·临床研究·

经皮二氧化碳测量在腹膜后腹腔镜泌尿外科手术中的准确性:一项前瞻性观察性研究

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[摘　要]　**目的:**比较呼气末二氧化碳分压(end-tidal carbon dioxide partial pressure,$P_{ET}CO_2$)和经皮二氧化碳分压(transcutaneous carbon dioxide partial pressure,$P_{TC}CO_2$)预测泌尿外科腹膜后腹腔镜手术患者动脉血二氧化碳分压(arterial carbon dioxide pressure,P_aCO_2)的准确性。**方法:**选择全身麻醉下行腹膜后腹腔镜泌尿外科手术患者50例,于气腹前及气腹后30、60、90 min分别测定P_aCO_2、$P_{ET}CO_2$、$P_{TC}CO_2$。计算P_aCO_2-$P_{ET}CO_2$和P_aCO_2-$P_{TC}CO_2$的差值。对P_aCO_2与$P_{ET}CO_2$、P_aCO_2与$P_{TC}CO_2$进行相关性和回归分析。采用Bland-Altman分析评价P_aCO_2与其他两个指标的一致性。**结果:**P_aCO_2-$P_{ET}CO_2$和P_aCO_2-$P_{TC}CO_2$的绝对差值分别为(13.20±4.43)mmHg和(4.35±2.56)mmHg(P < 0.05)。P_aCO_2与$P_{ET}CO_2$的相关系数为0.79(r^2=0.62,P < 0.001),与$P_{TC}CO_2$的相关系数为0.91(r^2=0.83,P < 0.001)。P_aCO_2与$P_{ET}CO_2$的95%一致性界限为4.53~21.88 mmHg,与$P_{TC}CO_2$的95%一致性界限为−3.18~10.48 mmHg。**结论:**$P_{TC}CO_2$监测可提高评估患者腹膜后腹腔镜泌尿外科手术中P_aCO_2的准确性。

[关键词]　经皮二氧化碳;腹膜后腹腔镜;泌尿外科手术;血气监测;呼气末二氧化碳
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The accuracy of transcutaneous carbon dioxide measurement in retroperitoneoscopic urologic surgery: a prospective observational study

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[**Abstract**]　**Objective:** To compare the accuracy of end-tidal carbon dioxide partial pressure ($P_{ET}CO_2$) and transcutaneous carbon dioxide partial pressure ($P_{TC}CO_2$) in predicting arterial carbon dioxide pressure (P_aCO_2) in patients undergoing retroperitoneoscopic urologic surgery. **Methods:** Fifty patients undergoing retroperitoneoscopic urologic surgery under general anesthesia were included. Values of P_aCO_2, $P_{ET}CO_2$, and $P_{TC}CO_2$ were measured before and 30, 60, 90 min after insufflation. The differences between P_aCO_2-$P_{ET}CO_2$ and P_aCO_2-$P_{TC}CO_2$ were calculated. Correlation and regression analysis were conducted between P_aCO_2 and $P_{ET}CO_2$, as well as between P_aCO_2 and $P_{TC}CO_2$. Bland-Altman analysis was used to assess the agreement between P_aCO_2 and the other two variables. **Results:** The absolute differences of P_aCO_2-$P_{ET}CO_2$ and P_aCO_2-$P_{TC}CO_2$ were (13.20 ± 4.43) mmHg and (4.35 ± 2.56) mmHg, respectively (P < 0.05). The correlation coefficient between P_aCO_2 and $P_{ET}CO_2$ was 0.79 (r^2=0.62, P < 0.001), and between P_aCO_2 and $P_{TC}CO_2$ was 0.91 (r^2=0.83, P < 0.001). The 95% limits of agreement between P_aCO_2 and $P_{ET}CO_2$ were 4.53 to 21.88 mmHg and between P_aCO_2 and $P_{TC}CO_2$ were −

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3.18 to 10.48 mmHg. **Conclusion:** $P_{TC}CO_2$ monitoring improves the accuracy of estimating P_aCO_2 in patients undergoing retroperitoneoscopic urologic surgery.

［**Key words**］ transcutaneous carbon dioxide; retroperitoneoscopic; urologic surgery; blood gas monitoring; end-tidal carbon dioxide

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Retroperitoneal laparoscopic（RPL）surgery，utilizing retroperitoneal carbon dioxide（CO_2）insufflation，is currently established as a safe and reliable technique for specific urologic procedures. Although arterial blood gas（ABG）remains the golden standard for monitoring arterial blood carbon dioxide partial pressure（P_aCO_2），it is invasive and lacks consistency. The frequent need for ABG analysis also contributes significantly to iatrogenic anemia，particularly in critically ill patients and infants.

