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Correlation between microstream P_{ET} CO_2 and $PaCO_2$ in patients with general anesthesia after tracheal catheter removal

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Abstract: Objective To evaluate the correlation between microstream partial pressure of end-tidal carbon dioxide ($P_{ET}CO_2$) and partial pressure of carbon dioxide in artery (PaCO) in patients with general anesthesia after tracheal catheter removal. dioxide in artery ($PaCO_2$) in patients with general anesthesia after tracheal catheter removal. **Methods** A total of 120 patients in Jiangsu Cancer Hospital undergoing abdominal operation under general anesthesia were selected and randomized. A total of 120 patients in Jiangsu Cancer Hospital undergoing abdominal operation under general anesthesia were selected and randomly divided into 3 groups, with 40 patients in each group after tracheal catheter removal. Each group received oxygen through nasal catheter at different flow rates: group L (2 L/min), group M (4 L/min) and group H (6 L/min). After 30 min of tracheal catheter removal, the value of P_{ET} CO_2 was recorded and arterial blood was drawn to measure $PaCO_2$, and the correlation between $P_{ET}CO_2$ and PaCO was analyzed. $PaCO_2$ was analyzed. **Results** There was a high correlation between microstream $P_{ET}CO_2$ and $PaCO_2$ in groups L, M and H ($r=0.931$, 0.878 and 0.838, $P<0.001$), and the correlation coefficients decreased with the increase of oxygen flow. **Conclusion** When microstream $P_{ET}CO_2$ was used to monitor patients under general anesthesia in PACU after tracheal catheter removal, there was a high correlation between $P_{ET}CO_2$ and $PaCO_2$ at 2-6 L/min oxygen flow, which can be used as an important reference for the evaluation of $PaCO_2$.

Keywords: Capnography; Oxygen inhalation therapy; Pulmonary ventilation; Postanesthesia Nursing; Partial pressure of end-tidal carbon dioxide; Arterial partial pressure of carbon dioxide

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The partial pressure of end-tidal carbon dioxide ($P_{ET}CO_2$) is the partial pressure of carbon dioxide in the mixed alveolar gas exhaled at the end of expiration. Carbon dioxide tracings continuously record the pressure of exhaled carbon dioxide gas and present it as images. Because of its ease of acquisition and real-time data acquisition, it has been used as a routine monitoring index in clinical anesthesia to evaluate the patient's ventilatory function, circulatory function, pulmonary blood flow, alveolar ventilation quality, and respiratory circuit patency.[1-4]. $P_{ET}CO_2$ is commonly used in clinical work to roughly estimate the arterial partial pressure of carbon dioxide ($PaCO_2$) [5-6]. As early as 2015, guidelines from the Association of Anaesthetists of the United Kingdom and Ireland recommended that $P_{ET}CO_2$ should be monitored during recovery from anesthesia until the patient with an endotracheal tube, supraglottic airway device, or deep sedation has fully recovered from anesthesia[7-8]. At present, for patients in the post-anesthesia care unit (PACU), $P_{ET}CO_2$ is usually monitored during mechanical ventilation, but $P_{ET}CO_2$ is seldom monitored after extubation. However, clinical practice has shown that respiratory depression often occurs after extubation of patients with general anesthesia due to residual anesthetic drugs, pain, and airway secretions, which may even cause severe hypoxemia, secondary intubation, and many other problems. However, clinical practice has shown that respiratory depression often occurs after removal of the tracheal tube in general anesthesia patients due to residual anesthetic drugs, pain, airway secretions, etc., and may even cause severe hypoxemia, secondary intubation, and other adverse events[9-10]. Several studies have reported that micro-bypass $P_{ET}CO_2$ monitoring for painless endoscopy and digital subtraction angiography can identify ventilation abnormalities early and reduce the incidence of hypoxemia through intervention[11-13]. However, its applicability to post-extubation patients in PACU is unclear, and the correlation between micro-bypass $P_{ET}CO_2$ and $PaCO_2$ is lacking. Therefore, in this study, we proposed to use a novel device for monitoring micro-bypass $P_{ET}CO_2$ (Capnostream™ 20p Bedside Monitor with Apnea-Sat Alert Algorithm) to monitor post-extubation patients in PACU during recovery from general anesthesia and to analyze the correlation between micro-bypass $P_{ET}CO_2$ and $PaCO_2$.

1 Information and methodology

1.1 General information

This study was approved by the Ethics Committee of Jiangsu Provincial Tumor Hospital (Ethics Approval No. 2021Technology-012). The patients or their families signed the informed consent. One hundred and twenty patients who underwent elective abdominal surgery from January to May 2021 in Jiangsu Provincial Cancer Hospital were selected. The random number table method was adopted to divide the patients into the low-flow group (L group), the medium-flow group (M group), and the high-flow group (H group), with 40 cases in each group.

