BMC Pediatrics

RESEARCH

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Noninvasive carbon dioxide monitoring in pediatric patients undergoing laparoscopic surgery: transcutaneous *vs*. end-tidal techniques

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Abstract

Purpose The present study aimed to investigate the correlation between transcutaneous carbon dioxide partial pressure ($PtcCO_2$) and arterial carbon dioxide pressure ($PaCO_2$) and the accuracy of $PtcCO_2$ in predicting $PaCO_2$ during laparoscopic surgery in pediatric patients.

Methods Children aged 2–8 years with American Society of Anesthesiologists (ASA) class I or II who underwent laparoscopic surgery under general anesthesia were selected. After anesthesia induction and tracheal intubation, $PtcCO_2$ was monitored, and radial arterial catheterization was performed for continuous pressure measurement. $PaCO_2$, $PtcCO_2$, and end-tidal carbon dioxide partial pressure ($PetCO_2$) were measured before pneumoperitoneum, and 30, 60, and 90 min after pneumoperitoneum, respectively. The correlation and agreement between $PtcCO_2$ and $PaCO_2$, $PetCO_2$, and $PaCO_2$ were evaluated.

Results A total of 32 patients were eventually enrolled in this study, resulting in 128 datasets. The linear regression equations were: $PtcCO_2 = 7.89 + 0.82 \times PaCO_2$ ($r^2 = 0.70$, $P < 0.01$); $PetCO_2 = 9.87 + 0.64 \times PaCO_2$ ($r^2 = 0.69$, $P < 0.01$). The 95% limits of agreement (LOA) of $PtcCO_2 - PaCO_2$ average was 0.66 ± 4.92 mmHg, and the 95% LOA of $PetCO_2 - PaCO_2$ average was -4.4 ± 4.86 mmHg. A difference of ≤ 5 mmHg was noted between $PtcCO_2$ and $PaCO_2$ in 122/128 samples and between $PetCO_2$ and $PaCO_2$ in 81/128 samples ($P < 0.01$).

Conclusion In pediatric laparoscopic surgery, a close correlation was established between $PtcCO_2$ and $PaCO_2$. Compared to $PetCO_2$, $PtcCO_2$ can estimate $PaCO_2$ accurately and could be used as an auxiliary monitoring indicator to optimize anesthesia management for laparoscopic surgery in children; however, it is not a substitute for $PetCO_2$.

Registration number of Chinese Clinical Trial Registry ChiCTR2100043636.

Keywords Transcutaneous carbon dioxide partial pressure, End-tidal carbon dioxide partial pressure, Laparoscopic surgery, Pediatric patients, General anesthesia

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Introduction

Arterial carbon dioxide pressure ($PaCO_2$) is one of the most critical indicators of a patient's respiratory function. The gold standard for measuring $PaCO_2$ in clinical practice is arterial blood gas analysis (ABGA) [1]. The patient's acid–base balance and electrolyte state can be determined using ABGA. However, arterial blood sampling is an invasive procedure with risks of bleeding, infection, thrombosis, and vascular and neurologic harm. Additionally, ABGA cannot be used to monitor the $PaCO_2$ level continuously [2].

End-tidal carbon dioxide partial pressure ($PetCO_2$) has become a routine monitoring item for patients undergoing general anesthesia with tracheal intubation. Anesthesiologists can estimate $PaCO_2$ based on $PetCO_2$. However, several factors, including patient's age, different types of surgery, combined cardiopulmonary diseases, and changes in pulmonary blood flow, can affect the accuracy of $PetCO_2$ monitoring results, increasing the difference between $PetCO_2$ and $PaCO_2$ in practice [3]. The correlation between $PetCO_2$ and $PaCO_2$ shows a decrease with the delay of pneumoperitoneum during laparoscopic surgery; thus, $PaCO_2$ values should be monitored intermittently by ABGA [4]. Therefore, $PetCO_2$ is not a reliable predictor of $PaCO_2$.