End-tidal carbon dioxide（$P_{ET}CO_2$）is a commonly used noninvasive method for predicting P_aCO_2 in mechanical ventilated patients. However，the accuracy of $P_{ET}CO_2$ can be influenced by various factors such as surgical position，as well as severe cardiovascular or pulmonary diseases. Another noninvasive method for monitoring CO_2 partial pressure is transcutaneous carbon dioxide partial pressure（$P_{TC}CO_2$）. This method has been widely accepted and is reported to provide better accuracy in predicting P_aCO_2 compared to $P_{ET}CO_2$ under many circumstances during laparoscopic surgery. In a study by XUE et al.[1]，in patients undergoing prolonged pneumoperitoneum laparoscopic surgery，88% and 17% of the samples showed a clinically acceptable difference（≤ 5mmHg）between $P_{TC}CO_2$-P_aCO_2 and $P_{ET}CO_2$-P_aCO_2，respectively.

Retroperitoneoscopic surgery，a minimally invasive surgical technique used for treating urinary system conditions，involves operating in the space behind the peritoneal cavity，which is enclosed by the posterior abdominal wall. This area contains loose connective tissue and adipose tissue and spans from the neck to the pelvis. During retroperitoneoscopic procedures，a surgical cavity is created by separating the peritoneum and posterior abdominal wall. However，this blunt dissection leads to significant surgical trauma，potentially results in higher CO_2 absorption compared to intraperitoneal laparoscopic techniques[2]. Despite this，there is inconsistency in CO_2 absorption between intraperitoneal and retroperitoneal pneumoperitoneum. KADAM et al.[3]found that CO_2 absorption does not depend on the route of surgery. They found no significant difference in CO_2 absorption between laparoscopic and retroperitoneal nephrectomy，with only subcutaneous emphysema notably increasing CO_2 absorption. Similarly，NG et al.[4]suggested that retroperitoneoscopy does not exhibit higher CO_2 absorption compared to transperitoneal laparoscopy for renal or adrenal surgeries. However，in STREICH et al.'s study[5]，they discovered that the retroperitoneal approach results in greater CO_2 absorption than intraperitoneal insufflation in urologic surgeries.

Given this inconsistency，the aim of this study was to investigate the accuracy of two distinct CO_2 partial pressure monitoring techniques（$P_{TC}CO_2$ and $P_{ET}CO_2$）and their correlation with P_aCO_2 in patients undergoing retroperitoneoscopic surgery.

1　Materials and methods

1.1　Materials

This prospective observational study received approval from the Institutional Ethics Committee of the First Affiliated Hospital of Nanjing Medical University and was registered on www.ClinicalTrials.gov（NCT03226041）. Initially，patients who were classified as the American Society of Anesthesiologists（ASA）Ⅰ-Ⅲ and scheduled for retroperitoneoscopic urologic surgery were screened. Those with severe cardiovascular or respiratory diseases，such as coronary heart disease，chronic obstructive pulmonary disease（COPD），asthma，a history of smoking or lung surgery（lobectomy or simple wedge resection），and individuals with morbid obese［body mass index（BMI）≥ 30 kg/m^2］were excluded. Subsequently，written consent was obtained from each participant before the surgery.

1.2　Methods

1.2.1　Sample size

Based on our preliminary study，a sample size of 45 achieves 90% power to detect a mean of paired differences of 5.0 mmHg, with an estimated standard deviation of differences of 9.9 mmHg, at a significance level α of 0.05 using a paired *t*-test. Given the possibility of loss to follow-up, we increased the sample size by 10%, resulting in a required sample size of 50.

