Evaluation of an Oxygen Mask-Based Capnometry Device in Subjects Extubated After Abdominal Surgery

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BACKGROUND: For early detection of respiratory and hemodynamic changes during anesthesia, continuous end-tidal carbon dioxide concentration (P_{ETCO_2}) is monitored by capnometry. However, the accuracy of CO_2 monitoring during spontaneous breathing in extubated patients remains undetermined. Therefore, we aimed to compare P_{ETCO_2} measured by capnometry using an oxygen mask with a carbon dioxide sampling port (capnometry-type oxygen mask) and P_{CO_2} in extubated subjects who had undergone abdominal surgery. Furthermore, we investigated whether spontaneous deep breathing affected dissociation between P_{aCO_2} and P_{ETCO_2}. METHODS: Adult post-abdominal surgery subjects admitted to the ICU were enrolled in this study. After extubation, oxygen was supplied at 6 L/min using the capnometry-type oxygen mask. After 30 min of oxygen supply, P_{aCO_2} blood gas analysis was performed, and P_{ETCO_2} was measured under resting and deep-breathing conditions. For both resting and deep-breathing conditions, the correlation between P_{aCO_2} and P_{ETCO_2} was analyzed. Furthermore, bias, precision, and limits of agreement were calculated using the Bland-Altman method. RESULTS: Twenty-five subjects (15 men, 10 women) with a mean age of 62 y (interquartile range of 57–76 y) and body mass index of 20–24 kg/m^2 were studied. The correlation (r) between P_{aCO_2} and P_{ETCO_2} under resting and deep-breathing conditions was 0.50 and 0.56, respectively. Compared with P_{aCO_2}, the bias and limits of agreement were −12.6 (−20.6 to −4.6) for resting P_{ETCO_2} and −9.1 (−16.0 to −2.1) for deep-breathing P_{ETCO_2}. The association between P_{aCO_2} and deep-breathing P_{ETCO_2} was significantly smaller compared with resting P_{ETCO_2} (P = .002). CONCLUSIONS: It is possible to measure the P_{ETCO_2} under varying breathing conditions with the capnometry-type oxygen mask in subjects receiving oxygen supplementation after extubation following upper abdominal surgery to determine whether they are properly ventilating. (ClinicalTrials.gov registration UMIN000011925.) *Key words: capnometry; end-tidal carbon dioxide; postoperative monitoring; ventilation/perfusion mismatch.* [Respir Care 2015;60(5):705–710. © 2015 Daedalus Enterprises]

Introduction

Compared with other surgeries, the incidence of pulmonary complications is higher after upper abdominal or chest surgery because both surgeries involve severe and prolonged alteration of pulmonary mechanics.[1] After abdominal operations, active collapse of the lungs along with hypoventilation is the major cause of postoperative hypoxia and pulmonary complications.[2,3] Furthermore, surgical trauma after thoracic and abdominal surgery affects respiratory muscles, leading to postoperative hypoxia and

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The study was supported by the Yokohama City University Hospital. The authors have disclosed no conflicts of interest.

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DOI: 10.4187/respcare.03557

pulmonary complications.[4] Three factors produce respiratory muscle dysfunction after abdominal surgery. First, muscle disruption by surgical incision impairs effectiveness of respiratory muscles. Second, postoperative pain may cause voluntary limitation of respiratory motion. Third, surgical trauma stimulates central nervous system reflexes mediated by both visceral and somatic nerves that produce reflex inhibition of the phrenic and other nerves, innervating respiratory muscles.[4] Therefore, monitoring respiratory function in patients who have undergone abdominal surgery is one of the essential assessments carried out in ICUs.

Capnography is an increasingly popular procedure; its widespread clinical use may improve patient care and safety. Assessment of the extrapolated end-tidal carbon dioxide concentration (P_{ETCO_2}) is one of the most useful aspects of capnography.[5] The levels of alveolar (P_{ETCO_2}) and arterial (P_{aCO_2}) CO_2 are similar in healthy subjects (eg, difference of < 5 mm Hg). Therefore, in subjects with normal dead space, it is safe to use P_{ETCO_2} as a substitute for P_{aCO_2}.[6-8] However, in patients who have undergone abdominal surgery, the levels of alveolar and arterial CO_2 are altered due to changes in respiratory and hemodynamic conditions.

