119.95 (107.75, 136.25)	–0.591	0.555
Surgical duration (hours)	2.80 (2.55, 3.25)	2.70 (1.75, 3.20)	–2.006	0.045
Intraoperative blood loss (mL)	200.00 (65.00, 500.00)	200.00 (20.00, 400.00)	–1.536	0.124
Intraoperative fluid volume (mL)	1500.00 (1000.00, 1500.00)	1500.00 (500.00, 1500.00)	–1.990	0.047
IPI	7.00 (7.00, 7.00)	8.50 (7.00, 10.00)	–9.848	<0.001
PEEP	5.00 (5.00, 5.00)	5.00 (0.00, 5.00)	–1.710	0.087
Type of surgery			-	<0.001
General surgery	29	53		
Hepatobiliary surgery	13	23		
Gastrointestinal endoscopy	6	25		
Cardiothoracic surgery	12	27		
Vascular intervention	9	52		
Others	27	0		

Table 1. Continued.

Indicator	PACU hypoxemia group (n = 96)	Non-PACU hypoxemia group (n = 180)	Z/χ^2	p
Anesthetic drugs			35.276	<0.001
Option 1	47	127		
Option 2	35	14		
Option 3	14	39		
Surgical position			1.531	0.465
Supine	72	127		
Lateral	9	14		
Others	15	39		

Note: BMI, body mass index; IPI, Integrated Pulmonary Index; PEEP, Positive End-Expiratory Pressure; PACU, post-anesthesia care unit; ASA, American Society of Aneshesiologists; SaO_2, arterial oxygen saturation.

Table 2. Variable assignment.

Influencing factors	Assignment
ASA classification	2 = 0, 3 = 1
Surgical duration	Original value
Intraoperative fluid volume	Original value
IPI	Original value
Type of surgery	Others = 0, General surgery = 1, Hepatobiliary surgery = 2, Gastrointestinal endoscopy = 3, Cardiothoracic surgery = 4, Vascular intervention = 5
Anesthetic drugs	Option 1 = 0, Option 2 = 1, Option 3 = 2

induction arterial oxygen saturation (SaO_2), preoperative hemoglobin, intraoperative blood loss, PEEP, or surgical position ($p > 0.05$). In contrast, statistically significant differences were observed between the two groups in ASA classification, surgical duration, intraoperative fluid volume, IPI, type of surgery, and anesthetic drugs ($p < 0.05$). Details are presented in Table 1.

Binary Logistic Regression Analysis of Factors

The significant variables identified in the univariate analysis were included as independent variables, with the occurrence of PACU hypoxemia after general anesthesia in elderly patients as the dependent variable (occurrence = 1, non-occurrence = 0). The results of the binary logistic regression analysis indicated that IPI was an independent influencing factor for the occurrence of PACU hypoxemia in elderly patients after general anesthesia (odds ratio [OR] = 0.704, 95% confidence interval [CI]: 0.563–0.881, $p < 0.05$), as shown in Tables 2,3.

ROC Curve Analysis of Predictive Value of Indicators

The ROC analysis results indicated that the area under the curve (AUC) for IPI was 0.843 (95% CI: 0.799–0.887, $p = 0.002$), with a standard error of 0.023. The

Table 3. Binary logistic regression analysis of factors.

Factor	β	SE	Wald	p	Exp(β)	95% CI	Tolerance	VIF
ASA classification	1.054	0.579	3.318	0.069	2.869	0.923–8.920	0.925	1.081
Surgical duration	0.321	0.307	1.095	0.295	1.379	0.755–2.516	0.445	2.248
Intraoperative fluid volume	0.000	0.000	1.195	0.274	1.000	1.000–1.001	0.465	2.150
IPI	–0.350	0.114	9.438	0.002	0.704	0.563–0.881	0.877	1.140
Type of surgery	-	-	7.492	0.187	-	-	0.949	1.054
General surgery	–22.585	7406.492	0.000	0.998	0.000	0.000–	-	-
Hepatobiliary surgery	–22.288	7406.492	0.000	0.998	0.000	0.000–	-	-
Gastrointestinal endoscopy	–22.255	7406.492	0.000	0.998	0.000	0.000–	-	-
Cardiothoracic surgery	–22.665	7406.492	0.000	0.998	0.000	0.000–	-	-
Vascular intervention	–22.740	7406.492	0.000	0.997	0.000	0.000–	-	-
Anesthetic drugs	-	-	1.832	0.400	-	-	0.599	1.669
Option 2	0.481	0.370	1.691	0.193	1.618	0.784–3.340	-	-
Option 3	0.493	0.819	0.363	0.547	1.638	0.329–8.156	-	-
Constant	22.771	7406.492	0.000	0.998	7.751	-	-	-

Note: SE, standard error; VIF, variance inflation factor; CI, confidence interval. The abnormal type of surgery data may be due to the complex types of surgeries, resulting in incomplete grouping. "0.000–" indicates no upper limit.