1.2.2 determination of $P_{TC}CO_2$ and $P_{ET}CO_2$

After entering the operating room, a 16-G intravenous (Ⅳ) catheter was inserted into the median cubital vein for fluid and drug administration, while a 20-G arterial catheter was cannulated in the non-operated radial artery for continuous blood pressure (BP) monitoring and ABG sampling. The arterial catheter was flushed with 500 mL of heparinized saline using a pressure bag. Standard monitoring including electrocardiogram (ECG), saturation of pulse oxygen (SpO_2), and arterial BP was performed for all patients before anesthesia, with these values recorded as baseline values. Anesthesia induction comprised propofol (1.5–2.5 mg/kg), fentanyl (2–4 μg/kg), and rocuronium (0.6 mg/kg). Following intubation, patients were ventilated with volume control ventilation (VCV) using 60% oxygen (2 L/min). The $P_{ET}CO_2$ values were maintained ideally between 35–45 mmHg by adjusting tidal volume, respiratory rate, and aspiration ratio (inspiratory∶expiratory, I∶E), with an upper limit of 50 mmHg allowed. $P_{ET}CO_2$ was measured by side stream spirometry (Mindray, BeneView T6, Shenzhen, China), while $P_{TC}CO_2$ was measured with the TCM-4 monitor (Radiometer, Copenhagen, Denmark). Before placement, calibration was performed by a trained author (LIU Shijiang) according to the manufacturer's recommendation. The electrode was then placed onto the patient's chest wall of the non-operated side, which was cleaned with alcohol to facilitate the adhesion of the disk to the skin, with the electrode working temperature set at 44 ℃. P_aCO_2 was determined using a blood gas/electrolyte analyzer (GEM premier 3000, Instrumentation Laboratory Co. MA 01730-2443, USA). Before ABG sampling, patients' hemodynamic was relatively stable for at least 5 min to ensure a stable P_aCO_2. $P_{TC}CO_2$ and $P_{ET}CO_2$ were recorded simultaneously with ABG sampling.

Anesthesia was maintained with propofol, sevoflurane, and remifentanil to limit the BP and heart rate (HR) fluctuations within 20% of baseline values. Patients requiring a vasopressor to maintain hemodynamic stability or experiencing a hemodynamic fluctuation exceeding 20% were excluded. Data collected before the use of a vasopressor or hemodynamic instability could still be used for analysis. Close communication was maintained with surgeons during the surgery. Patients were excluded if the peritoneum had been ruptured, but the data collected before peritoneal rupture was retained. Patient's temperature was continuously monitored and maintained above 36 ℃, while the room temperature was set at 23–25 ℃. The retroperitoneal CO_2 pressure was maintained at 12–15 mmHg during the surgery. P_aCO_2, $P_{ET}CO_2$, and $P_{TC}CO_2$ of each patient were measured at four time points: before CO_2 insufflation, 30, 60 and 90 min after CO_2 insufflation.

If $P_{ET}CO_2$ exceeded 50 mmHg during the surgery, adjustments could be made such as increasing respiratory rate, adjusting tidal volume, increasing the flow of fresh oxygen, reducing pneumoperitoneum pressure within the surgeon's acceptable range, or pausing the operation or closing the pneumoperitoneum if necessary to enhance CO_2 excretion and lower $P_{ET}CO_2$ levels.

1.3 Statistical analysis

Statistical analyses were performed using GraphPad 8.0 software (GraphPad Prism, La Jolla, California, USA). Quantitative data were presented as means ± standard deviation ($\bar{x} \pm s$) or median with interquartile range [$M(P_{25}, P_{75})$] depending on the type of distribution. A difference of ≤5 mmHg between $PaCO_2$ and $P_{ET}CO_2$, or between $PaCO_2$ and $P_{TC}CO_2$, was considered within the clinical acceptable range. Categorical variables, presented as frequencies (proportions) [n(%)], were analyzed using the *chi*-square test or Fisher's exact test as appropriate. Pearson correlation coefficient was employed to assess the correlation between $P_{ET}CO_2$ and P_aCO_2, as well as the correlation between $P_{TC}CO_2$ and P_aCO_2. Additionally, linear regression analysis was utilized to model and quantify these relationships. Bland-Altman analysis was used to compare the agreement between P_aCO_2 and $P_{ET}CO_2$, or between P_aCO_2 and $P_{TC}CO_2$. $P < 0.05$ is considered statistically significant.

2 Results

Ninety-seven patients were initially assessed for eligibility, of whom 31 were excluded due to severe complications, a history of surgery, or morbid obesity. Within the remaining 66 subjects, 6 were reluctant to participate and 10 were excluded because phenylephrine was used during anesthesia induction and surgery. Finally, 50 patients were included in this study. A detailed flowchart of participant enrollment was shown in ***Figure 1***. In addition, as shown in ***Table 1***, the 50 patients (16 women) have a mean age of (42.14 ± 14.42) years and a BMI of (23.34 ± 2.99) kg/m^2. Thirty-one underwent partial nephrectomy, while the rest underwent nephrectomy, urethroplasty, and renal cyst excision. The mean duration of CO_2 pneumoperitoneum was 91.42 (30.00–192.00) min.

