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Risk factors for hypoxemia in patients undergoing robot-assisted radical prostatectomy in the Anesthesia Intensive Care Unit

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Abstract: Objective To collect perioperative data of patients undergoing robot-assisted radical prostatectomy (RARP) and explore the related factors of postoperative hypoxemia in Anesthesia Intensive Care Unit (AICU). **Methods** Clinical data of patients who underwent RARP and were admitted to the AICU at Nanjing Drum Tower Hospital between January 2022 and May 2024 were retrospectively collected. According to the oxygenation index (OI) from the last arterial blood gas analysis before transfer out of the AICU, patients were divided into a hypoxemia group (OI<300 mmHg) and a non- hypoxemia group (OI≥300 mmHg). Clinical data of the two groups, including general information, laboratory results, surgery-related indicators, intraoperative medication use, and indicators after AICU admission, were collected and compared. Multivariate logistic regression analysis was used to identify risk factors for hypoxemia before transfer out of hypoxemia before transfer out of the AICU, with an incidence rate of 25.55%. There were significant differences between the two groups in age, body mass index (BMI), hypertension, history of pulmonary disease, white blood cell count, and blood glucose (P<0.05). Significant differences were also found in preoperative saturation of peripheral oxygen (SpO_2), operation duration, anesthesia duration, total colloid volume, morphine equivalent, and glucocorticoid use (P<0.05). And there were significant differences in the OI upon AICU admission, pH, PaCO2, C-reactive protein, high-sensitivity troponin T, and total AICU output (P<0.05). Multivariate analysis revealed that age ≥65 years (OR=1.551, 95%CI: 1.003-2.396, P=0.048), BMI>28 kg/m2 (OR=1.739, 95%CI: 1.033-2.928, P=0.037), hypertension (OR=1.586, 95%CI: 1.143-2.202, P=0.006), history of pulmonary disease (OR=1.600, 95%CI: 1.159-2.208, P=0.004), preoperative SpO2<95% (OR=2.807, 95%CI: 1.297-6.077, P=0.009), low OI upon AICU admission (OR=3.620, 95%CI: 2.553- 5.131, P<0.01), and delayed postoperative extubation time (OR=1.002, 95%CI: 1.000-1.003, P=0.013) were risk factors for hypoxemia in RARP patients in the AICU, while intraoperative glucocorticoid use (OR=0.613, 95%CI: 0.445-0.845, P=0.003) was a protective factor. **Conclusion** Age, BMI, hypertension, history of pulmonary disease, preoperative SpO2, OI upon AICU admission, postoperative extubation time, and intraoperative glucocorticoid use are closely associated with the occurrence of hypoxemia in RARP patients at AICU.

Keywords: Robot-assisted radical prostatectomy; Anesthesia intensive care unit; Hypoxemia; Glucocorticoid; Oxygenation index

Prostate cancer is the most common malignant tumor in the male urinary system [1]. Previous studies have shown that for patients with localized prostate cancer, surgical resection can reduce mortality. Compared with traditional open surgery, robot-assisted radical prostatectomy (RARP) is being increasingly widely adopted due to its advantages of less bleeding, shorter hospital stays, and reduced postoperative pain [2]. Although RARP offers benefits such as minimal invasiveness and faster recovery, the incidence of intraoperative hypoxemia remains at 18.8% [3]. Research by Sun et al. [4] found that over one-third of non-cardiac surgery patients experience postoperative hypoxemia, which can lead to arrhythmias, hypotension, and neurological damage. To ensure perioperative safety, accelerate postoperative recovery, and reduce surgical complications, some patients may be transferred to the Anesthesia Intensive Care Unit (AICU) for observation and recovery. However, there is limited research on hypoxemia occurring in the AICU. Therefore, this study retrospectively analyzed whether hypoxemia occurred after extubation in RARP patients transferred to the AICU, exploring potential related factors to provide a reference for personalized perioperative management.

1 Materials and Methods

1.1 General Data

This study was approved by the Ethics Committee of Nanjing Drum Tower Hospital (Ethics Approval No.: 2021-563-03). Medical records of patients who underwent elective RARP and were admitted to the AICU of Nanjing Drum Tower Hospital from January 2022 to May 2024 were retrospectively collected.

Inclusion criteria: (1) Preoperative prostate biopsy or postoperative histopathological confirmation of prostate cancer; (2) Scheduled for elective RARP; (3) Postoperative transfer to the AICU.

Exclusion criteria: (1) Incomplete electronic medical records; (2) Missing oxygenation-related data; (3) Undergoing a second surgery during the AICU stay.

1.2 Data Collection

Patient general information was collected through the electronic medical record information system, including age, body mass index (BMI), American Society of Anesthesiologists (ASA) physical status classification, history of underlying diseases (hypertension, diabetes, pulmonary disease, cardiac disease, cerebrovascular disease, malignant tumors), smoking history, preoperative prostate volume, and results of the last preoperative laboratory tests (white blood cell count, hemoglobin, albumin, blood glucose, serum creatinine, C-reactive protein). Pulmonary diseases included chronic obstructive pulmonary disease, asthma, recent pneumonia, and history of lung surgery. Cardiac diseases included coronary artery disease, valvular heart disease, atrial fibrillation, and high-degree atrioventricular block.

1.3 Anesthesia Management

Patients underwent a total intravenous anesthesia regimen. No premedication was administered. Anesthesia induction involved intravenous injection of midazolam (Jiangsu Enhua Pharmaceutical, batch No.: 210204) 0.05 mg/kg, 1% propofol (Beijing Fresenius Kabi Pharmaceutical, batch No.: 2010247) 1–2 mg/kg or etomidate (Jiangsu Enhua Pharmaceutical, batch No.: YT200909) 0.3–0.5 mg/kg, fentanyl (Yichang Humanwell Pharmaceutical, batch No.: 01E04081) 3–8 μg/kg, and vecuronium (Jiangsu Yangtze River Pharmaceutical Group, batch No.: 21011811) 0.08–0.12 mg/kg.

Anesthesia maintenance involved continuous infusion of propofol at 4–12 $mg\cdot kg^{-1}\cdot h^{-1}$, remifentanil (Yichang Humanwell Pharmaceutical, batch No.: 01A10101) at 0.05–0.2 $\mu g\cdot kg^{-1}\cdot min^{-1}$, and cisatracurium besylate (Jiangsu Hengrui Medicine, batch No.: 201208AK) at 1–3 $\mu g\cdot kg^{-1}\cdot min^{-1}$.

Based on anesthesia records, intraoperative data collected included preoperative peripheral oxygen saturation (SpO_2), surgery duration, anesthesia duration, fluid intake/output, calculation of the total area under the curve (AUC) using the trapezoidal method [5] — AUC-mean arterial pressure (MAP) based on MAP<65 mmHg and AUC- end-tidal carbon dioxide partial pressure ($P_{ET}CO_2$)based on $P_{ET}CO_2$>45 mmHg — and drug usage (propofol, etomidate, opioids, dexmedetomidine, glucocorticoids, non-steroidal anti-inflammatory drugs, inhalational anesthetics, vasoactive drugs), among others.

