Accuracy of Postoperative End-Tidal $PCO_2$ Measurements with Mainstream and Sidestream Capnography in Non-obese Patients and in Obese Patients with and without Obstructive Sleep Apnea

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Background: Obtaining accurate end-tidal carbon dioxide pressure measurements via nasal cannula poses difficulties in postanesthesia patients who are mouth breathers, including those who are obese and those with obstructive sleep apnea (OSA); a nasal cannula with an oral guide may improve measurement accuracy in these patients. The authors evaluated the accuracy of a mainstream capnometer with an oral guide nasal cannula and a sidestream capnometer with a nasal cannula that did or did not incorporate an oral guide in spontaneously breathing non-obese patients and obese patients with and without OSA during recovery from general anesthesia.

Methods: The study enrolled 20 non-obese patients (body mass index less than 30 kg/m²) without OSA, 20 obese patients (body mass index greater than 35 kg/m²) without OSA, and 20 obese patients with OSA. End-tidal carbon dioxide pressure was measured by using three capnometer/cannula combinations (oxygen at 4 l/min): (1) a mainstream capnometer with oral guide nasal cannula, (2) a sidestream capnometer with a nasal cannula that included an oral guide, and (3) a sidestream capnometer with a standard nasal cannula. Arterial carbon dioxide partial pressure was determined simultaneously. The major outcome was the arterial-to-end-tidal partial pressure difference with each combination.

Results: In non-obese patients, arterial-to-end-tidal pressure difference was 3.0 ± 2.6 (mean ± SD) mmHg with the mainstream capnometer, 4.9 ± 2.3 mmHg with the sidestream capnometer and oral guide cannula, and 7.1 ± 3.5 mmHg with the sidestream capnometer and a standard cannula ($P < 0.05$). In obese non-OSA patients, it was 3.9 ± 2.6 mmHg, 6.4 ± 3.1 mmHg, and 8.1 ± 5.0 mmHg, respectively ($P < 0.05$). In obese OSA patients, it was 4.0 ± 3.1 mmHg, 6.3 ± 3.2 mmHg, and 8.3 ± 4.6 mmHg, respectively ($P < 0.05$).

Conclusions: Mainstream capnometry performed best, and an oral guide improved the performance of sidestream capnometry. Accuracy in non-obese and obese patients, with and without OSA, was similar.

END-TIDAL carbon dioxide partial pressure ($EtC0_2$) is a breath-to-breath and noninvasive estimate of arterial carbon dioxide tension. Monitoring $EtC0_2$ during general anesthesia is considered a standard of care and is believed to reduce ventilation-related complications.

Postoperative respiratory monitoring is important because respiratory failure is the second most common postoperative morbidity after ischemic heart events. Because various factors are associated with postoperative respiratory depression, such as age, type of surgery, and use of opioids, it is difficult to predict which patient will experience respiratory complications and when. Opioid-induced respiratory depression is especially hard to predict. Furthermore, postoperative opioid administration is common, which presumably increases the likelihood of respiratory depression. According to Overdyk et al., more than 40% of patients whose pain is controlled with patient-controlled analgesia systems experience a bradypnea episode.

Currently, $EtC0_2$ monitoring is not a standard procedure during postoperative recovery. Obese and obstructive sleep apnea (OSA) patients at risk for respiratory complications may benefit from $EtC0_2$ monitoring, especially in the early postoperative period. Although measuring $EtC0_2$ in intubated patients is technically easy, it can be difficult to obtain accurate values in the postanesthetic care unit (PACU) when patients are no longer intubated. Some investigators report that $EtC0_2$ can be accurately measured via a nasal cannula during spontaneous ventilation in both adult and pediatric patients. However, in spontaneously breathing, unintubated patients, sampling $EtC0_2$ through a nasal cannula is potentially problematic when expired gas mixes with ambient air. The resulting inaccurate measurements produce artificially low values compared to a closed system with minimal dead space (e.g., a mouth piece, mask, or endotracheal tube). Furthermore, in our experience, $EtC0_2$ measurements collected through the nasal cannula are usually inaccurate when patients breathe through their mouths.

