Transcutaneous Carbon Dioxide Monitoring Accurately Predicts Arterial Carbon Dioxide Partial Pressure in Patients Undergoing Prolonged Laparoscopic Surgery

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BACKGROUND: There may be large differences between measurements of end-tidal carbon dioxide partial pressure (PETCO2) and arterial carbon dioxide partial pressure (PACO2) during laparoscopic surgeries. Transcutaneous carbon dioxide (PTCCO2) monitoring can be used to noninvasively and continuously estimate PACO2. In the present study we evaluated the accuracy of PTCCO2 monitoring in predicting the PACO2 during laparoscopic surgeries with prolonged pneumoperitoneum.

METHODS: Sixteen patients who underwent laparoscopic radical gastrectomy or radical proctectomy under general anesthesia were included in the study. Their PACO2, PETCO2, and PTCCO2 values were measured at 3 time points before and after pneumoperitoneum. Agreement among measures was assessed by the Bland–Altman method.

RESULTS: Forty-eight sample sets were obtained. The average PACO2−PTCCO2 difference was −0.9 ± 6.4 mm Hg (mean ± 2 SD). The average PACO2−PETCO2 difference was 7.5 ± 7.0 mm Hg (mean ± 2 SD). PACO2−PTCCO2 was less than or equal to ±5 mm Hg for 88% of the samples. PACO2−PETCO2 was less than or equal to ±5 mm Hg for 17% of the samples (P < 0.05).

CONCLUSIONS: While undergoing long-term pneumoperitoneum laparoscopic surgery, PTCCO2 monitoring is more accurate than is PETCO2 monitoring in predicting the patients’ PACO2. (Anesth Analg 2010;111:417–20)

The “gold standard” for the measurement of arterial carbon dioxide partial pressure (PACO2) is arterial blood gas (ABG), but this method is invasive and complicated.1 End-tidal carbon dioxide (PETCO2) monitoring is a noninvasive method that can accurately predict PACO2 under many circumstances. However, the accuracy decreases when ventilation–perfusion mismatches or other cardiovascular and respiratory pathologies occur.2,3 Transcutaneous carbon dioxide (PTCCO2) monitoring is another noninvasive method that can continuously and reliably measure PACO2 in pediatric and geriatric patients during surgery.4–6 The number of laparoscopic radical gastrectomy procedures and proctectomy procedures used in the treatments of gastric or rectal cancers have dramatically increased in clinical practice in the recent years.7–9 These surgeries often require prolonged pneumoperitoneum (usually >60 minutes), which can influence the difference between simultaneous PACO2 and PETCO2 measurements.10,11 Because the correlation between PACO2 measurements and PTCCO2 monitoring in this condition is unknown, we designed the present study to evaluate the accuracy of PTCCO2 in predicting PACO2 values during prolonged pneumoperitoneum in laparoscopic surgeries.

METHODS

This study was approved by the IRB of Ruijin Hospital. Before the study, written informed consent was obtained from 16 patients, who were ASA I–III and scheduled for either laparoscopic radical gastrectomy or radical proctectomy. Patients with severe cardiovascular or respiratory diseases, such as coronary heart disease, congestive heart failure, or chronic obstructive pulmonary disease were excluded from this study.

Patients were monitored by electrocardiography, pulse oxymetry, and noninvasive arterial blood pressure measurements using an A5/B monitor (Datex-Ohmeda, Finland). A 16-gauge (16-G) IV catheter was placed into the median cubital vein for fluid transfusion, and a 20-G arterial catheter was inserted into the left radial artery under local anesthesia for ABG sampling. The catheters were flushed using a pressure bag with 500 mL of heparinized saline. Before anesthesia, patients’ heart rate (HR) and arterial blood pressure were recorded as the preinduction values. Anesthesia was induced with propofol (4...
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**Table 1. CO₂ Partial Pressure at Different Time Points During the Surgeries (Mean ± SD, n = 16)**

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<thead>
<tr>
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<th>Before pneumoperitoneum</th>
<th>After pneumoperitoneum</th>
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<tr>
<td></td>
<td>Baseline (mm Hg)</td>
<td>30 minutes (mm Hg)</td>
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<td></td>
<td>r</td>
<td>r</td>
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<tr>
<td>Paco₂</td>
<td>40.11 ± 3.60</td>
<td>47.30 ± 3.50</td>
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<tr>
<td>Petco₂</td>
<td>33.06 ± 2.95</td>
<td>38.81 ± 1.83</td>
</tr>
<tr>
<td>Ptcco₂</td>
<td>39.04 ± 3.91</td>
<td>48.85 ± 2.80</td>
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</tbody>
</table>

Correlation between end-tidal carbon dioxide partial pressure (Petco₂) and arterial carbon dioxide partial pressure (Paco₂) and transcutaneous carbon dioxide (Ptcco₂) and Paco₂ at 3 time points. *P < 0.05.