1.4 AICU Management

After surgery, patients were transferred to the AICU by the anesthesiologist, surgeon, and nursing staff. Upon arrival, they were immediately connected to a ventilator, and vital signs were monitored. Synchronized intermittent mandatory ventilation mode was used. Ventilator (Shenzhen Mindray Bio-Medical, model Mindray A7) parameters were set as follows: tidal volume (VT) 6–8 mL/kg, inspiratory to expiratory ratio (I:E)=1:2, fraction of inspired oxygen (FiO_2)=50%, frequency (*f*) 12–14 breaths/min, and positive end-expiratory pressure (PEEP) =5 cmH_2O. Arterial blood gas analysis was performed immediately after monitoring was established. After the patient regained consciousness, spontaneous breathing, and muscle strength, they were weaned from the ventilator for a 30-minute observation period. Arterial blood gas was measured again. If the oxygenation index (OI), defined as arterial partial pressure of oxygen (PaO_2)/FiO_2, was>200 mmHg, there was no CO_2 retention, and no internal environment disturbance, extubation was performed after evaluation by the AICU anesthesiologist. After extubation, nasal cannula oxygen (oxygen flow rate 2 L/min) was administered, and the patient's respiration and circulation were observed. If vital signs remained stable, the patient was transferred to the general urology ward at 9:00 a.m. on the first postoperative day.

Based on the medical record system, data collected included AICU arterial blood gas results, laboratory test results [white blood cell count (WBC), hemoglobin, C-reactive protein (CRP), procalcitonin, interleukin-6, B-type natriuretic peptide (BNP), high-sensitivity troponin T (hs-TnT)], fluid intake/output, postoperative extubation time, and total hospital stay.

Patients were divided into a hypoxemia group (OI<300 mmHg) and a non-hypoxemia group (OI≥300 mmHg) based on the OI from the last arterial blood gas result before leaving the AICU. Postoperative extubation time was defined as the time from the end of skin suturing to extubation.

1.5 Statistical Methods

Statistical analysis was performed using SPSS 27.0 and R4.3.3 software. Normally distributed measurement data are expressed as $\bar{x}\pm s$ and compared between groups using the independent samples *t*-test. Non-normally distributed measurement data are expressed as $M(P_{25},P_{75})$ and compared between groups using the Mann-Whitney *U* test. Count data are expressed as *n*(%) and compared between groups using the chi-square test or Fisher's exact test. For continuous variables with a missing proportion<20%, multiple imputation (implemented using the 'mice' package in R) was used for imputation, with the number of imputations set to 5. To reduce feature dimensionality and screen for core associated variables, this study employed the elastic net regression algorithm for data dimensionality reduction. The regularization mixing parameter α was set to 0.5, and five-fold cross-validation was used to select the optimal regularization parameter. Variables selected by elastic net regression were included in a multivariate logistic regression analysis to identify independent risk factors for hypoxemia after extubation in RARP patients in the AICU. The significance level was set at α=0.05 for two-sided tests.

2 Results

2.1 Baseline Description

A total of 1,162 patients who underwent RARP surgery were admitted to the AICU. Among them, 154 patients had incomplete electronic medical records, 5 patients were missing the last oxygenation data before leaving the AICU, and 1 patient underwent a second surgery during the AICU stay. This study ultimately included 1,002 patients. Among them, 256 patients developed hypoxemia before transfer out of the AICU, with an incidence rate of 25.55%. 746 patients did not develop hypoxemia before transfer. The flowchart is shown in **Figure 1**.

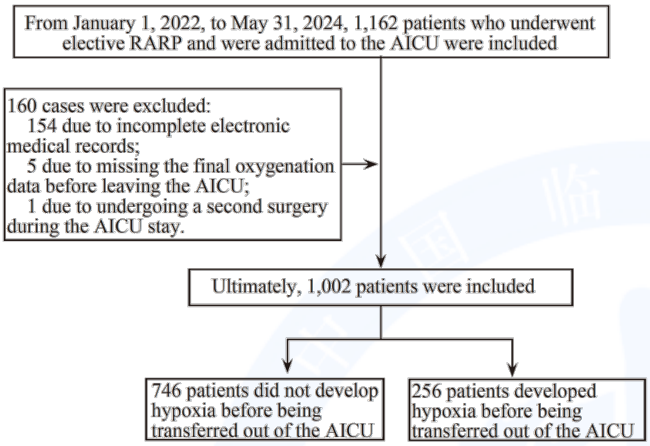

Fig.1 Flow chart of case inclusion and exclusion

The mean patient age was (69.75 ± 6.39) years, with 816 elderly patients (≥ 65 years), accounting for 81.44%. The mean BMI was (24.48 ± 2.94) kg/m², with 436 overweight patients (24–28 kg/m²), accounting for 43.51%, and 113 obese patients (> 28 kg/m²), accounting for 11.28%. There were 574 patients with hypertension (57.29%), 181 patients with type 2 diabetes (18.06%), 341 patients with a history of pulmonary disease (34.03%), 101 patients with a history of cardiac disease (10.08%), 134 patients with a history of cerebrovascular accident (13.37%), 43 patients with a history of malignant tumors (4.29%), and 347 smokers (34.63%).

2.2 Baseline Comparisons and Variable Screening

Statistically significant differences were observed between the two groups in terms of age, BMI, hypertension, history of pulmonary disease, WBC, and blood glucose (P<0.05). See **Table 1**.

Statistically significant differences were observed between the two groups in preoperative SpO_2, surgery duration, anesthesia duration, total intraoperative colloid volume, morphine equivalent dose, and the proportion of glucocorticoid use (P<0.05). See **Table 2**.

Statistically significant differences were observed between the two groups in the OI upon AICU admission, pH, $PaCO_2$, CRP, hs-TnT, and total AICU output (P<0.05). See **Table 2**.

To reduce dimensionality and select the most relevant variables, this study employed the elastic net regression algorithm, which identified 12 variables associated with hypoxemia after extubation in RARP patients in the AICU. These were: age, BMI, hypertension, history of pulmonary disease, preoperative SpO_2, total intraoperative colloid volume, dexmedetomidine use, glucocorticoid use, OI upon AICU admission, postoperative CRP, total AICU output, and postoperative extubation time.

2.3 Multivariate Analysis

Variables selected through elastic net regression were incorporated into a binary logistic regression analysis. The results indicated that the following were risk factors for the occurrence of hypoxia in the AICU among patients undergoing RARP: age ≥65 years (OR=1.551, 95%CI: 1.003–2.396, P=0.048), BMI>28 kg/m^2 (OR=1.739, 95%CI: 1.033–2.928, P=0.037), hypertension (OR=1.586, 95%CI: 1.143–2.202, P=0.006), history of pulmonary disease (OR=1.600, 95%CI: 1.159–2.208, P=0.004), preoperative SpO_2<95% (OR=2.807, 95%CI: 1.297–6.077, P=0.009), low OI upon AICU admission (OR=3.620, 95%CI: 2.553–5.131, P<0.01), and delayed postoperative extubation time (OR=1.002, 95%CI: 1.000–1.003, P=0.013) were risk factors for hypoxemia in RARP patients in the AICU, while intraoperative glucocorticoid use (OR=0.613, 95%CI: 0.445–0.845, P=0.003) was a protective factor. See **Table 3**.