(1) Inclusion criteria: ①American society of Aneshesiologists physical status classification system (ASA classification) II or III; ②age of 18-64 years old; ③Body mass index (BMI) <28 kg/m^2. (2) Exclusion criteria: ①preoperative coexistence of serious cardiopulmonary diseases; ②obvious abnormalities of maxillofacial anatomy; ③unplanned transfer to the intensive care unit (ICU) after surgery; ④the patient or family members requested to withdraw from the trial.

1.2 Methodology

1.2.1 Anesthesia methods

All patients were free of pre-anesthetic drugs, and blood pressure (BP), heart rate (HR), electrocardiogram (ECG) and pulse oxygen saturation (SpO_2) were routinely monitored after entering the operating room. Radial artery puncture was performed under local anesthesia for pressure measurement. Anesthesia was induced with 0.02-0.05 mg/kg midazolam, 0.3-0.5 μg/kg sufentanil, 1-2 mg/kg propofol, and 0.2 mg/kg cis-atracurium. Continuous intravenous pumping of 4-8 mg•kg^{-1}•h^{-1} propofol, 0.1-0.2 μg•kg^{-1}•min^{-1} remifentanil, 0.2-0.4 μg•kg^{-1}•h^{-1} dexmedetomidine, and 0.1-0.15 mg•kg^{-1}•h^{-1} cisatracurium were used for maintenance, and the Narcotrend index (Narcotrend™ Monitor and the Electroencephalogram) was maintained at D_1-E_0 (27-56). Mechanical ventilation was performed in volume control mode, with tidal volume set at 6-8 ml/kg (ideal body weight), respiratory rate (RR) at 12-16 beats/min, inspiratory to expiratory ratio at 1:2, and inspired oxygen concentration at 60%, and respiratory parameters were adjusted so that $P_{ET}CO_2$ was maintained at 35-45 mmHg, and SpO_2 was maintained at more than 95%. After the operation, the patient was admitted to the PACU to continue monitoring and treatment, and patient-controlled intravenous analgesia was used.

1.2.2 Extraction conditions

The criteria for removing the endotracheal tube were

1. the patient was awake and could respond to the call;
2. choking and swallowing reflexes were restored;
3. the head could be lifted off the pillow continuously for more than 5 seconds;
4. hemodynamic stabilization;
5. stable respiration, with a respiratory rate of 10-20 beats/min and $P_{ET}CO_2$ ≤45 mmHg.

The endotracheal tube was removed after assessment by an experienced anesthesiologist in the PACU.

1.2.3 Subgroup treatment

In group L, group M, and group H, the oxygen flow rate was 2, 4, and 6 L/min via a nasal catheter after extubation, and the $PETCO_2$ monitoring equipment (Capnostream™ 20p Bedside Monitor with Apnea-Sat Alert Algorithm) was used for continuous monitoring of $PETCO_2$. Arterial oxygen partial pressure (PaO_2) and $PaCO_2$ were measured at 30 min of extubation. Specific subgroups and oxygen flow rates were unavailable to the subjects and the investigator who collected the data throughout the study and were blinded when the trial was completed.

1.3 Observation indexes

(1) Preoperative general data included gender, age, BMI, American Society of Anesthesiologists (ASA) classification, past history (hypertension, diabetes mellitus, history of radiotherapy, history of smoking, history of alcohol consumption, and history of surgery); (2) Perioperative data included the type of surgery (luminal/open), surgical site, volume of rehydration solution, whether or not to transfuse blood, amount of blood, amount of urine, surgical time, and time of extubation. The primary observation indexes were $P_{ET}CO_2$ and $PaCO_2$ in each group at 30 min of extubation. The secondary observation indexes were PaO_2, SpO_2, and RR in each group.

1.4 Statistics Methods

SPSS 26.0 software was used to analyze the data. Measurement data conforming to normal distribution were expressed by $\bar{x}\pm s$, and comparisons were made using one-way ANOVA and *SNK-q* test for two-by-two comparisons. Count data were expressed as cases (%) and compared using the χ^2 test. Pearson correlation analysis was performed for $P_{ET}CO_2$ and $PaCO_2$ data. $P<0.05$ was considered a statistically significant difference.