Transcutaneous carbon dioxide partial pressure ($PtcCO_2$) can be used to estimate $PaCO_2$. $PtcCO_2$ monitoring is based on an electrochemical principle. The probe's internal heating electrode raises the local skin temperature. This results in the arterialization of dermal capillaries and improvement in their permeability, making it easier for CO_2 to enter the tissue space and diffuse away from the skin surface. CO_2 permeates the electrolyte layer via a high-permeability membrane on the sensor's surface, altering the pH value of the electrolyte layer, which is related to the variation in the CO_2 partial pressure [5]. The $PtcCO_2$ value is obtained by the monitor's internal programming algorithm. $PtcCO_2$ monitoring is a continuous and noninvasive method; however, due to advancements in monitoring technology and the miniaturization of the device, it is gaining increasingly popularity in clinical practice. Also, previous studies have shown that $PtcCO_2$ monitoring is effective in perioperative settings [6, 7], which suggests that compared to $PetCO_2$, $PtcCO_2$ has a better correlation and a smaller difference with $PaCO_2$. Nevertheless, Bolliger et al. indicated that $PtcCO_2$ monitoring does not accurately reflect $PaCO_2$ and does not provide more useful monitoring data than $PetCO_2$ [8].

Currently, there are no clinical reports regarding $PtcCO_2$ monitoring in pediatric laparoscopic surgery. This study aimed to investigate the correlation and consistency between $PtcCO_2$, $PetCO_2$, and $PaCO_2$ in children who underwent laparoscopic surgery (pneumoperitoneum time > 90 min).

Methods

The present study was approved by the Shenzhen Children's Hospital Ethics Committee (Shenzhen, China; Ethics approval number: 202007402), and written informed consent was obtained from the parents. A total of 35 children who underwent laparoscopic surgery, aged 2–8 years, and ASA class I or II were recruited for this study. Patients who required a vasoconstrictor to maintain blood pressure during the procedure and those with insufficient pneumoperitoneum time (< 90 min) were excluded from this study.

Children were escorted to the anesthesia room by their parents, and 2.5 mg/kg propofol was administered to induce sleep. The child was then transported to the operating room under the close supervision of the anesthesiologist. Electrocardiogram, pulse oxygen saturation (SpO_2), and blood pressure (BP)were monitored; the heart rate (HR) and BP were recorded as baseline values. Tracheal intubation was conducted following intravenous administration of benzenesulfonate cisatracurium 0.1 mg/kg and fentanyl 3 μg/kg. Breathing settings were established on the anesthesia machine: intermittent positive pressure ventilation, tidal volume 6–10 mL/kg, inspiration/expiration 1/2, inhalation oxygen concentration 50%, gas flow rate 2 L/min, and respiratory rate 15–25 times/min. $PetCO_2$ level was continuously measured using the side-stream capnography (Datex-Ohmeda, Finland, air pumping speed 150 mL/min). The respiratory rate and tidal volume were adjusted to maintain $PetCO_2$ 35–45 mmHg and airway pressure 10–25 cmH_2O. Anesthesia was maintained with inhalation sevoflurane concentration at 2–3%, intravenous pumping of remifentanil 0.2 μg/kg/min, and benzenesulfonate cisatracurium 0.1 mg/kg/h. The dosage of benzenesulfonate cisatracurium was adjusted according to the results of muscle relaxation monitoring.

After tracheal intubation, a $PtcCO_2$ monitor (SenTec Digital Monitor, SenTec Inc. Therwil, Switzerland) was attached. The monitoring site was located on the forehead, and the electrode-heating temperature was adjusted to 42 °C. The monitor was calibrated, and the electrode membrane was changed before each use. Radial artery catheterization was performed to facilitate invasive arterial blood pressure monitoring and the acquisition of blood gas analysis samples. The laparoscopic pneumoperitoneum pressure was chosen based on the children's ages (2–4 years old: 9 mmHg, 5–8 years old: 11 mmHg) and it was fine-tuned according to the surgical field's size when the pneumoperitoneum has just been established. Throughout the course of the procedure, there was no change in the pneumoperitoneum pressure. HR and BP were maintained within the range of ± 20% of the baseline value. The nasopharyngeal temperature of the child was maintained at 36–37 °C using an inflatable thermal blanket; the operating room temperature was set at 23–25 °C.