Tab. 1 Comparison of preoperative general data between the two groups ($\bar{x}\pm s$)

Item	Non-hypoxemia group (n=746)	Hypoxemia group (n=256)	χ^2/z value	P value
Age [n(%)]			6.345	0.012
<65 years	152 (20.38)	34 (13.28)		
≥ 65 years	594 (79.62)	222 (86.72)		
BMI [n(%)]			29.054	<0.001
<18.5 kg/m²	14 (1.88)	1 (0.39)		
18.5~24 kg/m²	352 (47.18)	86 (33.59)		
>24~28 kg/m²	316 (42.36)	120 (46.88)		
>28 kg/m²	64 (8.58)	49 (19.14)		
ASA grading [n(%)]			0.598	0.741
Grade II	25 (3.35)	7 (2.73)		
Grade III	690 (92.49)	236 (92.19)		
Grade IV	31 (4.16)	13 (5.08)		
Comorbidities [n(%)]				
Hypertension	398 (53.35)	176 (68.75)	18.470	<0.001
T2DM	133 (17.83)	48 (18.75)	0.109	0.741
Pulmonary diseases	240 (32.17)	101 (39.45)	4.501	0.034
Heart disease	75 (10.05)	26 (10.16)	0.002	0.962
Cerebrovascular accidents	96 (12.87)	38 (14.84)	0.642	0.423
Malignant tumors	32 (4.29)	11 (4.30)	<0.001	0.996
Smoking history[n(%)]	260 (34.85)	87 (33.98)	0.063	0.801
Prostate volume (cm³)	29.90 (22.70,40.80)	30.00 (23.60,41.20)	0.856	0.392
WBC (×10⁹/L)	5.70 (4.80,6.70)	6.00 (5.00,6.90)	2.306	0.021
Hemoglobin (g/L)	136.00 (127.00,145.00)	138.00 (129.00,146.00)	1.589	0.112
Albumin (g/L)	40.10 (38.40,41.70)	39.90 (38.30,41.50)	0.537	0.591
Creatinine (μmol/L)	72.00 (64.00,83.00)	72.00 (64.00,81.00)	0.152	0.879
Blood glucose(mmol/L)	4.70 (4.30,5.40)	4.80 (4.40,5.60)	2.264	0.024
CRP (mg/L)	2.90 (2.10,4.20)	3.00 (2.00,4.60)	0.981	0.326

Tab. 2 Comparison of intraoperative and postoperative data between the two groups [$M(P_{25},P_{75})$]

Item	Non-hypoxemia group (*n*=746)	Hypoxemia group (*n*=256)	χ^2/z value	*P* value
SpO_2 at entry [*n*(%)]				
<95%	20(2.68)	16(6.25)	7.009	**0.008**
≥95%	726(97.32)	240(93.75)		
Surgical duration (min)	160(140,190)	168(145,195)	2.401	**0.016**
Anesthesia duration (min)	180(155,210)	190(165,220)	2.377	**0.017**
Total amount of crystals (mL)	1 000(800,1 000)	1 000(1 000,1 000)	1.494	0.135
Total colloid volume (mL)	1 000(500,1 000)	1 000(500,1 000)	2.063	**0.039**
Urine volume (mL)	300(200,400)	300(200,400)	0.408	0.683
Bleeding volume (mL)	100(50,100)	100(100,100)	1.868	0.062
AUC-MAP	310(150,511)	277(143,494)	0.945	0.345
AUC-$P_{ET}CO_2$	0(0,0)	0(0,0)	1.643	0.100
Intraoperative medication				
Propofol (mg/kg)	13.97(11.47,16.57)	13.34(11.23,16.29)	1.349	0.177
Etomidate (mg)	12.00(10.00,16.00)	12.00(10.00,16.00)	0.155	0.877
Morphine equivalent (mg/kg)	1.00(0.85,1.15)	0.96(0.81,1.08)	2.749	**0.006**
Remifentanil (μg/kg)	16.00(12.58,21.31)	15.99(12.22,19.71)	1.247	0.212
Dexmedetomidine (μg/kg)	0.47(0.36,0.57)	0.46(0.37,0.57)	0.080	0.936
Corticosteroids [*n*(%)]	403(54.02)	116(45.31)	5.790	**0.016**
Non-steroidal anti-inflammatory drugs [*n*(%)]	213(28.55)	83(32.42)	1.371	0.242
Inhalation anesthesia gas [*n*(%)]	133(17.83)	44(17.19)	0.054	0.817
Vasoactive drugs [*n*(%)]	214(28.69)	74(28.91)	0.005	0.947
After joining AICU				
Low OI [*n*(%)]	272(36.46)	175(68.36)	78.484	**<0.001**
pH	7.38(7.34,7.41)	7.37(7.33,7.40)	2.318	**0.020**
$PaCO_2$(mmHg)	45.00(41.00,49.00)	46.00(43.00,50.00)	2.695	**0.007**
WBC (× 10^9/L)	6.70(5.20,8.30)	6.60(5.30,8.50)	0.870	0.384
Hemoglobin (g/L)	118.00(109.00,127.00)	120.00(110.00,128.00)	1.579	0.114
CRP (mg/L)	9.90(5.10,17.70)	12.50(6.60,22.40)	3.334	**0.001**
Procalcitonin (ng/mL)	0.026(0.020,0.035)	0.028(0.020,0.038)	1.946	0.052
Interleukin-6 (pg/mL)	19.49(11.41,28.32)	20.98(13.54,29.69)	1.713	0.087
B-type brain natriuretic peptide (pg/mL)	40.80(20.80,75.80)	42.00(20.80,73.70)	0.399	0.690
hs-TNT (μg/L)	0.009(0.007,0.012)	0.010(0.008,0.013)	3.281	**0.001**
Total output (mL)	1405(1 014,1 842)	1 473(1 120.50,1 975)	2.489	**0.013**
Total input volume (mL)	1 850(1 340,2 350)	1 900(1 400,2 400)	0.884	0.377
Postoperative extubation time (min)	140(105,195)	153(100,220)	1.440	0.150
Hospitalization days (d)	7(6,9)	8(6,9)	1.030	0.303

Tab. 3 Multivariate logistic regression analysis of hypoxemia in RARP patients in the AICU

Item	*β*	*SE*	Wald χ^2	*OR* value	95%*CI*	*P* value
Age≥65 years	0.439	0.222	3.899	1.551	1.003~2.396	0.048
BMI						
18.5~24 kg/m²				1.000		
<18.5 kg/m²	-1.355	1.075	1.589	0.258	0.031~2.121	0.207
>24~28 kg/m²	0.098	0.185	0.281	1.103	0.767~1.586	0.596
>28 kg/m²	0.553	0.266	4.329	1.739	1.033~2.928	0.037
History of hypertension	0.461	0.167	7.610	1.586	1.143~2.202	0.006
History of pulmonary diseases	0.470	0.164	8.175	1.600	1.159~2.208	0.004
SpO_2<95% when entering the room	1.032	0.394	6.865	2.807	1.297~6.077	0.009
Total colloidal amount	0.000	0.000	1.361	1.000	1.000~1.001	0.243
Dexmedetomidine	0.633	0.351	3.261	1.884	0.947~3.745	0.071
Glucocorticoid	-0.489	0.164	8.951	0.613	0.445~0.845	0.003
Entering AICU low OI	1.286	0.178	52.212	3.620	2.553~5.131	<0.001
CRP	0.003	0.005	0.297	1.003	0.993~1.013	0.586
Total output	0.000	0.000	2.522	0.999	0.999~1.001	0.112
Postoperative extubation time	0.002	0.001	6.202	1.002	1.000~1.003	0.013