Youden index was 0.58, with a sensitivity of 85.42% and a specificity of 72.22%. Based on the maximum Youden index, the optimal cut-off value was determined to be 7.5. An AUC value closer to 1 indicates better predictive value. In this study, the AUC of 0.843 falls within the range of 0.7–0.9, suggesting good predictive value (Fig. 2).

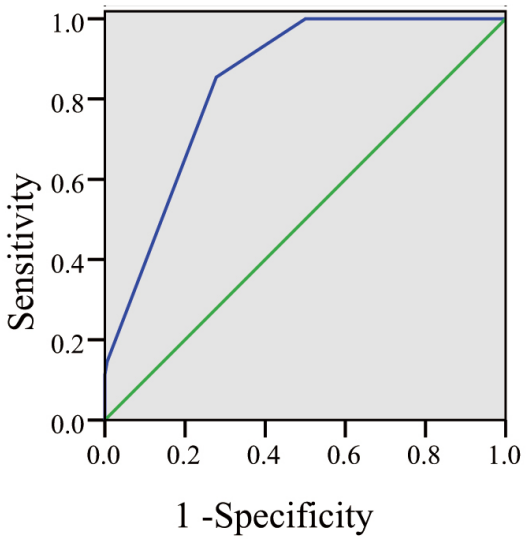

Fig. 2. ROC curve analysis. ROC, receiver operating characteristic.

Table 4. Optimal cut-off value of IPI and patient outcomes.

Item	IPI >7.5 group (n = 143)	IPI ≤7.5 group (n = 133)	χ^2	p
Discharge rate (%)	98.60	89.39	11.637	0.001
Discharged	141	118		
ICU	2	15		

Note: ICU, Intensive Care Unit.

Optimal Cut-Off Value of IPI and Patient Outcomes

The discharge rate of patients with IPI >7.5 was higher than that of patients with IPI ≤7.5, with a statistically significant difference ($p < 0.05$), as shown in Table 4.

Discussion

This study demonstrates that IPI holds significant value in predicting PACU hypoxemia in elderly patients following general anesthesia. Significant statistical differences were observed in the comparison of patient ASA classification, surgical duration, intraoperative fluid volume, IPI, type of surgery, and anesthetic drugs in the univariate analysis. Further confirmation was provided through binary logistic regression analysis, indicating that IPI is an independent influencing factor for the occurrence of PACU hypoxemia in elderly patients after general anesthesia. This finding correlates to some extent with previous research studies.

In a study by Kuroe et al. (2021), it was demonstrated that IPI can predict respiratory dysfunction in high-risk patients in the PACU, which aligns with the results of the present study. As a composite indicator of pulmonary function, IPI provides a comprehensive evaluation of a patient's preoperative lung function status, thereby exhibiting higher sensitivity and specificity in predicting postoperative hypoxemia. The ROC analysis in this study showed that both the area under the curve and the sensitivity of IPI were high. This result suggests that IPI has high accuracy in predicting hypoxemia in PACU in elderly patients following general anesthesia. Although specificity was relatively lower, the high sensitivity suggests that IPI is particularly effective in identifying patients at risk, allowing timely intervention to prevent complications. However, the IPI data were relatively concentrated with low variability, resulting in limited inflection points in the ROC curve. This, in turn, may restrict its evaluation capacity and limit the refinement of risk stratification. Nevertheless, previous research by Broens et al. (2021) also demonstrated the clinical value of IPI in assessing respiratory status in the PACU, which supports the findings observed in this study.

As a comprehensive pulmonary function assessment tool, the IPI integrates multiple parameters related to lung function, reflecting ventilation and gas exchange from different perspectives. In elderly patients, age-related physiological decline often leads to varying degrees of pulmonary impairment (Jia et al., 2023; Lin et al., 2022). The IPI can evaluate these changes comprehensively, providing clinicians with more precise preoperative lung function information. A low IPI suggests

poorer lung function and is associated with a higher risk of postoperative hypoxemia. This enables clinicians to implement proactive preventive measures, such as optimising anesthesia management and enhancing postoperative respiratory monitoring, to reduce the incidence of hypoxemia (Li et al., 2023; Wang et al., 2025).