2 Results

2.1 Comparison of clinical data

No patients were excluded from the trial, and a total of 120 patients were included in the study. The differences in the general data, past history, surgical site, and perioperative data of the three groups of patients were not statistically significant ($P>0.05$). **[Table 1]**

Tab.1 Comparison of clinical data among three groups (n=40, $\bar{x}\pm s$)

Item	Group L	Group M	Group H	χ^2/F value	P value
General information					
Male/Female (case)	25/15	22/18	27/13	1.340	0.512
Age (years, $\bar{x}\pm s$)	53.3±10.5	53.9±7.8	51.0±8.7	1.139	0.323
BMI (kg/m^2, $\bar{x}\pm s$)	24.1±2.9	24.0±3.6	24.9±3.3	0.905	0.407
ASA II/III (case)	36/4	33/7	31/9	2.280	0.320
Past history [cases (%)]					
Hypertension	8 (20.0)	7 (17.5)	6 (15.0)	0.346	0.841
Diabetes	4 (10.0)	5 (12.5)	3 (7.5)	0.556	0.758
History of radiotherapy	6 (15.0)	5 (12.5)	6 (15.0)	0.137	0.934
Smoking history	4 (10.0)	5 (12.5)	4 (10.0)	0.173	0.917
Drinking history	1(2.5)	2 (5.0)	2 (5.0)	0.417	0.812
Surgical history	4 (10.0)	6 (15.0)	5 (12.5)	0.457	0.796
Perioperative information					
Luminal/open (case)	13/27	9/31	10/30	1.108	0.575
Replenishment volume (ml, $\bar{x}\pm s$)	2,050±516	1,988±572	1,888±348	1.122	0.329
Blood transfusions [case (%)]	6 (15.0)	5 (12.5)	2 (5.0)	2.309	0.428
Bleeding volume (mL, $\bar{x}\pm s$)	275±87	298±98	293±99	0.651	0.523
Urine volume (mL, $\bar{x}\pm s$)	325±111	356±106	332±96	0.968	0.383
Surgical time (min, $\bar{x}\pm s$)	148±65	142±58	146±67	0.093	0.912
Extubation time (min, $\bar{x}\pm s$)	38.6±13.6	38.3±13.4	37.2±12.0	0.128	0.880

2.2 Comparison of $P_{ET}CO_2$, $PaCO_2$, PaO_2, SpO_2 and RR among three groups

At 30 min of extubation, the differences between the three groups $P_{ET}CO_2$, $PaCO_2$, and RR were not statistically significant (P>0.05). PaO_2 and SpO_2 in group L were significantly lower than that in group M and group H, and the differences were statistically significant (P<0.05). **[Table 2]**

Tab.2 Comparison of P_{ET} CO2, PaCO2, PaO_2 , SpO_2 and RR among three groups (n=40, $\bar{x}\pm s$)

Indicators	Group L	Group M	Group H	F value	P value
$PaCO_2$ (mmHg)	42.58±3.50	41.53±3.43	41.05±3.54	2.01	0.139
$P_{ET}CO_2$ (mmHg)	40.68±3.03	40.10±3.48	40.03±4.00	0.41	0.665
PaO_2 (mmHg)	109.68±29.48^{ab}	150.35±44.65	169.40±51.30	20.41	<0.001
SpO_2 (%)	98.58±1.68^{ab}	99.40±1.15	99.50±1.11	5.686	0.004
RR (beats/min)	14.53±3.11	14.63±3.54	14.50±4.30	0.014	0.987

Note:^{a} P<0.05 compared with group H;^{b} P<0.05 compared with group M.

2.3 Correlation analysis between $P_{ET}CO_2$ and $PaCO_2$

Pearson correlation analysis was performed between $P_{ET}CO_2$ and $PaCO_2$ in each group, and there was a positive correlation between $P_{ET}CO_2$ and $PaCO_2$ in group L, group M, and group H (r=0.931, 0.878, 0.838, P<0.01).

3 Discussion

Clinically, to avoid hypoxemia after removal of the tracheal tube in patients under general anesthesia, oxygen is usually administered continuously via nasal cannula, with an oxygen flow rate of no more than 6 L/min[14]. The PACU is a high-incidence site for airway adverse events, and residuals of opioids, skeletal and muscular relaxants, benzodiazepines, and other sedative-hypnotic medications can increase the risk of postoperative hypoventilation and respiratory depression. Kawanishi *et al.*[15] found that, among all the sites of adverse airway events, the probability of occurrence in the PACU was 16%, and about 1/4 of the adverse airway events occurred at the end of anesthesia or in the PACU. Anesthesiologists in the PACU mainly rely on the SpO_2 to identify hypoxemia and airway obstruction, but the SpO_2 is poorly sensitive and has a lag, which poses a risk to anesthesia management[16]. It has been found that during procedural sedation, SpO_2 maintains more than 90% during severe hypoventilation lasting 90 seconds. However, when oxygen reserves are depleted, SpO_2 decreases rapidly, and hypoxia occurs[17].