3 Discussion

Compared to conventional laparoscopic surgery, RARP is becoming the "gold standard" for the surgical treatment of prostate cancer due to its advantages of providing a clearer surgical field, more thorough tumor removal, and smaller incisional trauma [6]. However, since RARP patients are predominantly elderly, they often have reduced lung elasticity and diminished pulmonary functional reserve. Intraoperatively, the steep Trendelenburg position significantly decreases chest wall compliance. Furthermore, factors such as prolonged CO_2 pneumoperitoneum and residual effects of muscle relaxants postoperatively all contribute to an increased incidence of hypoxemia after RARP [7]. Following general anesthesia, respiratory complications are common, with an incidence rate of 5%–33%, and postoperative atelectasis occurs in approximately 90% of cases [8]. Prevention is key to reducing postoperative respiratory complications. Identifying high-risk patients through preoperative assessment and formulating personalized prevention and treatment measures for them is crucial. Effective prevention and control of postoperative respiratory complications are critical for ensuring surgical outcomes and a good prognosis [9-10]. The results of this study show that among patients transferred to the AICU after RARP treatment, the incidence of hypoxemia after extubation was 25.55%. The risk factors identified were: age≥65 years, BMI>28 kg/m², history of hypertension, history of pulmonary disease, preoperative SpO_2<95%, low oxygenation index upon AICU admission, and delayed postoperative extubation time. The use of glucocorticoids intraoperatively was identified as a protective factor.

Previous studies have shown that elderly patients are more prone to hypoxemia after general anesthesia, which may be related to systemic degenerative changes and reduced reserve function of vital organs. With increasing age, the imbalance in the pulmonary renin-angiotensin system exacerbates inflammation and lung injury [11-12]. The results of this study are consistent with this, showing that age≥65 years is closely associated with the occurrence of hypoxemia in the AICU after RARP. This is likely because elderly patients, due to their decreased pulmonary reserve, are more susceptible to the combined effects of the special positioning and pneumoperitoneum during RARP. Additionally, this study found that BMI is also an independent risk factor for hypoxemia in the AICU. This may be closely related to reduced lung and chest wall compliance, significantly increased alveolar-arterial oxygen difference, ventilation-perfusion mismatch, and airway hyperresponsiveness in obese patients. Severe obesity may also lead to increased production of inflammatory cytokines and immune cells [13-15]. Research by Laffin et al. [16] showed that the incidence of severe hypoxemia in obese patients was nearly 6 times higher compared to patients with normal BMI. A retrospective observational study on patients undergoing surgery for acute type A aortic dissection found that overweight was an independent risk factor for postoperative hypoxemia [17]. A retrospective cohort study by Kendal *et al.* [13] of 15,238 adult patients undergoing elective non-cardiac surgery under general anesthesia found that increased BMI was closely associated with the occurrence, severity, and prolonged duration of perioperative hypoxemia. Decreased chest wall compliance in obese patients, combined with diaphragm elevation during prolonged pneumoperitoneum, can further worsen oxygenation. Furthermore, CO_2 absorption through the peritoneum into the bloodstream can lead to CO_2 accumulation and respiratory acidosis. Maintaining tidal volume under higher ventilation pressures in this state increases the risk of respiratory muscle-associated lung injury.

Obesity is also associated with several medical comorbidities, such as hypertension, diabetes, coronary artery disease, and obstructive sleep apnea. An observational study showed that the main predictors of postoperative hypoxemia were obesity, chronic diseases (hypertension and bronchial asthma), current smoking history, pre-induction SpO_2<95%, emergency surgery, and hypoxia during transport to the post-anesthesia care unit [18]. Research indicates that male, age, smoking history, BMI≥30 kg/m², CRP≥5 mg/L, and pulmonary disease are significantly associated with decreased SpO_2 [19]. In a prospective observational study of emergency general anesthesia patients by Berhanu *et al.* [20], patients with preoperative SpO_2<95% were twice as likely to develop postoperative hypoxemia compared to those with SpO_2≥95%. Preoperative SpO_2<95% may be a surrogate marker for impaired preoperative respiratory function, and the results of this study are consistent with this. Furthermore, in this study, postoperative extubation time was also a significant predictor of hypoxemia in the AICU. This may be related to increased ventilator-associated lung injury from prolonged mechanical ventilation, which also impacts patient postoperative recovery [21].

The results of this study indicate that intraoperative use of glucocorticoids is a protective factor against hypoxemia after extubation. This may be related to the anti-inflammatory effects of glucocorticoids, their ability to reduce capillary permeability and pulmonary edema, relieve bronchospasm, and inhibit fibrosis. Numerous studies have reported the efficacy of glucocorticoids in treating pulmonary fibrosis and acute respiratory distress syndrome [22-23]. A multicenter, double-blind, randomized controlled trial showed that the use of dexamethasone was associated with a significant reduction in the incidence of complications within 14 days and all-cause mortality in patients undergoing non-intrathoracic surgery, but not in those undergoing intrathoracic surgery. In non-intrathoracic surgery patients, respiratory complications are likely primarily caused by excessive systemic inflammation, whereas pulmonary complications in intrathoracic surgery patients are likely related to atelectasis caused by direct tissue injury and thus may be less responsive to dexamethasone. Subgroup analysis results suggest caution when using dexamethasone in patients after intrathoracic surgery [24]. Further clinical studies are needed to explore the impact of glucocorticoid dosage and timing on postoperative hypoxemia.

The strength of this study lies in its exploration of the incidence and risk factors of post-extubation hypoxemia in the AICU for RARP patients. The sample size is relatively large, and factors potentially influencing hypoxemia were collected as comprehensively as possible. This study also has certain limitations. Firstly, intraoperative mechanical ventilation is an essential component of general anesthesia. The extent to which different tidal volumes and positive end-expiratory pressure affect postoperative hypoxia and lung injury remains unclear, which may have some impact on the study results. Secondly, different pneumoperitoneum pressures may also have varying effects on patients, which could be better explored through prospective studies in the future. Additionally, for retrospective data collected from a single institution, the results may be influenced by patient and variable selection bias.

In summary, this study shows that the incidence of hypoxemia after extubation in the AICU among RARP patients was 25.55%. Independent risk factors for hypoxemia included age≥65 years, BMI>28 kg/m², history of hypertension, history of pulmonary disease, preoperative SpO_2<95%, low oxygenation index upon AICU admission, and delayed postoperative extubation time. The intraoperative use of glucocorticoids was identified as a protective factor.