Physiological dead space is the sum of anatomical and alveolar dead space and is defined as the sum of all parts of the tidal volume that do not participate in gas exchange.[9] In healthy subjects, physiological dead space is small and inconsiderable; however, in postoperative patients, respiratory mechanics are altered, and several changes lead to increased physiological dead space. The functional residual capacity continuously decreases after an operation, usually reaching its lowest value 1–2 d after the operation, before slowly returning to normal values within 1 week.[10]

The most common problem during surgery is ventilation/perfusion mismatching that leads to impaired gas exchange, which persists during the postoperative period. The P_{ETCO_2} is continuously monitored by capnometry for early detection of respiratory or hemodynamic changes during anesthesia. However, in extubated patients, P_{ETCO_2} monitoring requires a device that can draw a continuous gas sample for spectrographic measurements with the capnometer.[11-13] Furthermore, the P_{ETCO_2} wave is normally unstable in non-intubated patients because the oxygen supply system is not closed compared with the oxygen system with mechanical ventilation using an endotracheal tube during anesthesia.

The newly developed capnometry-type oxygen mask (Japan Medical Next, Tokyo, Japan) has a P_{ETCO_2} sampling line for use in spontaneously breathing patients (Fig. 1). Previous studies have shown that this device is useful for monitoring respiration in extubated subjects.[14,15] However, dissociation between P_{ETCO_2} and P_{aCO_2} has not been investigated, and the precision of CO_2 monitoring by oxygen mask capnometry remains unclear.

The purpose of this study was to compare P_{ETCO_2} measured by capnometry using the capnometry-type oxygen mask with P_{aCO_2} obtained by blood gas analysis. The secondary goal was to evaluate the association between P_{aCO_2} and P_{ETCO_2} under different breathing conditions. Because functional residual capacity is frequently reduced in patients undergoing surgery near the diaphragm (ie, upper abdominal or thoracic incisions),[16] we assessed whether deep breathing that decreases the physiological dead space leads to dissociation between P_{ETCO_2} and P_{aCO_2}.

QUICK LOOK

Current knowledge

End-tidal carbon dioxide concentration monitoring with capnometry in anesthesia is a standard of care. Capnometry assures appropriate airway position and provides early detection of changes in ventilation and perfusion. The accuracy of carbon dioxide monitoring during spontaneous breathing in extubated patients receiving oxygen therapy is less reliable.

What this paper contributes to our knowledge

A simple mask modified to allow sidestream sampling of gases was able to reliably monitor expired carbon dioxide in a group of postoperative subjects. The system was effective across a range of breathing patterns during oxygen delivery.

Methods

This prospective study was conducted at the Yokohama City University Hospital, a teaching hospital in Japan. The ethics committee of the Yokohama City University Hospital approved the design of this study. This study was registered with the University Hospital Medical Information Network Center (UMIN000011925), and informed consent was obtained from all subjects. For this study, adult subjects admitted to the ICU after extubation in the operating room for an abdominal operation were included. These subjects were monitored in the ICU for preventive postoperative complications, such as bleeding, respiratory dysfunction, and hemodynamic instability. The exclusion criteria were: < 18 y old, inability to maintain an S_{pO_2} of $> 95\%$ with an oxygen mask, need for noninvasive mechanical ventilation, body mass index of > 30 kg/m^2, and absence of epidural anesthesia because conditions such as obesity and surgical trauma pain probably influence postoperative respiratory function, leading to ventilation-per-

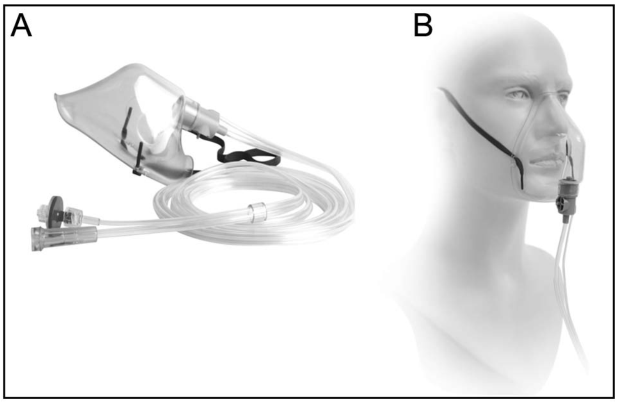

Fig. 1. A: Capnometry-type oxygen mask. This mask has a CO_2 sampling port next to the oxygen supply port. B: A capnometry-type oxygen mask is fitted like a normal face mask and can supply normal oxygen flow. Expiratory flow is drawn into the sidestream for measurement of end-tidal carbon dioxide concentration.