μg/mL using the target concentration infusion), fentanyl (2 μg/kg), and atracurium (0.6 mg/kg). After tracheal intubation, the patients’ lungs were ventilated with 100% oxygen (2 L/min), and their tidal volume and respiratory rate were adjusted to maintain the Petco₂ within 35 to 45 mm Hg. Anesthesia was maintained with propofol (2 μg/mL with target concentration infusion model), desflurane (6%), and fentanyl to keep the blood pressure and HR within 20% of the preinduction values. The patient’s body temperature was continuously monitored nasopharyngeally and maintained at 36° to 37°C by external heating. The room temperature was maintained at 24° to 26°C.

Ptcco₂ was monitored with a V-Sign™ system (SenTec Digital Monitor, SenTec Inc., Therwil, Switzerland) after induction of general anesthesia. Before measurements began, calibration was performed with standard gas, and the ear lobes and Ptcco₂ electrode were cleaned with alcohol. Paco₂ from the ABG was determined with an i-STAT Analyzer System, which was calibrated daily and before each analysis. Disposable EG7 cartridges were also verified through calibration. Petco₂ was measured with an A-Scal monitor.

ABG sampling was performed, and Ptcco₂ and Paco₂ were recorded simultaneously after the transcutaneous sensor had been on the patients’ ear lobes for 15 minutes and the patients’ blood pressure, HR, tidal volume, and respiratory rate were constant to obtain the stable Ptcco₂. These 3 preoperative values were regarded as the baseline level. Pneumoperitoneum was established and intraperitoneal CO₂ infusion pressure was maintained at 14 mm Hg during the surgery. Thirty and 60 minutes after pneumoperitoneum, Paco₂, Ptcco₂, and Petco₂ were measured simultaneously. Blood pressure, HR, tidal volume, and respiratory rate were kept constant for at least 5 minutes before the measurements were taken.

Quantitative data were presented as means ± SD (SD). Statistical analysis was conducted using SPSS version 13.0. Pearson correlation coefficient and linear regression analysis were used to establish the relationship, and the Bland–Altman method was used to analyze the agreement between Paco₂ and Petco₂ or between Paco₂ and Ptcco₂. A difference of 5 mm Hg or less between Paco₂ and the other 2 noninvasive variables was regarded as a clinically acceptable range and was compared by using the χ² test. A value of P < 0.05 was considered statistically significant.

**RESULTS**

Sixteen patients (8 men and 8 women) with a mean age of 65 ± 11 years (range = 44–86 years) were recruited into this study. The average body weight was 63 ± 11 kg (43–79 kg). Eleven patients underwent laparoscopic proctectomy, and the rest underwent laparoscopic radical gastrectomy. The mean time of CO₂ pneumoperitoneum was 83 ± 16 minutes.

The Paco₂, Petco₂, and Ptcco₂ values were recorded at 3 time points. Forty-eight samples were obtained. The mean values of these variables at different time points are presented in Table 1 and Figure 1. In these samples, both Ptcco₂ and Petco₂ were closely correlated with Paco₂ (the linear regression equations: Ptcco₂ = 0.74 × Paco₂ + 11.07, r² = 0.71, P < 0.0001; Petco₂ = 1.04 × Paco₂ + 6.45, r² = 0.55, P < 0.01; Figure 2 and Figure 3). In addition, Ptcco₂ was also correlated with Paco₂ at each time point (r = 0.57, 0.83, and 0.74, respectively, P < 0.05). Petco₂ was correlated with Paco₂ at baseline (r = 0.55, P < 0.05), but not 30 minutes and 60 minutes after pneumoperitoneum (r = 0.48 and 0.49, respectively, P > 0.05).

According to the Bland–Altman analysis, the average Paco₂ – Ptcco₂ difference was −0.9 ± 6.4 mm Hg (mean ± 2 SD) (Fig. 4), and the average Paco₂ – Petco₂ difference was 7.5 ± 7.0 mm Hg (mean ± 2 SD) (Fig. 5). There was a difference of 5 mm Hg or less between Paco₂ and Ptcco₂ in 42 of the 48 samples. There was a difference of 5 mm Hg or less between Paco₂ and Petco₂ in only 8 of the 48 samples (P < 0.05).