Conflict of Interest None

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·论　著·

机器人辅助根治性前列腺切除术患者在麻醉重症监护病房发生低氧血症的危险因素

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摘要：目的　收集行机器人辅助根治性前列腺切除术（RARP）患者的围手术期相关资料，探讨其术后在麻醉重症监护病房（AICU）发生低氧血症的相关因素。**方法**　回顾性收集2022年1月至2024年5月于南京鼓楼医院行RARP术后进AICU患者的临床资料。根据患者转出AICU前最后一次动脉血气中的氧合指数（OI）将患者分为低氧血症组（OI<300 mmHg）和非低氧血症组（OI≥300 mmHg）。收集两组患者的临床资料（包括一般资料、实验室检查结果、手术相关指标、术中用药、入AICU后指标）并进行组间比较。采用多因素logistic回归分析探索RARP患者转出AICU前发生低氧血症的危险因素。**结果**　本研究纳入分析患者1 002例，其中转出AICU前发生低氧血症的患者256例，发生率25.55%。两组患者在年龄、身体质量指数（BMI）、高血压、肺部疾病史、白细胞计数及血糖差异有统计学意义（$P<0.05$）。两组术前外周血氧饱和度（SpO_2）、手术时长、麻醉时长、胶体总量、吗啡当量、糖皮质激素差异有统计学意义（$P<0.05$）。两组入AICU时低OI、pH值、动脉二氧化碳分压、C反应蛋白、高敏肌钙蛋白T以及AICU总出量比较差异有统计学意义（$P<0.05$）。多因素分析显示，年龄≥65岁（OR=1.551，95%CI：1.003~2.396，P=0.048）、BMI>28 kg/m²（OR=1.739，95%CI：1.033~2.928，P=0.037）、高血压（OR=1.586，95%CI：1.143~2.202，P=0.006）、肺部疾病史（OR=1.600，95%CI：1.159~2.208，P=0.004）、术前SpO_2<95%（OR=2.807，95%CI：1.297~6.077，P=0.009）、入AICU时低OI（OR=3.620，95%CI：2.553~5.131，P<0.01）以及术后拔管时间迟（OR=1.002，95%CI：1.000~1.003，P=0.013）为RARP患者在AICU中发生低氧血症的危险因素，而术中使用糖皮质激素（OR=0.613，95%CI：0.445~0.845，P=0.003）则是保护性因素。**结论**　年龄、BMI、高血压、肺部疾病史、术前SpO_2、刚入AICU时OI、术后拔管时间以及术中使用糖皮质激素与RARP患者在AICU内发生低氧血症密切相关。

关键词： 机器人辅助根治性前列腺切除术；麻醉重症监护病房；低氧血症；糖皮质激素；氧合指数
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Risk factors for hypoxemia in patients undergoing robot-assisted radical prostatectomy in the Anesthesia Intensive Care Unit

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Abstract: Objective　To collect perioperative data of patients undergoing robot-assisted radical prostatectomy (RARP) and explore the related factors of postoperative hypoxemia in Anesthesia Intensive Care Unit (AICU). **Methods**　Clinical data of patients who underwent RARP and were admitted to the AICU at Nanjing Drum Tower Hospital between January 2022 and May 2024 were retrospectively collected. According to the oxygenation index (OI) from the last arterial blood gas analysis before transfer out of the AICU, patients were divided into a hypoxemia group (OI<300 mmHg) and a non-hypoxemia group (OI≥300 mmHg). Clinical data of the two groups, including general information, laboratory results, surgery-related indicators, intraoperative medication use, and indicators after AICU admission, were collected and compared. Multivariate logistic regression analysis was used to identify risk factors for hypoxemia before transfer out of

QR code for English version

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the AICU in RARP patients. **Results** A total of 1 002 patients were included in the analysis, of whom 256 developed hypoxemia before transfer out of the AICU, with an incidence rate of 25.55%. There were significant differences between the two groups in age, body mass index (BMI), hypertension, history of pulmonary disease, white blood cell count, and blood glucose (P<0.05). Significant differences were also found in preoperative saturation of peripheral oxygen (SpO_2), operation duration, anesthesia duration, total colloid volume, morphine equivalent, and glucocorticoid use (P<0.05). And there were significant differences in the OI upon AICU admission, pH, $PaCO_2$, C-reactive protein, high-sensitivity troponin T, and total AICU output (P<0.05). Multivariate analysis revealed that age ≥65 years (OR=1.551, 95%CI: 1.003−2.396, P=0.048), BMI>28 kg/m^2 (OR=1.739, 95%CI: 1.033−2.928, P=0.037), hypertension (OR=1.586, 95%CI: 1.143−2.202, P=0.006), history of pulmonary disease (OR=1.600, 95%CI: 1.159−2.208, P=0.004), preoperative SpO_2<95% (OR=2.807, 95%CI: 1.297−6.077, P=0.009), low OI upon AICU admission (OR=3.620, 95%CI: 2.553−5.131, P<0.01), and delayed postoperative extubation time (OR=1.002, 95%CI: 1.000−1.003, P=0.013) were risk factors for hypoxemia in RARP patients in the AICU, while intraoperative glucocorticoid use (OR=0.613, 95%CI: 0.445−0.845, P=0.003) was a protective factor. **Conclusion** Age, BMI, hypertension, history of pulmonary disease, preoperative SpO_2, OI upon AICU admission, postoperative extubation time, and intraoperative glucocorticoid use are closely associated with the occurrence of hypoxemia in RARP patients at AICU.

Keywords: Robot-assisted radical prostatectomy; Anesthesia intensive care unit; Hypoxemia; Glucocorticoid; Oxygenation index

前列腺癌是男性泌尿系统最常见的恶性肿瘤[1]。既往研究表明，对于局限性前列腺癌患者，手术切除可以降低其死亡率，而机器人辅助根治性前列腺切除术（robot-assisted radical prostatectomy，RARP）较传统的开放性手术相比，以其出血少、住院时间短和术后疼痛轻等优势正得到日益广泛的应用[2]。尽管RARP具有创伤小、恢复快的优势，但手术中出现低氧血症的发生率仍有18.8%[3]。Sun等[4]研究发现，超过三分之一的非心脏手术患者术后会发生低氧血症，严重的低氧血症可导致患者心律失常、低血压和神经系统损伤等。为保障患者围手术期安全，加速术后康复，减少手术并发症，部分患者术后可转至麻醉重症监护病房（anesthesia intensive care unit，AICU）进行观察复苏。而目前对AICU内出现低氧血症的研究尚少，因此本研究对转入AICU的RARP患者拔管后是否发生低氧血症进行回顾性分析，探讨与其相关的可能因素，为围手术期个性化管理提供参考。

1　资料与方法

1.1　*一般资料*　本研究经过南京鼓楼医院伦理委员会会研究批准（伦理编号：2021-563-03），回顾性收集南京鼓楼医院AICU于2022年1月至2024年5月收治的择期行RARP患者的病历资料。（1）纳入标准：①术前前列腺穿刺或术后组织病理学检查确诊为前列腺癌；②择期行RARP；③术后转入AICU。（2）排除标准：①电子病历记录不全；②氧合相关数据缺失；③在AICU期间行二次手术。

1.2　*数据收集*　通过电子病历信息系统和麻醉麦迪斯顿系统收集患者的一般资料，包括年龄、身体质量指数（body mass index，BMI）、美国麻醉医师协会（American Society of Anesthesiologists，ASA）分级、基础疾病史（高血压、糖尿病、肺部疾病、心脏疾病、脑血管疾病、恶性肿瘤）、吸烟史、术前前列腺体积及术前最后一次实验室检查结果（白细胞计数、血红蛋白、白蛋白、血糖、血肌酐、C反应蛋白）。肺部疾病包括慢性阻塞性肺疾病、哮喘、近期感染肺炎和肺部手术史；心脏疾病包括冠状动脉粥样硬化性心脏病（冠心病）、心脏瓣膜病、心房颤动和高度房室传导阻滞。