$PtcCO_2$ monitor sensor was removed during the postoperative recovery period of anesthesia; the local skin was cleaned and examined for signs of injury. After the removal of the arterial cannula, pressure dressings were applied. The tracheal tube was withdrawn when the child's spontaneous breathing was recovered, with SpO_2 maintained at 95% under inhaled air settings. Finally, the vital signs were observed carefully, and the child was transferred to the anesthesia recovery room for further monitoring after stabilization.

ABGA was conducted before (T0) and 30 min (T1), 60 min (T2), and 90 min (T3) after pneumoperitoneum. Also, $PtcCO_2$, $PetCO_2$, and $PaCO_2$ values were recorded at each time point. A blood gas analyzer (i-STAT Analyzer MN: 300-G, Singapore) was used to measure $PaCO_2$. HR, BP, SpO_2, tidal volume, respiratory rate, and body temperature at each time point. HR, BP, and the anesthesia machine's respiratory parameters were stabilized for at least 5 min before recording the measured values.

Data were analyzed using SPSS version 26.0. Measurement data were presented as mean ± standard deviation (SD). Pearson's correlation coefficient and linear regression analysis were conducted to establish the correlation, and the Bland–Altman method was utilized to assess the agreement between $PetCO_2$ and $PaCO_2$ or between $PtcCO_2$ and $PaCO_2$. A difference of ≤ 5 mmHg between $PaCO_2$ and the other two noninvasive variables was clinically acceptable [7, 9] and compared using the chi-square (χ^2) test. $P < 0.05$ indicated a statistically significant difference.

Results

Three children were excluded from the research due to the pneumoperitoneum's short duration (< 90 min), and 32 children (21 men and 11 women; mean age 4.31 ± 1.65 years) were eventually recruited. The average height and weight were 103.63 ± 11.98 cm and 17.45 ± 3.75 kg. Among them, 26 patients underwent laparoscopic pyeloplasty, and 6 patients underwent laparoscopic choledochal cyst excision. A total of 128 datasets were collected, consisting of simultaneous measurements of $PtcCO_2$, $PetCO_2$, and $PaCO_2$ at four time points (Table 1). During the course of the study, no adverse events were observed.

The correlation coefficient r between $PtcCO_2$ and $PaCO_2$ was 0.84 ($P < 0.01$, $n = 128$), and the linear regression equation was $PtcCO_2 = 7.89 + 0.82 \times PaCO_2$ ($r^2 = 0.70$, $P < 0.01$) (Fig. 1). A close correlation was established between $PtcCO_2$ and $PaCO_2$ at different monitoring time points; however, the correlation decreased slightly with increasing duration of pneumoperitoneum (Table 2).

Correlation coefficient r between $PetCO_2$ and $PaCO_2$ was 0.83 ($P < 0.01$, $n = 128$), and the linear regression equation was $PetCO_2 = 9.87 + 0.64 \times PaCO_2$ ($r^2 = 0.69$, $P < 0.01$) (Fig. 2). A good correlation was established between $PetCO_2$ and $PaCO_2$ at various time points; however, as the pneumoperitoneum time extended,

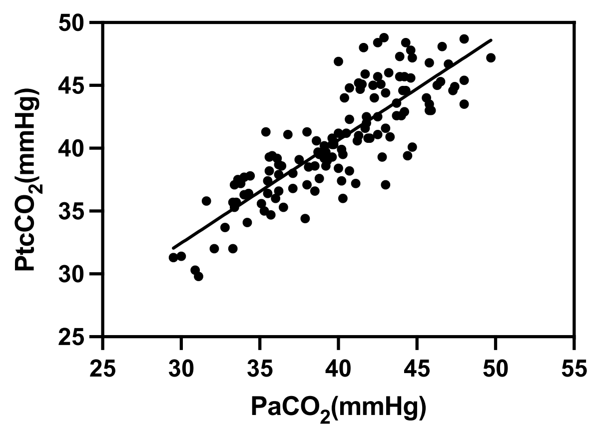

Fig. 1 Linear regression analysis between $PtcCO_2$ on the y-axis and $PaCO_2$ on the x-axis during laparoscopic surgery (pneumoperitoneum time > 90 min) in pediatric patients. The linear regression equation: $PtcCO_2 = 7.89 + 0.82 \times PaCO_2$ ($r^2 = 0.70$, $P < 0.01$, $n = 128$)