The values of P_aCO_2, $P_{ET}CO_2$, and $P_{TC}CO_2$ were recorded at the following four time points: before, and 30, 60, 90 min after pneumoperitoneum. After excluding values with a $P_{ET}CO_2$ < 35 mmHg or > 50 mmHg, 157 samples were finally analyzed. As shown in ***Table 2***, the average level of P_aCO_2, $P_{ET}CO_2$, and $P_{TC}CO_2$ at each time point were presented. Either P_aCO_2, $P_{ET}CO_2$ or $P_{TC}CO_2$ increased and reached a plateau at 30–60 min, and slightly decreased at 90 min after pneumoperitoneum.

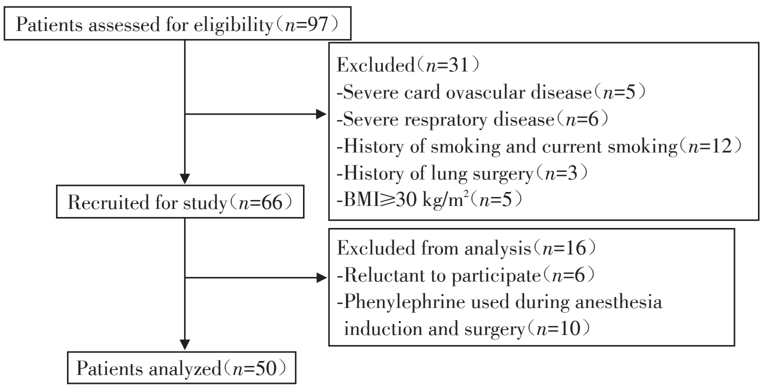

图1 参与者招募流程图

Figure 1 Flowchart of participant enrollment

表1 患者临床特征

Table 1 Clinical characteristics of the patients

Variable	Data
Female [n(%)]	16(32)
Age (years, $\bar{x} \pm s$)	42.14 ± 14.42
BMI (kg/m^2, $\bar{x} \pm s$)	23.34 ± 2.99
ASA physical status [n(%)]	
Ⅰ	8(16)
Ⅱ	40(80)
Ⅲ	2(4)
Indication [n(%)]	
Nephrectomy	12(24)
Partial nephrectomy	31(62)
Urethroplasty	4(8)
Renal cyst excision	3(6)
IAP (mmHg, $\bar{x} \pm s$)	13.52 ± 1.30
Operative time [min, M(P_{25}, P_{75})]	126.40(50.00, 248.00)
Pneumoperitoneum time [min, M(P_{25}, P_{75})]	91.42(30.00, 192.00)

BMI: body mass index; ASA: American Society of Anesthesiologists; IAP: intra-abdominal pressure.

The correlation analysis between P_aCO_2 and $P_{ET}CO_2$, as well as P_aCO_2 and $P_{TC}CO_2$, was performed at different time points or different $P_{ET}CO_2$ levels. As shown in ***Table 2 and 3***, a statistically significant correlation with P_aCO_2 was observed for both $P_{ET}CO_2$ and $P_{TC}CO_2$. Moreover, the correlation coefficient with P_aCO_2 was consistently greater for $P_{TC}CO_2$ compared to $P_{ET}CO_2$, whether detected at each time point or with $P_{ET}CO_2$ maintained at 35–40, 40–45, or 45–50 mmHg.

Furthermore, based on linear regression analysis, both $P_{ET}CO_2$ and $P_{TC}CO_2$ were closely correlated with P_aCO_2. The linear regression equations were as follows: $P_{ET}CO_2=0.60\times P_aCO_2+9.10$ ($r^2=0.62$, $P < 0.001$, ***Figure 2A***), $P_{TC}CO_2=1.07\times P_aCO_2-7.30$ ($r^2=0.83$, $P < 0.001$, ***Figure 2B***).

Additionally, the average P_aCO_2-$P_{ET}CO_2$ difference was (13.20 ± 4.43) mmHg, and the average P_aCO_2-$P_{TC}CO_2$ difference was (4.35 ± 2.56) mmHg ($P < 0.05$).