Table 1. Demographic and Perioperative Characteristics of Subjects

Characteristics	Subjects (*N* = 25)
Male, *n* (%)	15 (60)
Age, median (IQR), y	62 (57–76)
Weight, median (IQR), kg	59.7 (53.0–68.6)
BMI, median (IQR), kg/m^2	22 (20–24)
Smoker, *n* (%)	9 (36)
COPD, *n* (%)	4 (17)
Anesthesia duration, median (IQR), h	9.1 (7.4–10.6)
Hepatic surgery, *n* (%)	12 (48)
Pancreatoduodenectomy, *n* (%)	6 (24)
Cholecystectomy, *n* (%)	7 (28)
Laparotomy, *n*	5

IQR = interquartile range
BMI = body mass index

fusion mismatching.[4,17] In this study, we focused on accuracy of P_{ETCO_2} measurement using a capnometry-type oxygen mask in subjects without a past medical history of pulmonary disease.

The capnometer was calibrated before oxygen administration. Immediately after admission to the ICU, oxygen at 6 L/min was administered via an adult-size capnometry-type oxygen mask. The capnometry mask was positioned such that the bedside monitor displayed a normally shaped capnography waveform and a normal P_{ETCO_2} value. The P_{ETCO_2} was measured with a sidestream capnometer by spectrophotometry.

A blood sample for blood gas analysis was obtained from an artery before measurement of P_{ETCO_2}. After blood gas analysis, P_{ETCO_2} under the resting condition was measured using the capnometry-type oxygen mask; next, the subject was encouraged to take a few deep breaths, and P_{ETCO_2} under the deep-breathing condition was measured using the same device. Blood gas analysis and P_{ETCO_2} measurement were performed after a constant and normally shaped capnography waveform was confirmed after 30 min of oxygen administration.

Subjects who had episodes of apnea, dyspnea, and arterial desaturation (defined as $S_{pO_2} < 95\%$) were eliminated from this study. The study period was 30 min for each subject.

Statistics

Quantitative variables are expressed as median and interquartile range. The relationship between P_{ETCO_2} and P_{aCO_2} was analyzed by the Pearson product moment correlation coefficient for assessing validity and reliability. Because a few measurements were obtained for each subject, the mean bias and limits of agreement were estimated by a component of variance technique.[18] The agreement between P_{ETCO_2} and P_{aCO_2} was assessed using a Bland-Altman plot. Dissociation between P_{ETCO_2} and P_{aCO_2} under 2 breathing conditions was compared by the Student *t* test. For 2-tailed tests, $P < .05$ was considered statistically significant. Statistical analyses were performed with Prism 6 for Mac OS X 6.9b (GraphPad Software, San Diego, California).

Sample size was calculated based on power analysis performed with R 2.13.0 statistical software (R Foundation for Statistical Computing, Vienna, Austria), which showed that 20 samples were required for a 2-sided test with a significance of 0.05, power of 0.8, and estimated correlation coefficient of 0.6. Therefore, 27 subjects were enrolled in this study, considering the imminent elimination of subjects.

Results

Twenty-seven adult subjects were enrolled, and 2 subjects were excluded because their body mass index was > 30 kg/m^2. The characteristics of the subjects are provided in Table 1.

The results show that the capnometry-type oxygen mask was well tolerated by all subjects. No episodes of apnea or arterial desaturation were experienced during the study period. The correlation between P_{ETCO_2} and P_{aCO_2} under resting and deep-breathing conditions was statistically significant (Fig. 2). Pearson correlation analysis provided the following results: P_{aCO_2} versus resting P_{ETCO_2}, r = 0.50 (95% CI 0.126–0.745, *P* = .01); and P_{aCO_2} versus deep-breathing P_{ETCO_2}, r = 0.56 (95% CI 0.205–0.787, *P* = .001).

The Bland-Altman plot shows the relationship between blood gas analysis and P_{ETCO_2} for each subject (Fig. 3). The bias and limits of agreement were −12.6 (−20.6 to