Conventional sidestream capnometers, as might be used in the PACU, can compromise the accuracy of $EtC0_2$ values in two ways. First, a high aspiration flow rate (i.e., 100–150 ml/min) dilutes the expired gas sample with entrained ambient air. Second, the sample line can become occluded with water and secretions, delaying $EtC0_2$ readings. Two new capnometers designed for measurement of $EtC0_2$ in unintubated patients have recently become available com-
We thus tested the following hypotheses: (1) the arterial-
duced because of the low flow rate. The other new
pathway caused by moisture and humidity are re-
duced accuracy and response time. Obstructions in
adequate accuracy and response time. Obstructions in
sample cell. Because the sample cell is so small, the gas
flow rate can be reduced to 50 ml/min while maintaining
maintenance adequate accuracy and response time. Obstructions in
the pathway caused by moisture and humidity are re-
duced because of the low flow rate. The other new
capnometer is a mainstream system designed for use in
unintubated patients (Cap-ONE; Nihon Kohden, Tokyo,
Japan). It weighs only 10 g, so it is small enough to be
incorporated into a nasal cannula, preventing distortion
of the capnogram. As the mainstream carbon dioxide
sensor is located on the site that covers both oral and
nasal exhaled gas passways, it does not require a sam-
pling tube. Errors caused by ambient air mixing with the
sample gas are thus less likely than with other systems.
With the mainstream device, water and secretion ob-
structions are less likely to interfere with measurements.

Intermittent mouth breathing might also contribute to
 underestimated EtCO₂ values. Exhaled flow distribution be-
tween the mouth and nose highly affects the accuracy of
capnometry. Mouth breathing is common in obese pa-
tients, especially those with a history of OSA. Nasal
obstruction is associated with apneic episodes during
sleep, and nasal airway resistance tends to be high in OSA
patients. To reduce the effect of oral breathing on the
capnogram, nasal cannula are now available that include an
oral guide designed to trap exhaled gas via mouth and to
improve the accuracy of EtCO₂ measurements in patients
who breathe through their mouths.

It remains unknown whether mainstream capnog-
rophy systems perform better than conventional side-
stream systems in PACU patients, especially in patients
who are obese, with or without obstructive sleep apnea.
It is also unknown whether adding an oral guide to nasal
cannulae improves EtCO₂ measurements in the PACU.
We thus tested the following hypotheses: (1) the arterial-
to-end-tidal partial pressure difference (ΔCO₂) is less with
mainstream than sidestream devices; (2) ΔCO₂ is greater
in obese versus non-obese patients, and greater still in
obese patients with obstructive sleep apnea; (3) a nasal
cannula with an oral guide outperforms a similar cannula
without an oral guide.

Materials and Methods

The University of Louisville Human Studies Committee
(Louisville, Kentucky) approved the protocol, and each
patient gave written informed consent. We recruited 60
patients who were scheduled for general anesthesia with
continuous arterial pressure monitoring via an arterial
catheter; 20 were non-obese (defined by a body mass
index less than 30 kg/m²) without a diagnosis of OSA
(Non-obese non-OSA), 20 were obese (body mass index
greater than 35 kg/m²) without a diagnosis of OSA
(Obese non-OSA), and 20 were obese with OSA diag-
nosed by polysomnography (Obese OSA).

To avoid assigning undiagnosed OSA patients in either
of the non-OSA groups, patients were asked to complete
the Epworth Sleepiness Scale, a simple questionnaire
to determine daytime sleepiness. Patients having an Ep-
worth Sleepiness Scale of 10 or more were excluded
from the non-OSA groups. Patients with known severe
pulmonary disease (Hugh-Jones classification grade 3 or
above), cardiac disease (New York Heart Association
classification grade 3 or above), or who would be indi-
cated for a facemask for postoperative oxygen delivery
rather than nasal cannula were also excluded.