Hypoxia in PACU patients usually occurs because of inadequate ventilation, CO_2 retention, and airway obstruction, so monitoring $PaCO_2$, which reflects changes in ventilatory function, is more critical than SpO_2[18]. $PaCO_2$ is the gold standard for reflecting a patient's ventilatory function, but it requires arterial blood gas analysis, which is invasive and cannot be measured continuously. Under normal conditions, $PaCO_2$ strongly correlates with $P_{ET}CO_2$, and CO_2 diffuses quickly between the alveoli and the blood and is excreted at the end of the respiratory cycle. The difference between the two is minimal, usually ranging from 2 to 5 mmHg, so PETCO2 is indirectly used to measure $PaCO_2$[19]. $P_{ET}CO_2$ monitoring has the advantages of easy operation, non-invasive, and real-time dynamic monitoring, which is currently widely used in clinical anesthesia. The traditional bypass $P_{ET}CO_2$ monitoring can measure the partial pressure of CO_2 in the respiratory circuit during mechanical ventilation and display it as carbon dioxide tracings. However, it does not apply to patients who are breathing spontaneously after removing the endotracheal tube in the PACU. Moreover, the traditional bypass $P_{ET}CO_2$ monitoring requires a large volume of gas sampling, a high sampling flow rate, a long response time, the need for filtration, poor accuracy, and the need to be equipped with an accumulation cup to prevent water vapor from blocking the sampling tubes.

The new micro-bypass P_{ET} CO_2 monitoring device has a uniquely designed sampling line to collect and measure the partial pressure of CO_2 in the exhaled breath of spontaneously breathing patients through the nose, with a small spectral range, without filtering, and with a requirement for gas samples as low as 15 µL, a lower sampling flow rate (50 mL/min), and a more sensitive recognition of apnea and other events.[20] Meanwhile, a drying tube that can adsorb condensate in the sample line to prevent water vapor from clogging the line, thus eliminating the need for a water collection cup. Micro-bypass $P_{ET}CO_2$ monitoring is commonly used during painless endoscopy[4,17,21]. A study of 150 patients undergoing percutaneous gastrostomy found that airway interventions based on micro-bypass $P_{ET}CO_2$ monitoring reduced the incidence of hypoxemia from 57% to 28%[17]. A meta-analysis of nine clinical trials comprising 3,088 patients showed that $P_{ET}CO_2$ monitoring significantly reduced the incidence of hypoxemia and severe hypoxemia during painless endoscopy. However, there are fewer studies on the use of $P_{ET}CO_2$ monitoring in post-extubation patients within the PACU, and there is a lack of studies on the relevance of $P_{ET}CO_2$ and $PaCO_2$.

The results of this study showed that the PaO_2 and SpO_2 of patients in the 2 L/min group were significantly lower than those in the 4 L/min group and the 6 L/min group, and the difference between the three groups of $PaCO_2$ and $P_{ET}CO_2$ were not statistically significant. However, the micro-bypass flow $P_{ET}CO_2$ and $PaCO_2$ were highly correlated at 30 min after extubation, which indicated that the micro-bypass flow $P_{ET}CO$ could be more accurately reflected the PaCO of the patient's body as the correlation decreased with the increase in inhaled oxygen flow, and it was speculated that the reason might be the higher flow of oxygen therapy. It is also found that the correlation between $P_{ET}CO_2$ and $PaCO_2$ decreases with the increase of inhaled oxygen flow rate. It is hypothesized that the reason may be that when the oxygen therapy flow rate is higher, the gas collected by the sampling tube is diluted by the gas of higher oxygen therapy flow rate, which leads to the increase of the difference between $P_{ET}CO_2$ and $PaCO_2$.

There are some shortcomings in this study. First, influenced by patient turnover in the PACU, the observation point was chosen to be 30 min after removal of the endotracheal tube, and the relevance of more time points is unclear. Second, the inclusion of this study was for adults with normal lung function, and the clinical application in patients with high rates of secondary intubation, such as chronic obstructive pulmonary disease, old age, obesity, coronary artery disease, and thoracic surgery, needs to be further explored.

In conclusion, the microparasite P_{ET} CO_2 monitoring device has good applicability in patients after removal of endotracheal tube in PACU, and the micro-parasite $P_{ET}CO_2$ maintains a high correlation with $PaCO_2$ at all oxygen flow rates, with the highest correlation at a flow rate of 2 L/min, which can be used as an important reference to evaluate the $PaCO_2$ data.