表2 不同时间点的 $P_{ET}CO_2$ 与 P_aCO_2、$P_{TC}CO_2$ 与 P_aCO_2 相关性分析

Table 2 The correlation analysis between $P_{ET}CO_2$ and P_aCO_2 or letween $P_{TC}CO_2$ and P_aCO_2 at different time points (mmHg, $\bar{x} \pm s$)

Time point	Value	r	P
Before pneumoperitoneum			
P_aCO_2	48.03 ± 3.53	–	–
$P_{ET}CO_2$	36.92 ± 2.29	0.45	0.005
$P_{TC}CO_2$	44.34 ± 4.26	0.81	< 0.001
30 min after pneumoperitoneum			
P_aCO_2	57.48 ± 6.15	–	–
$P_{ET}CO_2$	43.65 ± 4.33	0.70	< 0.001
$P_{TC}CO_2$	53.29 ± 7.80	0.90	< 0.001
60 min after pneumoperitoneum			
P_aCO_2	58.81 ± 5.91	–	–
$P_{ET}CO_2$	43.62 ± 3.94	0.64	< 0.001
$P_{TC}CO_2$	54.82 ± 7.04	0.85	< 0.001
90 min after pneumoperitoneum			
P_aCO_2	56.15 ± 6.72	–	–
$P_{ET}CO_2$	44.79 ± 5.88	0.78	< 0.001
$P_{TC}CO_2$	54.00 ± 9.10	0.91	< 0.001

Among all 157 samples, a difference ≤5 mmHg or ≤3 mmHg between P_aCO_2 and $P_{ET}CO_2$ was observed in 5(3.2%) and 1(0.6%) sample, respectively. However,

表3 不同 $P_{ET}CO_2$ 水平下 $P_{ET}CO_2$ 与 P_aCO_2、$P_{TC}CO_2$ 与 P_aCO_2 的相关性分析

Table 3 The correlation analysis between $P_{ET}CO_2$ and P_aCO_2 or between $P_{TC}CO_2$ and P_aCO_2 at different $P_{ET}CO_2$ levels (mmHg, $\bar{x} \pm s$)

Group	Values	r	P
35≤$P_{ET}CO_2$<40			
P_aCO_2	50.61 ± 4.96	–	–
$P_{ET}CO_2$	37.73 ± 1.91	0.64	< 0.001
$P_{TC}CO_2$	46.51 ± 5.94	0.88	< 0.001
40≤$P_{ET}CO_2$<45			
P_aCO_2	56.89 ± 4.49	–	–
$P_{ET}CO_2$	43.12 ± 1.39	0.50	< 0.001
$P_{TC}CO_2$	54.82 ± 7.04	0.75	< 0.001
45≤$P_{ET}CO_2$<50			
P_aCO_2	63.11 ± 6.20	–	–
$P_{ET}CO_2$	50.03 ± 2.08	0.42	0.010
$P_{TC}CO_2$	61.76 ± 6.31	0.85	< 0.001

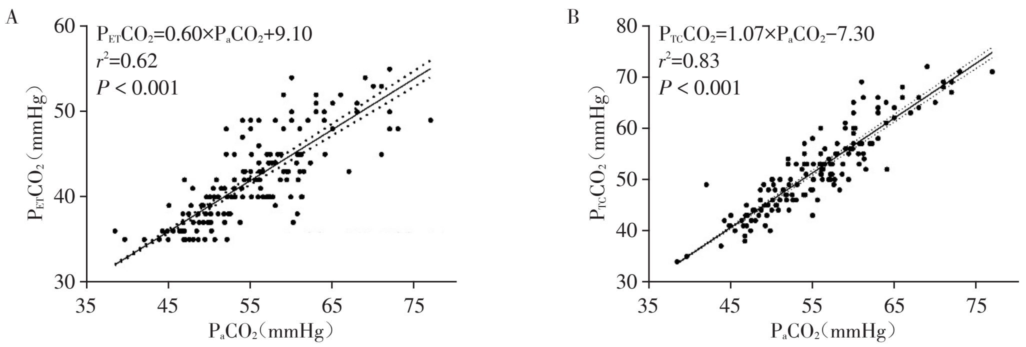

图2 泌尿外科腹膜后腹腔镜手术中 $P_{ET}CO_2$ 和 P_aCO_2(A)或 $P_{TC}CO_2$ 和 P_aCO_2(B)的相关性分析

Figure 2 Correlation analysis between $P_{ET}CO_2$ and P_aCO_2(A) or between $P_{TC}CO_2$ and P_aCO_2(B) during retroperitoneoscopic urologic surgery

a difference ≤5 mmHg or ≤3 mmHg between P_aCO_2 and $P_{TC}CO_2$ was recorded in 101 (64.3%) and 57 (36.3%) samples, respectively (P < 0.001). According to Bland-Altman analysis, the 95% limit of agreement (LOA) of P_aCO_2 versus $P_{ET}CO_2$ was 4.53 to 21.88 mmHg (***Figure 3A***) and P_aCO_2 versus $P_{TC}CO_2$ was − 3.18 to 10.48 mmHg (***Figure 3B***).