1.3　*麻醉管理*　患者实施全静脉麻醉方案。术前未给予预处理药物，麻醉诱导使用静脉注射咪达唑仑（江苏恩华药业，批号：210204）0.05 mg/kg，1%丙泊酚（北京菲森尤斯卡比医药，批号：2010247）1~2 mg/kg或依托咪酯（江苏恩华药业，批号：YT200909）0.3~0.5 mg/kg，芬太尼（宜昌人福药业，批号：01E04081）3~8 μg/kg，维库溴铵（江苏扬子江药业，批号：21011811）0.08~0.12 mg/kg。麻醉维持持续泵注丙泊酚4~12 mg·kg^{-1}·h^{-1}，瑞芬太尼（宜昌人福药业，批号：01A10101）0.05~0.2 μg·kg^{-1}·min^{-1}，苯磺顺阿曲库铵（江苏恒瑞医药，批号：201208AK）1~3 μg·kg^{-1}·min^{-1}。根据麻醉记录单，收集术中情况包括患者术前外周血氧饱和度（saturation of peripheral oxygen，SpO_2）、手术时长、麻醉时长、出入量、使用梯形面积法[5]计算曲线下总面积（area under curve，AUC）——基于平

均动脉压(mean arterial pressure, MAP)<65 mmHg的AUC-MAP以及基于呼气末二氧化碳分压(end-tidal carbon dioxide partial pressure, $P_{ET}CO_2$)>45mmHg的AUC-$P_{ET}CO_2$、药物使用情况(丙泊酚、依托咪酯、阿片类药物、右美托咪定、糖皮质激素、非甾体抗炎药、吸入性麻醉气体、血管活性药物)等。

1.4 AICU管理 术毕患者由麻醉医生、外科医生和护理人员共同转运至AICU,入室后立即连接呼吸机,监测患者的生命体征,采用同步间歇指令性通气模式,呼吸机(深圳迈瑞生物医疗,型号迈瑞A7)参数设定:潮气量(tidal volume, VT) 6~8 mL/kg,吸呼比(inspiratory to expiratory ratio, I∶E)=1∶2,吸入氧浓度(fraction of inspired oxygen, FiO_2)=50%,频率(f)为12~14次/min,呼气末正压通气(positive end expiratory pressure, PEEP)=5 cmH_2O(排除禁忌证)。接好监护后立即行动脉血气检查,待患者神志清楚,自主呼吸及肌力恢复后脱机观察30 min,测定血气,氧合指数[oxygenation index, OI,即动脉血氧分压(arterial partial pressure of oxygen, PaO_2)/FiO_2]>200 mmHg、无CO_2蓄积且无内环境紊乱,AICU麻醉医生评估后拔管。拔管后予鼻导管吸氧(氧流量2 L/min),观察患者呼吸及循环情况,若患者生命体征一切平稳,于术后第1天早上九时转至泌尿外科普通病房。根据病历系统记录患者AICU内动脉血气结果、实验室检查结果(白细胞计数、血红蛋白、C反应蛋白、降钙素原、白细胞介素-6、B型脑钠肽、高敏肌钙蛋白T)、出入量、术后拔管时间以及总的住院天数。根据患者转出AICU前最后一次动脉血气结果中的OI将患者分为低氧血症组(OI<300 mmHg)和非低氧血症组(OI≥300 mmHg)。术后拔管时间定义为手术缝皮结束至拔管的时间。

1.5 统计学方法 使用SPSS 27.0和R4.3.3软件进行统计分析。对符合正态分布的计量资料以$\bar{x}\pm s$表示,组间比较采用独立样本t检验;偏态分布的计量资料以$M(P_{25}, P_{75})$表示,组间比较采用Mann-Whitney U检验;计数资料以例(%)表示,组间比较采用χ^2检验或Fisher确切概率法。对于缺失比例<20%的连续性变量,使用多重插补法(基于R语言中的mice包实现)进行填补,设定插补次数为5次。为降低特征维度并筛选核心关联变量,本研究采用弹性网回归算法进行数据降维,其中正则化混合参数α设定为0.5,同时使用五折交叉验证来选择最佳的正则化参数。将弹性网回归筛选出的变量,纳入多因素logistic回归分析,得到AICU中行RARP患者拔管后发生低氧血症的独立危险因素。检验水准α=0.05,双侧检验。

2 结 果

2.1 基线描述 在AICU中接受RARP手术治疗的患者共1 162例,其中电子病历记录不全的患者154例,离开AICU前缺失最后一次氧合数据的患者有5例,在AICU期间发生二次手术的患者1例,本研究最终纳入患者1 002例,其中转出AICU前发生低氧血症的患者256例,发生率为25.55%,746例患者转出AICU前未发生低氧血症,流程图见图1。患者年龄(69.75±6.39)岁,其中老年患者(≥65岁)816例,占81.44%;BMI(24.48±2.94)kg/m²,其中超重患者(24~28 kg/m²)436例(43.51%),肥胖患者(>28 kg/m²)113例(11.28%)。高血压患者574例(57.29%),2型糖尿病患者181例(18.06%),肺部疾病史341例(34.03%),心脏疾病史101例(10.08%),脑血管意外史134例(13.37%),恶性肿瘤史43例(4.29%),吸烟者347例(34.63%)。

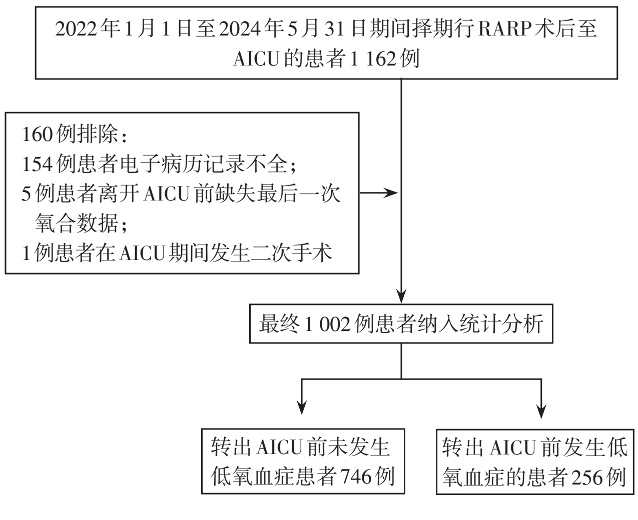

图1 病例纳入和排除流程图

Fig.1 Flow chart of case inclusion and exclusion

2.2 基线比较与变量筛选 两组患者年龄、BMI、高血压、肺部疾病史、白细胞计数及血糖差异有统计学意义(P<0.05)。见表1。两组术前SpO_2、手术时长、麻醉时长、术中胶体总量、吗啡当量、糖皮质激素使用比例组间差异有统计学意义(P<0.05)。入AICU时低OI、pH值、$PaCO_2$、C反应蛋白、高敏肌钙蛋白T以及AICU总出量组间差异有统计学意义(P<0.05)。见表2。为降低维度并选择最相关的变量,本研究采用弹性网回归算法筛选出AICU中行RARP的患者拔管后发生低氧血症的12个相关变量,分别为年龄、BMI、高血压、肺部疾病史、术前SpO_2、术中胶体总量、右美托咪定、糖皮质激素、入AICU时低OI、术后C反