This study further reveals that the discharge rate of patients with IPI >7.5 is statistically higher than that of patients with IPI ≤ 7.5. This finding suggests that IPI is not only related to the occurrence of postoperative hypoxemia, but may also affect patient discharge rates. A higher IPI indicates relatively better preoperative lung function in patients, enhancing patients' ability to tolerate the stress of surgery and anesthesia. Consequently, these patients may experience faster postoperative recovery, leading to shorter hospital stays and earlier discharge. From a physiological perspective, adequate lung function helps maintain efficient oxygenation postoperatively, ensuring normal organ metabolism and function (Wang et al., 2024). Effective gas exchange reduces the occurrence of complications such as hypoxemia and respiratory failure, thereby promoting physical recovery (Sungworawongpana et al., 2025). Therefore, the IPI may serve as an important reference indicator for postoperative recovery capacity and discharge time in elderly patients.

The results of this study hold significant clinical implications. During the preoperative assessment, the IPI provides clinicians with comprehensive information on a patient's lung function, aiding in accurately assessing the risk of PACU hypoxemia following general anesthesia. For patients with lower IPI values, personalised anesthesia and surgical strategies can be devised by selecting more suitable anesthetic drugs and doses, optimising mechanical ventilation parameters, among other strategies, to reduce the likelihood of hypoxemia occurrences. In the postoperative management, the IPI assists clinicians in promptly identifying high-risk patients, enabling enhanced respiratory monitoring and care for these individuals. Preventive measures, including supplemental oxygen therapy, secretion clearance through coughing, and respiratory exercises, can be implemented early to mitigate the adverse effects of hypoxemia. Furthermore, the IPI may serve as a reference for evaluating postoperative recovery and discharge times, aiding clinicians in appropriately scheduling hospital stays and rehabilitation plans, thereby improving the efficiency of healthcare resource utilisation.

Despite the significant findings generated by this research, it is imperative to recognise several limitations. Firstly, the retrospective nature of its design gives rise to the potential for selection bias as well as information bias. Because the data were extracted from existing medical records, some cases may have been incomplete or inaccurate, which could have influenced the reliability of the results. Secondly, the sample size employed in the study was comparatively limited. The limited number of ROC inflection points suggests that the concentrated population distribution may restrict the stability and reliability of the findings, while also limiting the ability to capture broader population variability. As a result, prospective investigations incorporating larger sample sizes are warranted to confirm the predictive efficacy of IPI. Moreover, this study was conducted at a single center and focused on a specific region, thereby limiting the applicability of its conclusions to a broader context. Potential confounding factors, such as age and underlying

diseases, were not sufficiently adjusted for, and the classification criteria for drug combinations were unclear. Moreover, neither refined dose analyses nor more robust classification were applied. The absence of a power calculation and validation cohort also limits the credibility of the results. Collectively, these factors may have affected the accuracy of the conclusions and highlighted the need for further methodological improvements. Future research should address these limitations. It is imperative to conduct multi-center, prospective studies with expanded sample sizes to elevate the accuracy and external validity of IPI in forecasting PACU hypoxemia among elderly patients following general anesthesia. Expanding the study population across different hospitals and regions will further improve the universality of the results. Additionally, interventional studies should explore whether IPI-based strategies can reduce the incidence of postoperative hypoxemia and improve recovery outcomes. For example, for patients with low IPI, targeted respiratory exercise, medication, and other interventions were given before surgery to observe their impact on the incidence of postoperative hypoxemia and patient recovery.

Conclusion

In conclusion, this study demonstrates that the IPI holds predictive value for the risk of PACU hypoxemia in elderly patients after general anesthesia. As a comprehensive indicator of pulmonary function, the IPI provides clinicians with crucial information regarding a patient's preoperative lung function. This information aids in accurately assessing the risk of PACU hypoxemia and facilitates the implementation of appropriate preventive measures.

Key Points

- The purpose of this study was to investigate the predictive value of the comprehensive Integrated Pulmonary Index (IPI) in predicting the high risk of hypoxemia in PACU after general anesthesia in elderly patients.
- IPI was found to be an independent influencing factor for PACU hypoxemia in elderly patients after general anesthesia.
- ROC curve analysis indicated high predictive value, with an optimal cut-off value of 7.5.
- The IPI provides useful information regarding the risk of PACU hypoxemia in elderly patients, and higher IPI values (>7.5) were associated with an increased rate of safe discharge.

Availability of Data and Materials

The data used to support the findings of this study are available from the corresponding author upon request.

Author Contributions

SHX designed the research study. SHX and WNZ performed the research and analysed the data. SHX drafted the manuscript. Both authors contributed to the important editorial changes in the manuscript. Both authors read and approved the final manuscript. Both authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki. The study was approved by the Ethics Committee of Zhongshan Hospital, Fudan University (B2025-305). The principle of informed consent was followed throughout the experiment, and information about the study was provided to patients, and consent was obtained.

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Conflict of Interest

The authors declare no conflict of interest.

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