Conflict of interest None

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· 论 著 ·

全身麻醉患者拔除气管导管后微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 的相关性

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摘要：目的 探讨全身麻醉患者拔除气管导管后微旁流呼气末二氧化碳分压（$P_{ET}CO_2$）与动脉血二氧化碳分压（$PaCO_2$）的相关性。**方法** 选择江苏省肿瘤医院 2021 年 1 月至 5 月择期行腹部手术的患者 120 例，采取随机数字表法将患者分为 3 组，每组 40 例，分别经鼻导管不同流量吸氧，低流量组（L 组）2 L/min，中流量组（M 组）4 L/min和高流量组（H 组）6 L/min。在拔除气管导管 30 min 时记录 $P_{ET}CO_2$ 数值并抽取动脉血测量 $PaCO_2$，Pearson 法分析 $P_{ET}CO_2$ 与 $PaCO_2$ 的相关性。**结果** 拔管 30 min 时，三组 $P_{ET}CO_2$、$PaCO_2$、RR 差异无统计学意义（$P>0.05$）；L 组 PaO_2和 SpO_2均显著低于 M 组和 H 组（$P<0.05$）。L 组、M 组、H 组微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 均呈高度相关（$r=0.931$、0.878、0.838，$P<0.01$），二者的相关性随着氧流量的升高而降低。**结论** PACU 内全身麻醉患者拔除气管导管后使用微旁流 $P_{ET}CO_2$ 监测时，在 2～6 L/min 的氧流量下微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 均保持高度相关性，可作为评估 $PaCO_2$ 的重要参考。

关键词： 二氧化碳描记术；氧吸入疗法；肺通气；呼气末二氧化碳分压；动脉血二氧化碳分压
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Correlation between microstream $P_{ET}CO_2$ and $PaCO_2$ in patients with general anesthesia after tracheal catheter removal

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Abstract: Objective To evaluate the correlation between microstream partial pressure of end-tidal carbon dioxide ($P_{ET}CO_2$) and arterial partial pressure of carbon dioxide ($PaCO_2$) in patients with general anesthesia after tracheal catheter removal. **Methods** A total of 120 patients in Jiangsu Cancer Hospital undergoing abdominal operation under general anesthesia were selected and randomly divided into 3 groups, with 40 patients in each group. Each group received oxygen through nasal catheter at different flow rates: group L (2 L/min), group M (4 L/min) and group H (6 L/min). After 30 min of tracheal catheter removal, the value of $P_{ET}CO_2$ was recorded and arterial blood was drawn to measure $PaCO_2$, and the correlation between $P_{ET}CO_2$ and $PaCO_2$ was analyzed by Pearson. **Results** At 30 min of extubation, the differences in $P_{ET}CO_2$, $PaCO_2$, and RR among the three groups were not statistically significant ($P>0.05$); PaO_2 and SpO_2 in group L were significantly lower than those in groups M and H ($P<0.05$). There was a high correlation between microstream $P_{ET}CO_2$ and $PaCO_2$ in group L, M and H ($r=0.931$, 0.878 and 0.838, $P<0.01$), and the correlation coefficients decreased with the increase of oxygen flow. **Conclusion** When microstream $P_{ET}CO_2$ is used to monitor patients under general anesthesia in PACU after tracheal catheter removal, there is a high correlation between $P_{ET}CO_2$ and $PaCO_2$ at 2-6 L/min oxygen flow, which can be used as an important reference for the evaluation of $PaCO_2$.
Keywords: Capnography; Oxygen inhalation therapy; Pulmonary ventilation; Partial pressure of end-tidal carbon

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dioxide; Arterial partial pressure of carbon dioxide
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呼气末二氧化碳分压($P_{ET}CO_2$)是指呼气终末期呼出的混合肺泡气中所含二氧化碳分压。二氧化碳描记图可连续记录呼出二氧化碳气体的压力并用图像形式表现,因其采集简便且可实时获取数据,在临床麻醉中已作为一项常规监测指标来评价患者的通气功能、循环功能、肺血流、肺泡通气质量、呼吸回路的通畅度等[1-4]。临床工作中常用 $P_{ET}CO_2$ 粗略估计动脉血二氧化碳分压($PaCO_2$)[5-6]。早在 2015 年,就有指南建议,对于有气管导管、声门上气道装置或深度镇静的患者,在麻醉恢复期应进行 $P_{ET}CO_2$ 监测,直到患者从麻醉中完全恢复[7-8]。目前对于麻醉后监测治疗室(PACU)中的患者,在机械通气时通常监测 $P_{ET}CO_2$,但拔除气管导管后很少监测 $P_{ET}CO_2$,然而临床实践表明全麻患者拔除气管导后常因麻醉药物残余、疼痛、气道分泌物等发生呼吸抑制,甚至可能引起严重低氧血症、二次插管等多项不良事件[9-10]。多项研究报道微旁流 $P_{ET}CO_2$ 监测用于无痛内镜、数字减影血管造影等非插管镇静患者中可早识别通气异常,并通过干预减少低氧血症的发生[11-13]。但其是否适用于 PACU 内拔管后患者尚不清楚,且尚缺乏微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 相关性研究。因此本研究拟使用新型的微旁流 $P_{ET}CO_2$ 监测设备(柯惠 Capnostream™ 20_P 床边监护仪,规格:CS08652-02)对 PACU 内全麻恢复期拔管后的患者进行监测,并分析微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 的相关性。