Table 1 $PtcCO_2$, $PetCO_2$, and $PaCO_2$ levels at different time points

Variable	T0	T1	T2	T3
$PaCO_2$ (mmHg)	35.17 ± 3.06	42.32 ± 3.96	41.51 ± 3.43	40.78 ± 3.44
$PtcCO_2$ (mmHg)	35.85 ± 2.98	42.57 ± 3.75	42.26 ± 3.39	41.71 ± 3.43
$PetCO_2$ (mmHg)	31.75 ± 2.54	37.28 ± 2.93	36.69 ± 2.61	36.44 ± 2.54

Mean ± standard deviation is used to express the values. T0, T1, T2, and T3 refer to before and 30, 60, and 90 min after pneumoperitoneum, respectively

Table 2 Correlation between $PtcCO_2$ and $PaCO_2$ at different time points

	T0	T1	T2	T3
r	0.77	0.76	0.71	0.68
P	< 0.01	< 0.01	< 0.01	< 0.01

T0, T1, T2, and T3 refer to before and 30, 60, and 90 min after pneumoperitoneum, respectively

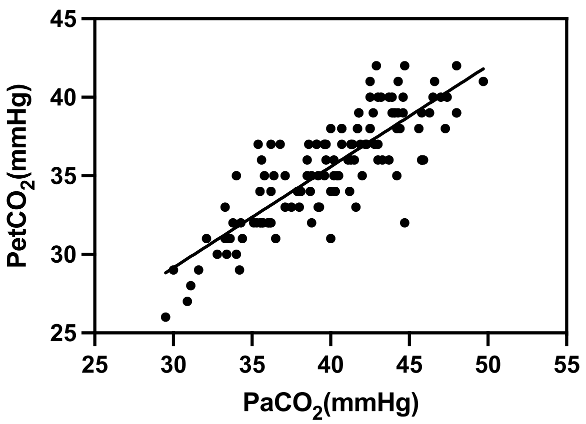

Fig. 2 Linear regression analysis between $PetCO_2$ on the y-axis and $PaCO_2$ on the x-axis during laparoscopic surgery (pneumoperitoneum time > 90 min) in pediatric patients. Linear regression equation: $PetCO_2 = 9.87 + 0.64 \times PaCO_2$ ($r^2 = 0.69$, $P < 0.01$, $n = 128$)

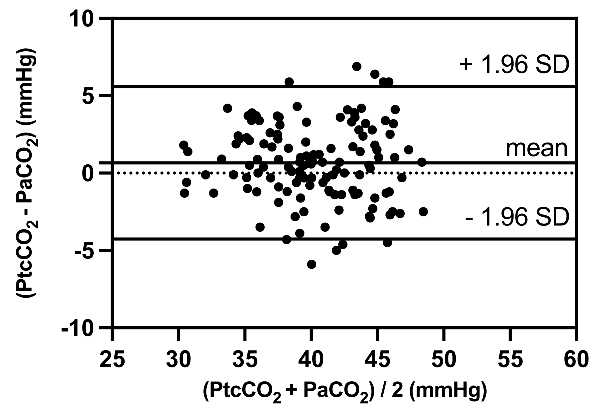

Fig. 3 Agreement between $PtcCO_2$ and $PaCO_2$ was analyzed using the Bland–Altman method. X-axis: $(PtcCO_2 + PaCO_2)/2$; Y-axis: $PtcCO_2 - PaCO_2$. The 95% LOA of $PtcCO_2 - PaCO_2$ average was 0.66 ± 4.92 mmHg (mean ± 1.96 SD) ($n = 128$)

Table 3 Correlation between $PetCO_2$ and $PaCO_2$ at different time points

	T0	T1	T2	T3
r	0.87	0.78	0.64	0.58
P	< 0.01	< 0.01	< 0.01	< 0.01

T0, T1, T2, and T3 refer to before pneumoperitoneum and 30 min, 60, and 90 min, respectively