3 Discussion

Our results demonstrated that $P_{TC}CO_2$ estimated P_aCO_2 more accurately than $P_{ET}CO_2$ in patients undergoing retroperitoneoscopic urologic surgery. Of note, the correlation between P_aCO_2 and $P_{TC}CO_2$ was consistently higher than that between P_aCO_2 and $P_{ET}CO_2$ at all time points, even when $P_{ET}CO_2$ was maintained within the ranges of 35−40 mmHg, 40−45 mmHg, or 45−50 mmHg.

A difference of ≤ 5 mmHg between two measurements is generally considered clinically acceptable, indicating interchangeability. In the present study, the difference between P_aCO_2 and $P_{TC}CO_2$ was ≤5 mmHg in 101 out of 157 measurements (64.3%) whereas the difference between P_aCO_2 and $P_{ET}CO_2$ was ≤5 mmHg in

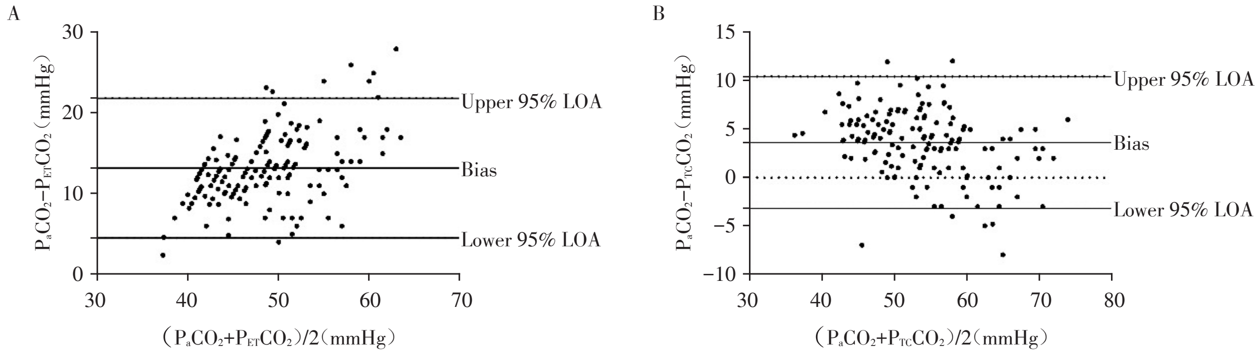

图3 $P_{ET}CO_2$和P_aCO_2（A）或$P_{TC}CO_2$和P_aCO_2（B）一致性的Bland-Altman图

Figure 3 Bland-Altman plots of agreement between $P_{ET}CO_2$ and P_aCO_2（A），or between $P_{TC}CO_2$ and P_aCO_2（B）

only 5 out of 157 measurements（3.2%）. Compared to other studies defining acceptable bias as ≤3 mmHg[6-8]，36.3% of $P_{TC}CO_2$ values and only 0.6% of $P_{ET}CO_2$ values fell within this threshold in our study. Our findings suggested that $P_{TC}CO_2$ showed a greater accuracy than $P_{ET}CO_2$ in predicting P_aCO_2，with more values within 3 mmHg or 5 mmHg of P_aCO_2. Additionally，the mean P_aCO_2 - $P_{ET}CO_2$ difference was（13.20 ± 4.43）mmHg（95%CI：4.53-21.88 mmHg）. In contrast，the mean P_aCO_2 - $P_{TC}CO_2$ difference was（4.35 ± 2.56）mmHg（95% CI：- 3.18 to 10.48 mmHg）. Taken together，these results indicate that $P_{TC}CO_2$ estimated P_aCO_2 more accurately than $P_{ET}CO_2$ in patients undergoing retroperitoneoscopic urologic surgery.

Retroperitoneoscopic surgery provides a minimally invasive approach to treating urinary system disease. The retroperitoneum refers to the space behind the peritoneal cavity，bounded by the posterior abdominal wall. This space is filled with adipose and loose connective tissue，extending from the neck to the pelvis，and it is highly vascularized. During the operation，extensive tissue dissection is required to create the retroperitoneal space，potentially increasing CO_2 absorption compared to intraperitoneal laparoscopy. Consequently，hypercarbia may occur.