1　资料及方法

1.1　一般资料　本研究经江苏省肿瘤医院伦理委员会批准(伦理审批号:2021 技-012),患者或家属均签署知情同意书。选择江苏省肿瘤医院 2021 年 1 月至 5 月择期行腹部手术的患者 120 例,采取随机数字表法将患者分为低流量组(L 组)、中流量组(M 组)和高流量组(H 组),每组 40 例。(1) 纳入标准:① 美国麻醉医师协会(ASA)分级Ⅱ或Ⅲ级;② 年龄 18~64 岁;③ BMI<28 kg/m^2。(2) 排除标准:① 术前并存严重心肺疾病;② 颌面部解剖明显异常;③ 计划术后转入 ICU 治疗。(3) 剔除标准:① 出现手术意外(如大出血等);② 苏醒延迟或恢复期躁动;③ 非计划转入 ICU 治疗;④ 患者或家属要求退出试验。

1.2　*方法*

1.2.1　麻醉方法　所有患者均无麻醉前用药,入手术室后常规监测血压、心率、心电图、脉搏血氧饱和度(SpO_2),局麻下行桡动脉穿刺置管测压。以咪达唑仑 0.02~0.05 mg/kg、舒芬太尼 0.3~0.5 μg/kg、丙泊酚 1~2 mg/kg、顺式阿曲库铵 0.2 mg/kg 行麻醉诱导。持续静脉泵注丙泊酚 4~8 mg/(kg·h)、瑞芬太尼 0.1~0.2 μg/(kg·min)、右美托咪啶 0.2~0.4 μg/(kg·h)和顺式阿曲库铵 0.1~0.15 mg/(kg·h)进行维持,维持 Narcotrend指数(Narcotrend 脑电意识深度监测系统,德国)在 D_1~E_0(27~56)之间。机械通气采用容量控制模式,潮气量设置为 6~8 mL/kg(理想体重),呼吸频率(RR)为 12~16 次/min,吸呼比为 1∶2,吸入氧浓度为 60%,调整呼吸参数使 $P_{ET}CO_2$ 维持在 35~45 mmHg,SpO_2 维持在 95%以上。术毕进入 PACU 继续监护治疗,使用全凭静脉自控镇痛。

1.2.2　拔管条件　拔除气管导管标准为:(1) 患者清醒,呼之能应;(2) 呛咳、吞咽反射恢复;(3) 头能持续抬离枕头 5 s 以上;(4) 血流动力学稳定;(5) 呼吸平稳,呼吸频率 10~20 次/min,$P_{ET}CO_2 \leq 45$ mmHg。由 PACU 内经验丰富的麻醉医生评估后拔除气管导管。

1.2.3　分组处理　L 组、M 组和 H 组在拔除气管导管后经鼻导管吸氧流量分别为 2、4、6 L/min,同时采用经鼻导管微旁流式 $P_{ET}CO_2$ 监测设备持续监测 $P_{ET}CO_2$,并在拔管 30 min 时抽取动脉血测量动脉血氧分压(PaO_2)和 $PaCO_2$。在整个研究过程中,受试者和进行数据采集的研究员无法获知具体分组和吸氧流量,待试验完成后进行揭盲。

1.3　*观察指标*　(1) 术前一般资料,包括性别、年龄、BMI、ASA 分级、既往史(高血压、糖尿病、放化疗史、吸烟史、饮酒史、手术史);(2) 围术期资料,包括手术类别(腔镜/开放)、手术部位、补液量、是否输血、出血量、尿量、手术时间、拔管时间。主要观察指标为拔除气管导管 30 min 时各组 $P_{ET}CO_2$ 与 $PaCO_2$;次要观察指标为各组 PaO_2、SpO_2、RR。