应蛋白、AICU 总出量、术后拔管时间。

2.3　多因素分析　将弹性网络回归筛选的变量纳入二元 logistic 回归分析，结果显示，≥65 岁（OR=1.551，95%CI：1.003~2.396，P=0.048）、BMI>28 kg/m^2（OR=1.739，95%CI：1.033~2.928，P=0.037）、高血压（OR=1.586，95%CI：1.143~2.202，P=0.006）、肺部疾病史（OR=1.600，95%CI：1.159~2.208，P=0.004）、术前 SpO_2<95%（OR=2.807，95%CI：1.297~6.077，P=0.009）、入 AICU 时 OI 低（OR=3.620，95%CI：2.553~5.131，P<0.01）、术后拔管时间迟（OR=1.002，95% CI：1.000~1.003，P=0.013）为行 RARP 患者 AICU 中发生低氧血症的危险因素，而术中使用糖皮质激素（OR=0.613，95%CI：0.445~0.845，P=0.003）则是保护性因素。见表 3。

表 1　两组患者术前一般资料的比较　[$M(P_{25}, P_{75})$]

Tab.1　Comparison of preoperative general data between two groups　[$M(P_{25}, P_{75})$]

指标	非低氧血症组（n=746）	低氧血症组（n=256）	t/χ^2/Z 值	P 值
年龄[例(%)]				
<65 岁	152(20.38)	34(13.28)	6.345	0.012
≥65 岁	594(79.62)	222(86.72)		
BMI[例(%)]				
<18.5 kg/m^2	14(1.88)	1(0.39)	29.054	<0.001
18.5~24 kg/m^2	352(47.18)	86(33.59)		
>24~28 kg/m^2	316(42.36)	120(46.88)		
>28 kg/m^2	64(8.58)	49(19.14)		
ASA 分级[例(%)]				
Ⅱ级	25(3.35)	7(2.73)	0.598	0.741
Ⅲ级	690(92.49)	236(92.19)		
Ⅳ级	31(4.16)	13(5.08)		
并存疾病[例(%)]				
高血压	398(53.35)	176(68.75)	18.470	<0.001
2 型糖尿病	133(17.83)	48(18.75)	0.109	0.741
肺部疾病史	240(32.17)	101(39.45)	4.501	0.034
心脏疾病史	75(10.05)	26(10.16)	0.002	0.962
脑血管意外史	96(12.87)	38(14.84)	0.642	0.423
恶性肿瘤史	32(4.29)	11(4.30)	<0.001	0.996
吸烟史[例(%)]	260(34.85)	87(33.98)	0.063	0.801
前列腺体积(cm^3)	29.90 (22.70, 40.80)	30.00 (23.60, 41.20)	0.856	0.392
白细胞计数(×10^9/L)	5.70(4.80, 6.70)	6.00(5.00, 6.90)	2.306	0.021
血红蛋白(g/L)	136.00 (127.00, 145.00)	138.00 (129.00, 146.00)	1.589	0.112
白蛋白(g/L)	40.10 (38.40, 41.70)	39.90 (38.30, 41.50)	0.537	0.591
血肌酐(μmol/L)	72.00 (64.00, 83.00)	72.00 (64.00, 81.00)	0.152	0.879
血糖(mmol/L)	4.70(4.30, 5.40)	4.80(4.40, 5.60)	2.264	0.024
C 反应蛋白(mg/L)	2.90(2.10, 4.20)	3.00(2.00, 4.60)	0.981	0.326

表 2　两组患者术中、术后资料的比较　[$M(P_{25}, P_{75})$]

Tab.2　Comparison of intraoperative and postoperative data between two groups　[$M(P_{25}, P_{75})$]

指标	非低氧血症组（n=746）	低氧血症组（n=256）	χ^2/Z 值	P 值
术前 SpO_2[例(%)]				
<95%	20(2.68)	16(6.25)	7.009	0.008
≥95%	726(97.32)	240(93.75)		
手术时长(min)	160(140, 190)	168(145, 195)	2.401	0.016
麻醉时长(min)	180(155, 210)	190(165, 220)	2.377	0.017
晶体总量(mL)	1 000 (800, 1 000)	1 000 (1 000, 1 000)	1.494	0.135
胶体总量(mL)	1 000 (500, 1 000)	1 000 (500, 1 000)	2.063	0.039
尿量(mL)	300(200, 400)	300(200, 400)	0.408	0.683
出血量(mL)	100(50, 100)	100(100, 100)	1.868	0.062
AUC-MAP	310(150, 511)	277(143, 494)	0.945	0.345
AUC-$P_{ET}CO_2$	0(0, 0)	0(0, 0)	1.643	0.100
术中用药				
丙泊酚(mg/kg)	13.97 (11.47, 16.57)	13.34 (11.23, 16.29)	1.349	0.177
依托咪酯(mg)	12.00 (10.00, 16.00)	12.00 (10.00, 16.00)	0.155	0.877
吗啡当量(mg/kg)	1.00 (0.85, 1.15)	0.96 (0.81, 1.08)	2.749	0.006
瑞芬太尼(μg/kg)	16.00 (12.58, 21.31)	15.99 (12.22, 19.71)	1.247	0.212
右美托咪定(μg/kg)	0.47 (0.36, 0.57)	0.46 (0.37, 0.57)	0.080	0.936
糖皮质激素[例(%)]	403(54.02)	116(45.31)	5.790	0.016
非甾体抗炎药[例(%)]	213(28.55)	83(32.42)	1.371	0.242
吸入性麻醉气体[例(%)]	133(17.83)	44(17.19)	0.054	0.817
血管活性药物[例(%)]	214(28.69)	74(28.91)	0.005	0.947
入 AICU 后				
低 OI[例(%)]	272(36.46)	175(68.36)	78.484	<0.001
pH 值	7.38 (7.34, 7.41)	7.37 (7.33, 7.40)	2.318	0.020
$PaCO_2$(mmHg)	45.00 (41.00, 49.00)	46.00 (43.00, 50.00)	2.695	0.007
白细胞计数(×10^9/L)	6.70 (5.20, 8.30)	6.60 (5.30, 8.50)	0.870	0.384
血红蛋白(g/L)	118.00 (109.00, 127.00)	120.00 (110.00, 128.00)	1.579	0.114
C 反应蛋白(mg/L)	9.90 (5.10, 17.70)	12.50 (6.60, 22.40)	3.334	0.001
降钙素原(ng/mL)	0.026 (0.020, 0.035)	0.028 (0.020, 0.038)	1.946	0.052
白细胞介素-6(pg/mL)	19.49 (11.41, 28.32)	20.98 (13.54, 29.69)	1.713	0.087
B 型脑钠肽(pg/mL)	40.80 (20.80, 75.80)	42.00 (20.80, 73.70)	0.399	0.690
高敏肌钙蛋白 T(μg/L)	0.009 (0.007, 0.012)	0.010 (0.008, 0.013)	3.281	0.001
总出量(mL)	1 405 (1 014, 1 842)	1 473 (1 120.50, 1975)	2.489	0.013
总入量(mL)	1 850 (1 340, 2 350)	1 900 (1 400, 2 400)	0.884	0.377
术后拔管时间(min)	140(105, 195)	153(100, 220)	1.440	0.150
住院天数(d)	7(6, 9)	8(6, 9)	1.030	0.303

表3　AICU内RARP患者发生低氧血症的多因素logistic回归分析

Tab.3　Multivariate logistic regression analysis of hypoxemia in RARP patients in the AICU