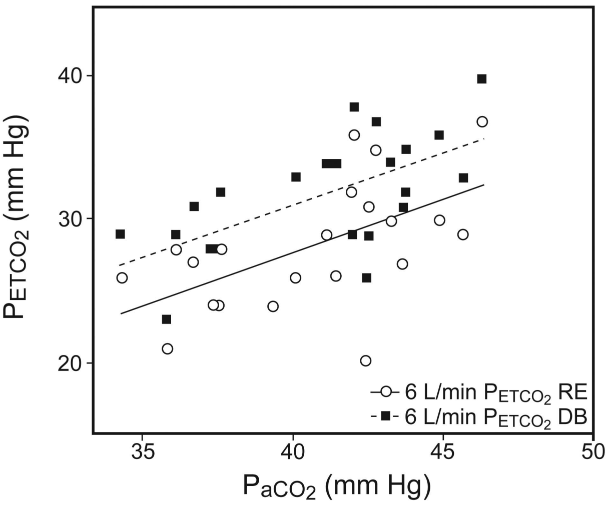

Fig. 2. Relationship between P_{aCO_2} and end-tidal carbon dioxide concentration (P_{ETCO_2}) under resting (RE) and deep-breathing (DB) conditions. P_{ETCO_2} and P_{aCO_2} were statistically correlated (r = 0.50 and 0.56, respectively).

−4.6) for resting P_{ETCO_2} and −9.1 (−16.1 to −2.1) for deep-breathing P_{ETCO_2}. The dissociation between deep-breathing P_{ETCO_2} and P_{aCO_2} was significantly smaller than that between resting P_{ETCO_2} and P_{aCO_2} (*P* = .002).

Discussion

To evaluate the use of a capnometry-type oxygen mask for continuous monitoring of CO_2 in subjects extubated after abdominal surgery, we compared P_{ETCO_2} measured by capnometry using the new capnometry-type oxygen mask with P_{aCO_2} measured by blood gas analysis. We also compared the dissociation between P_{aCO_2} and P_{ETCO_2} under resting and deep-breathing conditions.

In our study, P_{aCO_2} and P_{ETCO_2} were significantly correlated under various breathing conditions (resting condition, r = 0.50; deep breathing, r = 0.56). Normally, dissociation between P_{aCO_2} and P_{ETCO_2} depends on the sum of space composed of apparatus, anatomical, and physiological dead space. In the postoperative situation, various factors affect dead space, leading to the dissociation between P_{aCO_2} and P_{ETCO_2}. In our study, similar subjects with fewer respiratory complications were enrolled. Therefore, the sum of dead space was probably similar for all subjects, resulting in the statistically significant correlation between P_{aCO_2} and P_{ETCO_2}. However, the effect of other factors, such as comorbidity, skin incision, and postoperative pain, on postoperative respiratory function varied between subjects. These various perioperative conditions might affect a wide range of the limits of agreement. It was difficult to estimate the extent of dead space between subjects.

Statistically, the dissociation between P_{aCO_2} and deep-breathing P_{ETCO_2} was significantly smaller than that between P_{aCO_2} and resting P_{ETCO_2} (*P* = .002). We believe that the change in dissociation may be due to reduced ventilation/perfusion mismatching caused by a decrease in physiological dead space. Although continuous CO_2 monitoring with deep-breathing P_{ETCO_2} may be useful in clinical settings, it is difficult to predict the precise value of P_{aCO_2} under the 2 breathing conditions. Because the limits of agreement have a wide range and are similar for both breathing patterns (16.0 [resting] vs 14.0 [deep breathing]), the bias of P_{aCO_2} and P_{ETCO_2} becomes smaller during deep breathing (−12.6 to −9.1). Therefore, it is difficult to postulate which breathing pattern is superior for the