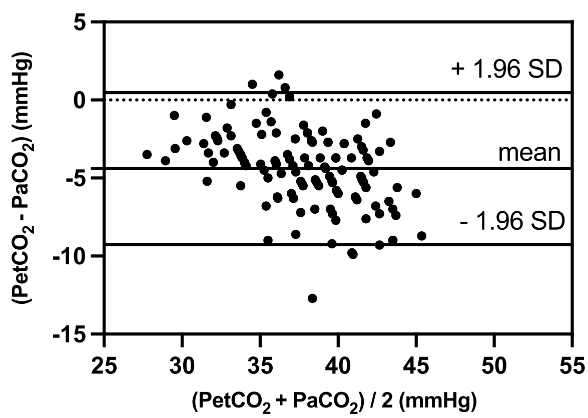

Fig. 4 Agreement between $PetCO_2$ and $PaCO_2$ was analyzed using the Bland–Altman method. X-axis: $(PetCO_2 + PaCO_2)/2$; Y-axis: $PetCO_2 - PaCO_2$. The 95% LOA of $PetCO_2 - PaCO_2$ average was -4.4 ± 4.86 mmHg (mean ± 1.96 SD) ($n = 128$)

this correlation decreased significantly compared to $PtcCO_2$. The correlation was lowest at T3 (Table 3).

Difference between $PtcCO_2$ and $PaCO_2$ was 0.66 ± 2.51 mmHg ($n = 128$). The 95% limits of agreement (LOA) of $PtcCO_2 - PaCO_2$ average was 0.66 ± 4.92 mmHg (mean ± 1.96 SD) (Fig. 3). Difference between $PetCO_2$ and $PaCO_2$ was -4.4 ± 2.48 mmHg ($n = 128$). The 95% LOA of $PetCO_2 - PaCO_2$ average was -4.4 ± 4.86 mmHg (mean ± 1.96 SD) (Fig. 4). $PtcCO_2 - PaCO_2$ and $PetCO_2 - PaCO_2$ values at each time point are shown in Table 4. A difference of ≤ 5 mmHg was observed between $PtcCO_2$ and $PaCO_2$ in 122/128 samples and between $PetCO_2$ and $PaCO_2$ in 81/128 samples ($P < 0.01$).

Discussion

Since the development of minimally invasive surgery, the laparoscopic operation has gained increasingly popular in pediatric surgeries due to its advantages of less trauma, a short hospital stay, less postoperative wound pain, and fewer complications. CO_2 is the most common gas utilized to create a pneumoperitoneum and provide a good operating view for the surgeon. However, the diffusion capacity of CO_2 is strong, and the absorption of CO_2 is sufficient in children due to factors such as the small volume of the abdominal cavity, the proximity of the capillaries to the peritoneum, and the larger abdominal surface area related to weight compared to adults [10]. A risk of hypercapnia is associated with prolonged artificial pneumoperitoneum. Increased CO_2 alters the body's acid–base balance and stimulates sympathetic nerves, thus increasing catecholamine and cortisol release and leading to hemodynamic fluctuations [10, 11]. Close monitoring of the CO_2 level during laparoscopic surgery and timely adjustment of the ventilator parameters is essential to avoid the disruption of physiological functions. $PaCO_2$ levels are stabilized after 60 min of pneumoperitoneum [12]; hence, a pneumoperitoneum time of at least 90 min was appropriate to observe the variables in this investigation.

Table 4 $PtcCO_2 - PaCO_2$ and $PetCO_2 - PaCO_2$ values at different time points

Variable	T0	T1	T2	T3
$PtcCO_2 - PaCO_2$ (mmHg)	0.69 ± 2.06	0.25 ± 2.66	0.75 ± 2.58	0.94 ± 2.75
$PetCO_2 - PaCO_2$ (mmHg)	−3.42 ± 1.51	−5.04 ± 2.50	−4.82 ± 2.66	−4.34 ± 2.84

Mean ± standard deviation is used to express the values. T0, T1, T2, and T3 refer to before and 30, 60, and 90 min after pneumoperitoneum, respectively