1.4　*统计学方法*　采用 SPSS 26.0 软件分析数据。符合正态分布的计量资料采用 $\bar{x}\pm s$ 表示,比较使用单因素方差分析及两两比较的 SNK-q 检验;计数资料以例(%)表示,比较采用 χ^2 检验。对 $P_{ET}CO_2$ 与 $PaCO_2$ 资料进行 Pearson 相关性分析。$P<0.05$ 为差异有统计学意义。

2　结　果

2.1　*临床资料比较*　试验中无患者被剔除,共 120

例患者纳入研究，三组患者一般资料、既往史、围术期资料等差异无统计学意义(P>0.05)。见表 1。

2.2　三组 $P_{ET}CO_2$、$PaCO_2$、PaO_2、SpO_2 和 RR 比较　拔管 30 min 时，三组 $P_{ET}CO_2$、$PaCO_2$、RR 差异无统计学意义(P>0.05)；L 组 PaO_2 和 SpO_2 均显著低于 M 组和 H 组，差异有统计学意义(P<0.05)。见表 2。

2.3　$P_{ET}CO_2$ 与 $PaCO_2$ 相关性分析　对各组 $P_{ET}CO_2$ 与 $PaCO_2$ 进行 Pearson 相关性分析，L 组、M 组和 H 组 $P_{ET}CO_2$ 与 $PaCO_2$ 均呈正相关(r = 0.931、0.878、0.838, P<0.01)。

表 1　三组临床资料比较　(n=40)

Tab. 1　Comparison of clinical data among three groups　(n=40)

项目	L 组	M 组	H 组	χ^2/F 值	P 值
一般资料					
男/女 (例)	25/15	22/18	27/13	1.340	0.512
年龄 (岁, $\bar{x}\pm s$)	53.3±10.5	53.9±7.8	51.0±8.7	1.139	0.323
BMI (kg/m^2, $\bar{x}\pm s$)	24.1±2.9	24.0±3.6	24.9±3.3	0.905	0.407
ASA Ⅱ/Ⅲ级 (例)	36/4	33/7	31/9	2.280	0.320
既往史[例(%)]					
高血压	8(20.0)	7(17.5)	6(15.0)	0.346	0.841
糖尿病	4(10.0)	5(12.5)	3(7.5)	0.556	0.758
放化疗史	6(15.0)	5(12.5)	6(15.0)	0.137	0.934
吸烟史	4(10.0)	5(12.5)	4(10.0)	0.173	0.917
饮酒史	1(2.5)	2(5.0)	2(5.0)	0.417	0.812
手术史	4(10.0)	6(15.0)	5(12.5)	0.457	0.796
围术期资料					
腔镜/开放 (例)	13/27	9/31	10/30	1.108	0.575
补液量 (mL, $\bar{x}\pm s$)	2 050±516	1 988±572	1 888±348	1.122	0.329
输血 [例(%)]	6(15.0)	5(12.5)	2(5.0)	2.309	0.428
出血量 (mL, $\bar{x}\pm s$)	275±87	298±98	293±99	0.651	0.523
尿量 (mL, $\bar{x}\pm s$)	325±111	356±106	332±96	0.968	0.383
手术时间 (min, $\bar{x}\pm s$)	148±65	142±58	146±67	0.093	0.912
拔管时间 (min, $\bar{x}\pm s$)	38.6±13.6	38.3±13.4	37.2±12.0	0.128	0.880

表 2　三组 $P_{ET}CO_2$、$PaCO_2$、PaO_2、SpO_2 和 RR 比较　(n=40, $\bar{x}\pm s$)

Tab. 2　Comparison of $P_{ET}CO_2$, $PaCO_2$, PaO_2, SpO_2 and RR among three groups　(n=40, $\bar{x}\pm s$)

指标	L 组	M 组	H 组	F 值	P 值
$PaCO_2$(mmHg)	42.58±3.50	41.53±3.43	41.05±3.54	2.010	0.139
$P_{ET}CO_2$(mmHg)	40.68±3.03	40.10±3.48	40.03±4.00	0.410	0.665
PaO_2(mmHg)	109.68±29.48^{ab}	150.35±44.65	169.40±51.30	20.324	<0.001
SpO_2(%)	98.58±1.68^{ab}	99.40±1.15	99.50±1.11	5.686	0.004
RR(次/min)	14.53±3.11	14.63±3.54	14.50±4.30	0.014	0.987