指标	β	*SE*	Wald χ^2	*OR*值	95%*CI*	*P*值
年龄≥65岁	0.439	0.222	3.899	1.551	1.003~2.396	0.048
BMI						
18.5~24 kg/m^2				1.000		
<18.5 kg/m^2	−1.355	1.075	1.589	0.258	0.031~2.121	0.207
>24~28 kg/m^2	0.098	0.185	0.281	1.103	0.767~1.586	0.596
>28 kg/m^2	0.553	0.266	4.329	1.739	1.033~2.928	0.037
高血压史	0.461	0.167	7.610	1.586	1.143~2.202	0.006
肺部疾病史	0.470	0.164	8.175	1.600	1.159~2.208	0.004
术前SpO_2<95%	1.032	0.394	6.865	2.807	1.297~6.077	0.009
胶体总量	0.000	0.000	1.361	1.000	1.000~1.001	0.243
右美托咪定	0.633	0.351	3.261	1.884	0.947~3.745	0.071
糖皮质激素	−0.489	0.164	8.951	0.613	0.445~0.845	0.003
入AICU低OI	1.286	0.178	52.212	3.620	2.553~5.131	<0.001
C反应蛋白	0.003	0.005	0.297	1.003	0.993~1.013	0.586
总出量	0.000	0.000	2.522	0.999	0.999~1.001	0.112
术后拔管时间	0.002	0.001	6.202	1.002	1.000~1.003	0.013

3　讨　论

与普通腔镜手术相比，RARP因其能够提供更清晰的手术视野、肿瘤切除更为彻底、切口创伤更小等优势，正成为前列腺癌外科治疗的“金标准”[6]。但是由于行RARP的患者多为高龄患者，老年患者存在肺弹性减弱、肺功能储备下降的问题，并且术中头低脚高特伦德伦堡（Trendelenburg）体位使得患者胸廓顺应性显著下降，以及术中长时间CO_2气腹、术后肌肉松弛药残余作用等因素均会增加RARP术后低氧血症的发生率[7]。全身麻醉后，呼吸系统并发症是常见并发症，发生率为5%~33%，其中术后肺不张的发生率约为90%[8]。降低术后呼吸系统并发症重在预防，通过术前评估筛选出高危患者并针对其制定个性化防治措施至关重要，术后呼吸系统并发症的有效防控是保障手术效果和良好预后的关键环节[9-10]。本研究结果显示，在接受RARP治疗术后转入AICU的患者中，拔管后出现低氧血症的发生率为25.55%，其中，年龄≥65岁、BMI>28 kg/m^2、高血压史、肺部疾病史、术前SpO_2<95%、入AICU时OI低以及术后拔管时间迟为其危险因素，而术中使用糖皮质激素则是其保护性因素。

已有研究表明，老年患者更易在全身麻醉术后发生低氧血症，这可能与全身性退行性病变及重要器官储备功能降低有关，并且随着年龄增长，肺肾素-血管紧张素系统失衡，加剧炎症和肺损伤[11-12]，本研究结果与之一致，年龄≥65岁与RARP患者术后在AICU中发生低氧血症密切相关，考虑老年患者因肺储备功能减退，更易受RARP术中特殊体位与气腹的叠加影响。另外，本研究发现BMI也是AICU内发生低氧血症的独立影响因素，这可能与肥胖患者肺和胸壁顺应性降低、肺泡-动脉氧差显著增加、通气血流比例失调、气道高反应等密切相关，过度肥胖还可能导致疾病的炎症细胞因子和免疫细胞产生增加[13-15]。Laffin等[16]研究表明，与正常BMI患者相比，肥胖患者严重低氧血症的发生率增加了近6倍。一项对急性A型主动脉夹层手术患者的回顾性观察研究发现，超重是术后低氧血症的独立危险因素[17]。Kendal等[13]对全身麻醉下择期行非心脏手术的15 238例成人患者的回顾性队列研究发现，BMI的增加与围手术期低氧血症的发生、严重程度和持续时间延长密切相关。肥胖患者的胸壁顺应性下降，在长时间气腹操作中导致患者膈肌上抬，会进一步恶化氧合功能，此外CO_2的吸收会通过腹膜进入血液循环，引起CO_2的蓄积，出现呼吸性酸中毒，此时更高通气压力下维持的潮气量增加了呼吸肌相关肺损伤的风险。

肥胖还与一些内科合并症相关，如高血压、糖尿病、冠状动脉疾病和阻塞性睡眠呼吸暂停。一项观察性研究显示，肥胖患者、患有慢性病（高血压和支气管哮喘）的患者、当前吸烟史、麻醉诱导前SpO_2<95%、急诊手术以及转运进入麻醉恢复室期间缺氧是术后低氧血症发生的主要预测因素[18]。研究表明，男性、年龄、吸烟史、BMI≥30 kg/m^2、C反应蛋白≥5 mg/L及肺部疾病与SpO_2下降显著相关[19]。Berhanu等[20]在对急诊全身麻醉患者的一项前瞻性观察性研究中发现，术前SpO_2<95%的患者发生术后低氧血症的可能性是SpO_2≥95%患者的2倍。术前SpO_2<95%可能是患者术前呼吸功能受损的替代指标，本研究结果与之一致。此外，在本研究中，术后拔管时间也是AICU中发生低氧血症的重要预测因素之一，这可能与长时间机械通气增加相关肺损伤有关，也影响了患者的术后康复[21]。

本研究结果显示，术中使用糖皮质激素是拔管后低氧血症的保护性因素，这可能与糖皮质激素抗炎、减轻毛细血管渗透和肺水肿、缓解支气管痉挛以及抑制纤维化有关。已有较多文献报道糖皮质激素在治疗肺纤维化以及急性呼吸窘迫综合征方面卓有成效[22-23]。一项多中心、双盲、随机对照试验显示，使用地塞米松与非胸腔内手术患者术后14 d并发症发

生率和全因死亡率的显著降低相关,而与胸腔内手术无关[24]。在非胸腔内手术患者中,呼吸系统并发症很可能主要是由过度的全身性炎症引起,而胸腔内手术患者的肺部并发症很可能与直接组织损伤引起的肺不张有关[24],因此可能对地塞米松的反应性较差,并且亚组分析结果提示胸腔内手术后患者应慎用地塞米松[24]。后续还需要更多的临床研究去探索糖皮质激素的使用剂量及使用时间对术后低氧血症的影响。

本研究的优势在于探索了RARP患者术后AICU内拔管后低氧血症的发生情况及危险因素,样本量较大,并且对可能影响低氧血症的因素进行了尽可能全面的收集。本研究也存在一定的局限性,首先术中机械通气是全身麻醉的重要组成部分,不同潮气量和呼气末正压对术后缺氧和肺损伤的影响程度目前尚不清楚,这可能对研究结果有一定影响。另外,不同气腹压力对患者可能也有一定的影响,后期可以进行前瞻性研究更好地探究其中的关系。此外,对于单一机构收集的回顾性数据,结果可能会受到患者和变量选择偏倚的影响。

综上所述,RARP患者在AICU拔管后出现低氧血症的发生率为25.55%,其中年龄≥65岁、BMI>28 kg/m^2、高血压史、肺部疾病史、术前SpO_2<95%、入AICU时OI低以及术后拔管时间迟是低氧血症的独立危险因素,而术中使用糖皮质激素则是保护性因素。

利益冲突　无

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