Clinically，hypercapnia principally impacts the cerebrovascular and cardiovascular system. Elevated P_aCO_2 causes cerebral vasodilation and increases intracranial pressure despite autoregulatory mechanisms. Moreover，acute hypercapnia may increase the release of catecholamines due to β - adrenergic stimulation. This may be detrimental in procedures like retroperitoneoscopic adrenalectomy，especially for pheochromocytoma，as heightened catecholamine levels exacerbate hemodynamic instability. Given the intermittence of ABG analysis，a continuous，non-invasive method to accurately predict P_aCO_2 during retroperitoneoscopic surgery is necessary. $P_{TC}CO_2$ was found to be equivalent or even superior to $P_{ET}CO_2$ in predicting P_aCO_2 in different populations[9-11]. However，the correlation between $P_{TC}CO_2$ and P_aCO_2 remains unclear in retroperitoneoscopic surgery. In this study，P_aCO_2 and $P_{TC}CO_2$ showed a stronger correlation than P_aCO_2 and $P_{ET}CO_2$ across all subject groups（0.83 *vs*. 0.62）. Subgroup analysis revealed a declining correlation between $P_{ET}CO_2$ and P_aCO_2 as $P_{ET}CO_2$ rose from 35-40 mmHg to 45-50 mmHg（0.41 to 0.18）. In contrast，P_aCO_2 - $P_{TC}CO_2$ correlation remained high at 0.72 when $P_{ET}CO_2$ exceeded 45 mmHg. This indicates $P_{TC}CO_2$ monitoring may have greater accuracy and sensitivity for detecting hypercapnia than $P_{ET}CO_2$. In other studies，the correlation between P_aCO_2 and $P_{ET}CO_2$ values or between P_aCO_2 and $P_{TC}CO_2$ values was higher than those in the present study，especially at baseline. This difference may be attributed to hemodynamic fluctuations during anesthesia induction and positional changes，which increased the mismatch of the ventilation/perfusion（V/Q）ratio.

A patient position has a considerable influence on the accuracy of $P_{ET}CO_2$ monitoring. The lateral position often used in retroperitoneoscopic surgery can increase intrathoracic pressure and pulmonary pressures while decreasing venous return. Collectively，these effects reduce pulmonary blood flow，creating a mismatch between alveolar ventilation and perfusion. Thus，the difference between P_aCO_2 and $P_{ET}CO_2$ in lateral position was greater than those in other positions[12-13]. Furthermore, study had shown that $P_{TC}CO_2$ monitoring more accurately predicted P_aCO_2 than $P_{ET}CO_2$ monitoring in trendelenburg position [10]. Similarly, our study found more $P_{TC}CO_2$ than $P_{ET}CO_2$ values were within ≤3 mmHg or ≤5 mmHg of P_aCO_2. Whether the position affects $P_{TC}CO_2$ accuracy remains unclear, although tissue perfusion and electrode position can significantly affect accuracy[14-16]. Therefore, we chose the front chest wall in lateral position to ensure sufficient blood flow through the electrode.

In spite of the $P_{TC}CO_2$ can precisely estimate P_aCO_2, many technical factors can still affect the accuracy of $P_{TC}CO_2$ monitoring, including monitor factors (penetration of air bubbles, incorrect electrode positions, damage of electrode membranes, and inaccurate calibration, etc.) and patient factors (skin blood perfusion, skin thickness, edema, dehydration, vascular active drug and anoxic acidosis. etc.)[8, 17-18]. Heating electrodes can improve the reaction time, and increase local blood flow through capillary arterialization but reduces measurement accuracy. NISHIYAMA et al.[19] thought the electrodes should be heated to at least 43 ℃ to guarantee more accurate estimates of P_aCO_2 and P_aO_2. SϕRENSEN et al.[20] found that lower electrode temperature increases the system error of measured values in premature and neonates. However, higher temperatures increase skin burn risk. Hence, we chosed 44 ℃ $P_{ET}CO_2$ values of 35-50 mmHg based on our data.

In conclusion, $P_{TC}CO_2$ demonstrated superior accuracy over $P_{ET}CO_2$ for estimating P_aCO_2 in retroperitoneoscopic urologic surgery. Although $P_{TC}CO_2$ may not replace the application of $P_{ET}CO_2$, it provides a promising continuous, non-invasive approach for monitoring P_aCO_2 and an early warning for hypercapnia.