$PetCO_2$ is a routine measurement during the perioperative period and one of the primary indicators used to adjust ventilator parameters. However, factors that affect lung ventilation/perfusion may interfere with the accuracy of $PetCO_2$ measurements, and thus, the use of $PetCO_2$ in non-tracheal intubated patients is restricted. The increased abdominal pressure during laparoscopic surgery results in a diaphragmatic rise and an increase in thoracic pressure; subsequently, airway resistance and airway pressure also rise, with pulmonary vasoconstriction and reduced pulmonary blood flow. Pediatric patients are vulnerable to pneumoperitoneal pressure effects. This study revealed that during the entire monitoring process, a good correlation was established between $PetCO_2$ and $PaCO_2$, $r = 0.83$ ($P < 0.01$). Nevertheless, as the pneumoperitoneum time was prolonged, the correlation between $PetCO_2$ and $PaCO_2$ decreased gradually, which was consistent with previous findings [6, 9].

Several clinical studies have focused on the application of $PtcCO_2$ monitoring in different types of surgery and patients [13–17] under non-tracheal intubation monitoring anesthesia [18, 19]. These studies confirmed the effectiveness of $PtcCO_2$ monitoring. The current results showed a close correlation between $PtcCO_2$ and $PaCO_2$, $r = 0.84$ ($P < 0.01$), and although the correlation was decreased with prolonged pneumoperitoneum time, it was not very significant compared to $PetCO_2$. According to Bland–Altman analysis, a lesser mean difference was detected between $PetCO_2$ and $PaCO_2$ than between $PetCO_2$ and $PaCO_2$. Therefore, $PtcCO_2$ performed better than $PetCO_2$ in estimating $PaCO_2$, which is in agreement with the previous results [6, 7, 9]. In our experiment, we can combine $PetCO_2$, $PaCO_2$, and $PtcCO_2$ to regulate the patient's acid–base, so there is no accumulation of CO_2 during the whole operation. However, due to the limitations of $PetCO_2$ monitoring, especially in the case of prolonged pneumoperitoneum, relying solely on $PetCO_2$ to regulate the patient's respiratory parameters cannot guarantee that the patient is in acid–base balance, particularly for young children. And $PtcCO_2$ can more accurately estimate $PaCO_2$, so its application can reduce the risk of CO_2 accumulation. Conway et al. conducted a meta-analysis on the effectiveness of $PtcCO_2$ monitoring [20] and demonstrated that is challenging to achieve a uniform standard due to the involvement of various clinical aspects, including the monitoring site, electrode heating temperature, and application population; thus, it is critical to monitor the $PtcCO_2$ trend throughout the monitoring process.

The CO_2 level measured by $PtcCO_2$ monitoring consists of two parts: one derived from the blood (arterial, capillary, and venous), and the other from the metabolism of the tissue cells [21, 22]. The warming effect of the electrode increases the skin blood flow and enhances the contribution of arterial blood to CO_2 by opening the precapillary sphincter [23]. A rise in the local skin temperature increases the metabolism of tissue cells, producing excessive CO_2. Therefore, the $PtcCO_2$ monitoring value is theoretically higher than that of $PaCO_2$. $PtcCO_2$ monitors used in clinical practice correct the initial measured value based on the selected heating temperature to reduce the deviation from $PaCO_2$ [21]. In the present study, $PtcCO_2$ monitoring values were less than $PaCO_2$ in 51/128 data sets; hence, the correction method for $PtcCO_2$ monitors needs to be investigated further.

Several factors affect $PtcCO_2$ monitoring, including the temperature of the electrodes, the monitoring location of the sensor, and the patient's clinical state. Nishiyama et al. demonstrated that when the anterior chest (between the clavicle and nipple) was chosen as the monitoring site, $PtcCO_2$ correlated best with $PaCO_2$ at 43 °C ($R^2 = 0.7568$) among the different electrode-heating temperatures (37, 40, 42, 43, and 44 °C) in its setting, and the monitoring required less time to stabilize at higher temperatures as blood CO_2 levels change, but required > 150 s [24]. According to a study on the optimal electrode temperature for monitoring $PtcCO_2$ in preterm infants, the mean difference between $PtcCO_2$ and $PaCO_2$ was the smallest at 42 °C [25]. A higher temperature may result in skin damage in pediatric patients due to thin skin, but previous studies have not reported any skin injuries in children or infants. In this study, we chose 42 °C as the electrode temperature for $PtcCO_2$ monitoring; no adverse events were observed.