General anesthesia was administered by using tracheal
intubation or a laryngeal mask airway, with no other restric-
tions on anesthetic management.

Measurements

Patients were extubated in the operation room and
just after patients admitted to PACU, patients were ran-
domly assigned to three different capnometer systems
device/cannula combination (fig. 1): (A) Cap-ONE
mainstream capnometer system (Nihon Kohden) that
includes an oral guided nasal cannula (Mainstream oral
guide); (B) Microcap sidestream capnometer with a
Smart CapnoLine Plus nasal cannula (Oridion Capnog-
raphy Inc.) that incorporates an oral guide along with
ACCURACY OF MAINSTREAM CAPNOGRAPHY

Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Non-obese Non-OSA (n = 20)</th>
<th>Obese Non-OSA (n = 20)</th>
<th>Obese OSA (n = 20)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>55.7 ± 11.0</td>
<td>49.6 ± 10.8</td>
<td>50.3 ± 14.1</td>
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<td>4/16</td>
<td>5/15</td>
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<td>Race</td>
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<td></td>
<td></td>
<td>0.58</td>
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<td>Caucasian</td>
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<td>16</td>
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<tr>
<td>African American</td>
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<td></td>
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<tr>
<td>Asian</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td></td>
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<tr>
<td>Latino</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>24.4 ± 2.7</td>
<td>40.2 ± 7.4*</td>
<td>40.1 ± 6.8*</td>
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<tr>
<td>Height, cm</td>
<td>168 ± 8</td>
<td>164 ± 6</td>
<td>166 ± 8</td>
<td>0.20</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>69 ± 10</td>
<td>108 ± 20*</td>
<td>111 ± 24*</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Philtrum, mm</td>
<td>17 ± 2</td>
<td>18 ± 3</td>
<td>18 ± 4</td>
<td>0.50</td>
</tr>
<tr>
<td>Epworth Sleepiness Scale</td>
<td>2.1 ± 1.8</td>
<td>2.3 ± 2.1</td>
<td>10.3 ± 3.3*</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

Data reported as means ± SDs or number of patients. * Statistically significantly different (P < 0.05) from Non-obese non-OSA patients. † Statistically significantly different (P < 0.05) from both the Non-obese non-OSA and Obese non-OSA patients.

BMI = body mass index; Non-obese non-OSA = normal weight patients (defined as a BMI < 30 kg/m²) without a diagnosis of OSA; Obese non-OSA = obese patients (body mass index > 35 kg/m²) without a diagnosis of OSA; Obese OSA = obese patients (body mass index > 35 kg/m²) with polysomnography-diagnosed OSA.

A carbon dioxide sampling port (Sidestream oral guide); or (C) Microcap sidestream capnometer (Oridion Capnography Inc.) with a CapnoLine H nasal cannula (standard nasal cannula with no oral guide) (Sidestream standard).

All patients had their EtCO₂ measured by using each system and a constant oxygen flow rate of 4 l/min through the nasal cannula. Because the respiratory state was not always stable during the measurements and might be influenced by opioids given for pain control, the application order of the two capnometers and two sidestream cannulas was randomized on the basis of computer-generated assignments that were kept in sequentially numbered opaque envelopes that were opened in the PACU.

Exhaled carbon dioxide was recorded (capnogram) for 5 min by using each capnometer system. At the end of each 5-min interval, an arterial blood sample was taken for blood gas analysis. (GEM Premier 3000; Instrumentation Laboratory, Lexington, MA).

Morphometric and demographic characteristics of the participating patients were recorded, i.e., age, body weight, height, body mass index, gender, race, length of philtrum, and type of surgery. EtCO₂ was determined breath-by-breath by each capnograph. The average EtCO₂ during the final 60 s of 5-min measurement period was recorded by a computerized system.

During measurements, if needed hydromorphone or morphine was given for analgesia according to physician’s order who was independent of this study.