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[References]

[1] XUE Q S, WU X W, JIN J, et al. Transcutaneous carbon dioxide monitoring accurately predicts arterial carbon dioxide partial pressure in patients undergoing prolonged laparoscopic surgery[J]. Anesth Analg, 2010, 111(2): 417-420

[2] BAIRD J E, GRANGER R, KLEIN R, et al. The effects of retroperitoneal carbon dioxide insufflation on hemodynamics and arterial carbon dioxide[J]. Am J Surg, 1999, 177(2): 164-166

[3] KADAM P G, MARDA M, SHAH V R. Carbon dioxide absorption during laparoscopic donor nephrectomy: a comparison between retroperitoneal and transperitoneal approaches[J]. Transplant Proc, 2008, 40(4): 1119-1121

[4] NG C S, GILL I S, SUNG G T, et al. Retroperitoneoscopic surgery is not associated with increased carbon dioxide absorption[J]. J Urol, 1999, 162(4): 1268-1272

[5] STREICH B, DECAILLIOT F, PERNEY C, et al. Increased carbon dioxide absorption during retroperitoneal laparoscopy[J]. Br J Anaesth, 2003, 91(6): 793-796

[6] NOSOVITCH M A, JOHNSON J O, TOBIAS J D. Noninvasive intraoperative monitoring of carbon dioxide in children: endtidal versus transcutaneous techniques[J]. Paediatr Anaesth, 2002, 12(1): 48-52

[7] TINGAY D G, STEWART M J, MORLEY C J. Monitoring of end tidal carbon dioxide and transcutaneous carbon dioxide during neonatal transport[J]. Arch Dis Child Fetal Neonatal Ed, 2005, 90(6): F523-F526

[8] DUYU M, MOCAN ÇAĞLAR Y, KARAKAYA Z, et al. Comparison of arterial CO_2 estimation by end-tidal and transcutaneous CO_2 measurements in intubated children and variability with subject related factors[J]. J Clin Monit Comput, 2021, 35(1): 101-111

[9] SPELTEN O, FIEDLER F, SCHIER R, et al. Transcutaneous $P_{TC}CO_2$ measurement in combination with arterial blood gas analysis provides superior accuracy and reliability in ICU patients[J]. J Clin Monit Comput, 2017, 31(1): 153-158

[10] LEE H J, CHAE J S, AN S M, et al. Strategy to reduce hypercapnia in robot-assisted radical prostatectomy using transcutaneous carbon dioxide monitoring: a prospective

observational study[J]. Ther Clin Risk Manag，2022，18：249-258
[11] LIU S J，SUN J，CHEN X，et al. The application of transcutaneous CO_2 pressure monitoring in the anesthesia of obese patients undergoing laparoscopic bariatric surgery[J]. PLoS One，2014，9（4）：e91563
[12] CHAUHAN R，MAHAJAN S，LUTHRA A，et al. Evaluation of arterial to end-tidal carbon dioxide pressure differences during laparoscopic renal surgery in the lateral decubitus position[J]. Anesth Essays Res，2019，13（3）：583
[13] GRENIER B，VERCHÈRE E，MESLI A，et al. Capnography monitoring during neurosurgery：reliability in relation to various intraoperative positions[J]. Anesth Analg，1999，88（1）：43-48
[14] CONWAY A，TIPTON E，LIU W H，et al. Accuracy and precision of transcutaneous carbon dioxide monitoring：a systematic review and meta-analysis[J]. Thorax，2019，74（2）：157-163
[15] NISHIYAMA T，NAKAMURA S，YAMASHITA K. Comparison of the transcutaneous oxygen and carbon dioxide tension in different electrode locations during general anaesthesia[J]. Eur J Anaesthesiol，2006，23（12）：1049-1054
[16] NISHIYAMA T，KOHNO Y，KOISHI K. Comparison of ear and chest probes in transcutaneous carbon dioxide pressure measurements during general anesthesia in adults[J]. J Clin Monit Comput，2011，25（5）：323-328
[17] MCBRIDE S D JR，JOHNSON J O，TOBIAS J D. Noninvasive carbon dioxide monitoring during neurosurgical procedures in adults[J]. South Med J，2002，95（8）：870-874
[18] REID C W，MARTINEAU R J，MILLER D R，et al. A comparison of transcutaneous，end-tidal and arterial measurements of carbon dioxide during general anaesthesia[J]. Can J Anaesth，1992，39（1）：31-36
[19] NISHIYAMA T，NAKAMURA S，YAMASHITA K. Effects of the electrode temperature of a new monitor，TCM4，on the measurement of transcutaneous oxygen and carbon dioxide tension[J]. J Anesth，2006，20（4）：331-334
[20] SØRENSEN L C，BRAGE-ANDERSEN L，GREISEN G. Effects of the transcutaneous electrode temperature on the accuracy of transcutaneous carbon dioxide tension[J]. Scand J Clin Lab Investig，2011，71（7）：548-552

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