Nishiyama et al. reported that $PtcCO_2$ was correlated with $PaCO_2$ when the monitoring sensor was located on the chest ($R^2 = 0.76$) but not when it was located on the upper arm and forearm ($R^2 < 0.5$) [26]. When the anterior chest is chosen as a monitoring site in pediatric patients, the area of surgical disinfection might be affected, especially in younger kids. Anesthesiologists were usually positioned on the cephalic side of the patient, such that the forehead was selected as the site in this study, facilitating the administration of the probe. In the current study, $PetCO_2$ showed a close correlation with $PaCO_2$ than $PtcCO_2$ before pneumoperitoneum; however, the mean difference between $PtcCO_2$ and $PaCO_2$ was smaller than the mean difference between $PetCO_2$ and $PaCO_2$. However, whether $PetCO_2$ correlates better with $PaCO_2$ than $PtcCO_2$ in pediatric patients under non-pneumoperitoneal conditions with the forehead as the monitoring site needs to be studied further with a large sample size.

In the event that patients' peripheral tissues and organs are not supplied adequately with blood, such as in shock, the CO_2 produced by tissue metabolism cannot be carried away quickly, and $PtcCO_2$ monitoring values increase gradually [22]. Thus, $PtcCO_2$ can be utilized as one of the indicators for assessing a patient's microcirculatory status, which is useful in guiding the treatment [27]. However, the study on $PtcCO_2$ monitoring in surgical patients with circulatory failure has been rarely reported, and the correlation between the $PtcCO_2$ gradient changes and skin tissue perfusion status requires further clinical investigation. Other factors, such as poor skin contact with the fixed connection loop and insufficient gel, may allow contact between the probe and air, thus interfering with the monitoring results. CO_2 permeability films that have not been replaced for a long time or are damaged or air bubbles under the film can also affect the accuracy of $PtcCO_2$ monitoring.

Since $PtcCO_2$ monitoring is a continuous and non-invasive method that can be used to assess $PaCO_2$ to some extent, its perioperative application is promoted in the different types of surgery and populations. Endotracheal intubation is not required for gastrointestinal endoscopy or other operations that can be performed using nerve blocks. The use of intravenous anesthetic medications intraoperatively can improve operating conditions and increase patient comfort during these procedures. When the nerve block is unsatisfactory, or when specific operations call for an enhanced level of sedation, supplemental narcotic medicines are required. Understanding the CO_2 level of patients allows us to more precisely regulate the intravenous anesthetic medicine dosage. However, it is often difficult to accurately monitor the CO_2 levels of patients during these operations. In this situation, $PtcCO_2$ monitoring is a good choice. It has been shown [18, 19, 28] that $PtcCO_2$ monitoring is an effective way to detect hypoventilation in patients, which reduces the incidence, extent, and duration of hypercapnia, improving the safety of patients under sedation. High-frequency ventilation is often used to maintain oxygenation in some airway procedures performed with a rigid bronchoscope. However, evaluating the ventilatory status of patients with $PetCO_2$ in the open ventilation mode of high-frequency ventilation is challenging. As a result, we can adjust the parameters of high-frequency ventilation to avoid the accumulation of CO_2 according to $PtcCO_2$ [29].

Usually, patients undergoing thoracic surgery have chronic lung diseases and require one-lung breathing in the lateral decubitus position during operation. These factors can affect lung ventilation/perfusion, leading to the increase of the difference between $PetCO_2$ and $PaCO_2$, and patients are more likely to develop respiratory acidosis. Oshibuchi M's study [30] showed that $PtcCO_2$ can more accurately predict $PaCO_2$ compared with $PetCO_2$ in both two-lung ventilation and one-lung ventilation. It has been shown [31] that $PtcCO_2$ monitoring remains highly accurate even when one-lung ventilation is prolonged (more than 2 h) and permissive hypercapnia is present.