注：与 H 组比较，^aP<0.05；与 M 组比较，^bP<0.05。

3　讨　论

临床上为了避免全麻患者拔除气管导管后发生低氧血症，通常经鼻导管持续吸氧，氧流量不高于 6 L/min[14]。PACU 是气道不良事件的高发场所，阿片类药物、肌松剂、苯二氮䓬类及其他镇静催眠药物的残留均可增加术后通气不足、呼吸抑制的风险。Kawanishi 等[15]研究发现，在所有气道不良事件的发生场所中，PACU 中发生的概率为 16%，约 1/4 的气道不良事件发生在麻醉结束时或 PACU 内。PACU 内麻醉医生主要依靠 SpO_2 来识别低氧血症和气道梗阻，但是 SpO_2 灵敏性差、具有滞后性，给麻醉管理带来风险[16]。研究发现在程序性镇静期间，严重的通气不足持续 90 s 时 SpO_2 仍能维持 90%以上，但当氧储备耗尽时，SpO_2 下降十分迅速，机体发生缺氧[17]。

PACU 内的患者发生缺氧的原因通常为通气不足、CO_2 潴留及气道梗阻等，因此监测反映通气功能变化的 $PaCO_2$ 比 SpO_2 更为重要[18]。$PaCO_2$ 是反映患者通气功能的金标准，但需行动脉血气分析，有创且无法连续测量。正常情况下 $PaCO_2$ 与 $P_{ET}CO_2$ 有很强的相关性，CO_2 在肺泡和血液之间很容易扩散，并在呼吸周期结束时排出，两者差异非常小，通常在 2~5 mmHg，因此 $P_{ET}CO_2$ 通常用作间接测量 $PaCO_2$ 的工具[19]。传统的旁流式 $P_{ET}CO_2$ 监测可测量患者机械通气期间呼吸回路中的 CO_2 分压，并以二氧化碳描记图的形式显示，但不适用于 PACU 内拔除气管导管后自主呼吸的患者，并且传统的旁流式 $P_{ET}CO_2$ 监测所需的气体采样量较大、采样流速偏大、反应时间长、需要滤波、精确性较差且必须配备积水杯以防止水汽阻塞采样管。

新型的微旁流 $P_{ET}CO_2$ 监测设备具备独特设计的采样管路，可经鼻采集并测量自主呼吸患者呼出气中 CO_2 分压，且光谱范围小，无需滤波，对气体样本的需求量可低至 15 μL，采样流速更小(50 mL/min)，对于呼吸暂停等事件识别更灵敏[20]，同时干燥管可对采样管中的冷凝水进行吸附，防止水蒸气阻塞管路，故无需配备积水杯。微旁流 $P_{ET}CO_2$ 监测常见于无痛内镜诊疗过程中[4,17]。有研究对 150 例经皮内镜下胃造瘘术患者研究发现，基于微旁流 $P_{ET}CO_2$ 监测的气道干预使低氧血症的发生率从 57%下降到 28%[17]。一项纳入 9 个临床试验，包含 3 088 例患者的荟萃分析显示，$P_{ET}CO_2$ 监测可显著降低无痛内镜检查时低氧血症的发生率[21]。但在 PACU 内，$P_{ET}CO_2$ 监测应用于拔管后患者的相关研究较少。

本研究结果显示，经鼻导管吸氧 2 L/min 组患者 PaO_2 和 SpO_2 显著低于 4 L/min 组和 6 L/min 组，三组 $PaCO_2$、$P_{ET}CO_2$ 差异无统计学意义。但微旁流 $P_{ET}CO_2$ 与 $PaCO_2$ 在拔管 30 min 时均呈高度相关，表明微旁流 $P_{ET}CO_2$ 应用于全麻拔管后患者可较为精准地反映患者 $PaCO_2$。同时研究发现 $P_{ET}CO_2$ 与 $PaCO_2$ 的相关性随吸入氧流量的升高而降低，推测原因可能为氧疗流量较高时，采样管采集的气体被较高的氧疗

流量气体稀释，导致 $P_{ET}CO_2$ 与 $PaCO_2$ 差异增大。

本研究仍存在不足之处。第一，受 PACU 内患者周转的影响，观察点选择在拔除气管导管后 30 min，更多时间点的相关性尚不明确。第二，研究对象为肺功能正常的成年人，在慢性阻塞性肺疾病、老龄、肥胖、冠心病、胸科手术等二次插管率较高的患者中的临床应用需要进一步探索。

综上所述，微旁流 $P_{ET}CO_2$ 监测设备在 PACU 拔除气管导管后的患者具有良好适用性，在各种氧流量下微旁流 $P_{ET}CO_2$ 均与 $PaCO_2$ 保持高度相关性，其中 2 L/min 流量下相关性最高，可作为评估 $PaCO_2$ 数据的重要参考。

利益冲突　无

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