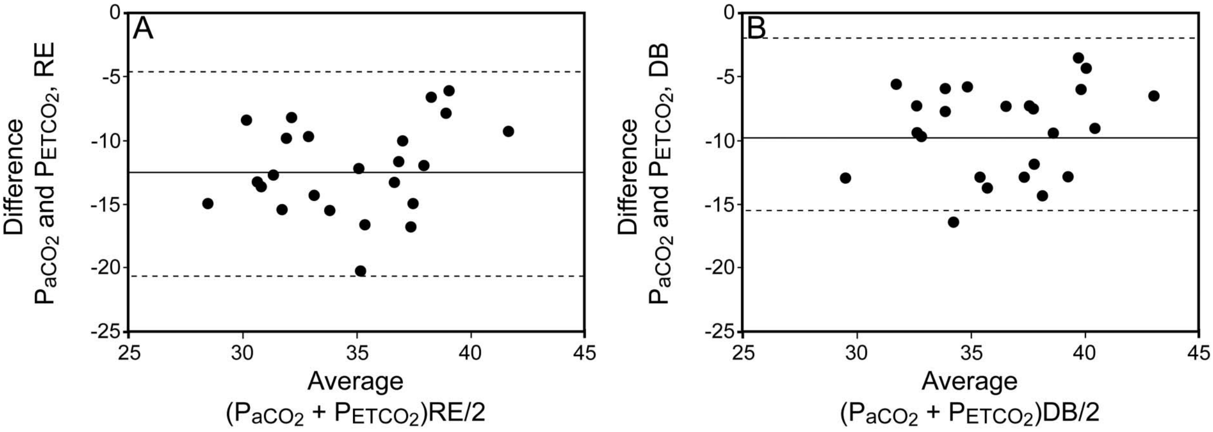

Fig. 3. A: The Bland-Altman plot shows differences in measurement of end-tidal carbon dioxide concentration (P_{ETCO_2}) under the resting condition (RE) and P_{aCO_2} at 6 L/min. The bias and limits of agreement were −12.6 (−20.6 to −4.6). B: The Bland-Altman plot shows differences in measurement of P_{ETCO_2} under the deep-breathing condition (DB) and P_{aCO_2} at 6 L/min. The bias and limits of agreement were −9.1 (−16.1 to −2.1).

prediction of P_{aCO_2}. Moreover, monitoring P_{ETCO_2} may not be useful for evaluating the absolute value of P_{aCO_2}; however, it may be useful for assessing the P_{aCO_2} trend.

In extubated subjects after general anesthesia, continuous monitoring of CO_2 using the capnometry-type oxygen mask correlated with P_{aCO_2}, especially under the deep-breathing condition. Continuous capnometric monitoring previously required the patient to be intubated; therefore, its use was limited mostly to ventilated patients. A nasal cannula and face mask have been developed to monitor spontaneous breathing patterns in subjects requiring supplemental oxygen.[11-13,19,20] However, a nasal cannula carries the risk of leakage if a patient exhales CO_2 through the mouth. The accuracy of CO_2 monitoring by a capnometer has been described; however, the relationship between P_{ETCO_2} under the deep-breathing condition and P_{aCO_2} has not been elucidated.

Continuous monitoring of P_{ETCO_2} is useful for arterial CO_2 assessment, particularly in patients with normal ventilation/perfusion relationships.[5] However, in cases of impaired ventilation/perfusion relationships, such as post-abdominal operations, P_{ETCO_2} monitoring for arterial CO_2 assessment is equivocal.

When patients resort to mouth breathing after extubation, nasal devices do not work. However, the capnometry-type oxygen mask samples expired CO_2 from both the nose and mouth, reducing the risk of false alarms. However, this mask also carries the risk of rebreathing that is exacerbated by high breathing rates and use of long sampling catheters.[21,22] Because the risk of rebreathing CO_2 during oxygen delivery at a low rate has not been evaluated, it seems advisable to reserve this device for patients who require a supplemental oxygen flow conventionally used for oxygen face masks ($>$ 5 L/min). In our study, the oxygen supplementation rate was 6 L/min, which minimized the risk of CO_2 rebreathing and is probably why none of the subjects developed CO_2 retention.

This study has several limitations. First, the sample size was small (25 subjects), and subjects who underwent open upper abdominal surgery or laparotomy were included. These diverse operation methods lead to varying extents of postoperative pain and respiratory muscle dysfunction. Functional disruption of respiratory muscles by incision, even after surgical repair, may impair their effectiveness. Furthermore, postoperative pain may limit respiratory motion and influence CO_2 production. Therefore, the usefulness of the capnometry-type oxygen mask in other conditions remains unclear. Second, smokers and subjects with COPD were enrolled in this study. However, previous studies on P_{ETCO_2} monitoring showed limited accuracy in both intubated and non-intubated subjects with pulmonary disease.[23,24] These comorbidities may affect pulmonary mechanisms after extubation. Third, data collection was not blinded, which may have affected P_{ETCO_2} measurement under the deep-breathing condition. This relates to our conclusion that deep breathing elevates P_{ETCO_2} due to reduction of ventilation/perfusion mismatching. However, in a few subjects, P_{ETCO_2} decreased after deep breathing compared with that under the resting condition. The P_{ETCO_2} was measured only twice by blood gas analysis. Therefore, it was difficult to confirm the usefulness of this device for continuous respiratory monitoring.

Conclusions

Further studies should be undertaken on continuous monitoring of P_{ETCO_2} during the entire postoperative period using this device following similar surgeries with similar pulmonary conditions. In summary, our study shows that it is possible to measure the P_{ETCO_2} under varying breathing conditions with the capnometry-type oxygen mask in subjects receiving oxygen supplementation after extubation following upper abdominal surgery to determine whether they are properly ventilating.

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