Most patients need to recover in anesthesia recovery room after surgery. Due to the presence of residual opioids and muscle relaxants, patients are at potential risk of developing respiratory depression, especially in elderly and obese patients. $PtcCO_2$ monitoring effectively reflects $PaCO_2$ levels and is more suitable for observing changes in CO_2 fluctuations over time so that we can take appropriate treatment measures [32]. For pediatric patients, the anesthesia has certain particularity. Children are often unable to cooperate with us for some examination operations. They must be under sedation and analgesia conditions prior to nerve block or spinal anesthesia. Children must maintain a certain level of sedation throughout the whole operation, but the use of anesthetic drugs will always have an impact on their breathing more or less. By using $PtcCO_2$ monitoring, anesthesiologists are able to determine in time whether CO_2 accumulation in patients is occurring so that the appropriate treatment can be administered.

$PtcCO_2$ monitoring also has some limitations. The monitoring site should be cleaned in advance to remove the hair and grease; also, the $PtcCO_2$ monitor requires a calibration time of approximately 15 min before use and needs to be recalibrated either after the patient is removed from the monitoring site or after prolonged monitoring. When CO_2 in the blood changes, $PtcCO_2$ monitoring takes about 2 min to reflect $PaCO_2$ with a degree of delay [33]. These factors limit its use in surgery patients. Therefore, the $PtcCO_2$ monitor needs further improvement to facilitate its use during the perioperative period. Some studies have reported that $PtcCO_2$ monitoring techniques are not based on electrochemical principles [34–36]. Because of the different monitoring mechanisms, the local heating on the skin is avoided, and the time required for calibration and stabilization is short, rendering the monitors convenient to use. However, the application is still not mature in clinical practice. Although $PetCO_2$ is susceptible to various factors, it plays an essential role in determining the position of the tracheal tube, tube folding, and accidental decannulation [37]. Additionally, $PetCO_2$ provides information about the patient's pulmonary blood flow status and circulatory function [38], and the patient's airway status can also be determined from the $PetCO_2$ waveform, thereby deeming that $PtcCO_2$ is not a substitute for $PetCO_2$.

In conclusion, $PtcCO_2$ shows a close correlation with $PaCO_2$ when the forehead is chosen as a monitoring site in children undergoing laparoscopic surgery. Compared to $PetCO_2$, $PtcCO_2$ can accurately estimate $PaCO_2$ and could be used as an auxiliary monitoring indicator to optimize anesthesia management for laparoscopic surgery in children; however, it is not a substitute for $PetCO_2$.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12887-023-03836-2.

Additional file 1.

Acknowledgements
We thank Dr. Ruijun Gao (Department of Anesthesiology, Shenzhen Children's Hospital) for suggestions in designing this study. We thank Fang Chen (Department of Anesthesiology, Shenzhen Children's Hospital) for her assistance in manuscript preparation and revision.

Authors' contributions
Xinggang Ma and Liang Xu contributed to the study's concept and design. Weitao Wang and Zhifa Zhao conducted the experiments and collected data. Guanglin Shang was responsible for material preparation and device maintenance. Data were analyzed by Weitao Wang and Xinjie Tian. The first draft of the manuscript was written by Weitao Wang. Furthermore, all authors commented on the previous versions of the manuscript. All authors read and approved the final manuscript.

Funding
Transcutaneous carbon dioxide partial pressure monitoring device (SenTec Digital Monitor, SenTec Inc. Therwil, Switzerland) and consumables were provided by SenTec AG China distributor. The study was also supported by Shenzhen Children's Hospital of China Medical University institutional sources. The authors declare that funders had no role in the study design, data collection, statistical analysis, and manuscript preparation.

Availability of data and materials
All data and material generated or analysed during this study are included in this published article and its supplementary information files. And the datasets used and/or analysed during the current study are also available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Shenzhen Children's Hospital Ethics Committee (Ethical approval number: 202007402). All methods were carried out in accordance with relevant guidelines and regulations. Written informed consent was obtained from the parents of the participants.

Consent for publication
Not applicable.

Competing interests
All authors certify that they have no affiliations with or involvement in any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this manuscript.

Received: 2 October 2022 Accepted: 3 January 2023
Published online: 14 January 2023

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