**DISCUSSION**

The number of laparoscopic radical gastrectomy and proctectomy procedures in clinical practice has increased rapidly...
because of advantages that include minimized invasiveness, reduced pain, and fast recovery. However, these laparoscopic surgeries require prolonged CO₂ pneumoperitoneum, which may facilitate CO₂ absorption and its accumulation in blood and tissues, eventually causing hypercapnia. Accurate evaluation of PACO₂ is necessary in anesthesia management during the aforementioned surgeries to assess ventilation efficacy and to avoid hypercapnia, which may lead to sympathetic excitation, hypertension, tachycardia, and other complications. PETCO₂ cannot reliably estimate PACO₂ under these circumstances because CO₂ inflated into the abdominal cavity may cause pulmonary atelectasis, resulting in decreased functional residual capacity and ventilation–perfusion mismatch. Klopfenstein et al. measured PACO₂ and PETCO₂ simultaneously during laparoscopic colon surgery, with prolonged CO₂ pneumoperitoneum, and concluded that the correlation between PACO₂ and PETCO₂ was inconsistent after the initiation of CO₂ inflation. Our study also found that PETCO₂ was correlated with PACO₂ only at baseline, before pneumoperitoneum, and underestimated PACO₂ when CO₂ pneumoperitoneum was established.

Ptcco₂ monitoring is another noninvasive method that can continuously and accurately predict PACO₂. Although Bolliger et al. found that Ptcco₂ monitoring had a small bias in predicting PACO₂, the agreement between Ptcco₂ and PACO₂ has been verified in many studies. Our study demonstrated that Ptcco₂ had advantages over PETCO₂ in the prediction of PACO₂ during prolonged CO₂ pneumoperitoneum during laparoscopic radical gastrectomy and proctectomy. In contrast to the patients in Bolliger et al.’s study, patients participating in our study had no cardiovascular or respiratory diseases, and IV plus inhaled anesthesia (propofol and desflurane) was used to maintain steady cardiovascular variables during the surgeries. Propofol may improve the potential hypoxic pulmonary vasoconstriction induced by desflurane, as is implicated in many animal studies. The stable cardiovascular and respiratory function and constant skin temperature under the monitor sensor play an important role in the increased consistency between Ptcco₂ and PACO₂.
Previous studies found that the CO₂ partial pressure is at its highest 30 minutes after pneumoperitoneum and is stable 60 minutes after pneumoperitoneum. Therefore, determination of PrTcco₂ 15 minutes after pneumoperitoneum in our study may not be feasible for some patients. In Casati et al.’s study, stable hemodynamic and respiratory variables were achieved 30 minutes after pneumoperitoneum, whereas both Domingo et al. and Cuvelier et al. suggested that CO₂ partial pressure was stable 20 minutes after pneumoperitoneum. These findings may explain why the correlation coefficient between PrTcco₂ and Paco₂ at baseline was lower than that at 30 minutes and 60 minutes after pneumoperitoneum. Further studies are needed to investigate whether PrTcco₂ is still correlated with Paco₂ 60 minutes after pneumoperitoneum.

Bland–Altman analysis was used in the present study to measure the agreement among PrTcco₂ or PetTcco₂ and Paco₂. On the basis of previous studies, a difference of 5 mm Hg or less between Paco₂ and other noninvasive measurements was a clinically acceptable difference. The scatter diagram of PetTcco₂ and Paco₂ shows that many of the data points were outside of the acceptable range, indicating poor agreement between PetTcco₂ and Paco₂.

In summary, our study demonstrates that PrTcco₂ is more accurate in predicting Paco₂ than is PetTcco₂ during laparoscopic radical gastrectomy and proctectomy with prolonged CO₂ pneumoperitoneum. Therefore, PrTcco₂ monitoring can be used reliably during prolonged CO₂ pneumoperitoneum surgeries to improve anesthesia management. PrTcco₂ monitoring does, however, have its own limitations such as the relatively slow response time, difficulty in maintaining good contact between the sensor and the patient’s skin, and the long warm-up time for the sensor to reach its final operating temperature. We suggest that PrTcco₂ monitoring, used to measure Paco₂ noninvasively during prolonged CO₂ pneumoperitoneum, may increase the quality of anesthesia management.

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REFERENCES