Data Analysis

Our major outcome was the accuracy of EtCO₂ measurements with each capnometer system in the three patient groups. The mean EtCO₂ value for each device/cannula combination measurements was subtracted from the arterial partial pressure of carbon dioxide (PaCO₂) measurement that was measured simultaneously. This provided the difference between the EtCO₂ and the PaCO₂ (ΔCO₂), which defined accuracy.

An average ΔCO₂ difference of 3 mmHg between any two combinations of capnometers and nasal cannulas in obese versus non-obese or OSA versus non-OSA was determined a priori as technically important bias. From a preliminary study of the mainstream device (cap-ONE; Nihon Kohden), we expected the SD of the ΔCO₂ to be 4.5 mmHg. Assuming values within patients to be correlated at least at r = 0.5, we needed 17 patients in each patient group to have 90% power to detect a difference of 3 mmHg with a repeated-measures ANOVA, α = 0.05.

Our secondary outcome was oxygenation efficacy. EtCO₂, ΔCO₂, and Pao₂ were compared in a two-factor (both having three levels), mixed model, repeated-measures ANOVA. The factors were (1) the three device/cannula combinations (Mainstream oral guide, Side- stream oral guide, and Sidestream standard) and (2) the three patient groups (Non-obese non-OSA, Obese non-OSA, Obese OSA). Significant differences between groups were analyzed using Tukey post hoc testing. To further analyze the effectiveness of each combination of capnometer and nasal cannula, we examined Pearson’s...
correlation coefficient and used a Bland-Altman analysis to check for bias and effect modification with the capnometer and nasal cannula combinations across the full range of measured values.21

Data are presented as means ± SDs for continuous variables and percentages for categorical variables. $P < 0.05$ was considered statistically significant. All statistical analyses were done by SPSS for Windows version 16.0 (SPSS Inc, Chicago, IL).

Results

A total of 180 EtCO2–PaCO2 measurement pairs were analyzed from 60 patients. Of these, 20 patients were non-obese without OSA (Non-obese non-OSA), 20 were obese without OSA (Obese non-OSA), and 20 were obese with OSA (Obese OSA). Patient characteristics for the three groups are shown in table 1. Although gender was not uniformly distributed among the groups, the length of the philtrum was similar in all groups. Patients in the Obese OSA group reported a significantly greater Epworth Sleepiness Scale score (10 ± 3) than the Non-obese non-OSA group (2 ± 2) and the Obese non-OSA group (2 ± 2; $P < 0.001$). No patients in the Non-obese non-OSA or Obese non-OSA groups reported a score greater than 10.

There were significant differences inΔCO2 among the three device/cannula combinations in all three patient groups. ΔCO2 was smallest when measured with the mainstream capnometer, slightly greater with the sidestream capnometer with an oral guide, and greater still for the sidestream capnometer with the standard nasal cannula (fig. 2).

PaO2 was similar in all groups during all device/cannula combinations, except for the obese non-OSA patients who had a higher PaO2 during the period when they were measured by sidestream standard device (fig. 3). All other blood gas measurements, including pH, bicarbonate, base excess, and PaCO2, were similar among device/cannula combinations in all patient groups.

The correlations between EtCO2 and PaCO2 are shown in figure 4. Correlation coefficients were highest with the Mainstream oral guide device and lowest with the Sidestream standard device, but they tended to be highest in Non-obese non-OSA group and lowest in Obese OSA group. Carbon dioxide data and correlations were the most accurate when using the mainstream device.

The bias in the relationship between EtCO2 and PaCO2 is illustrated in figure 5 where the difference is plotted against the average of the values.21 On Bland-Altman plots, bias was more widely distributed in Obese patients with and without OSA. Bias was also greater with the standard nasal cannula than with the cannula that included an oral guide.

Discussion

This study shows that EtCO2 measured with a mainstream capnometer produces better correlation between...
Etco\textsubscript{2} and Paco\textsubscript{2} than other systems. Our results also indicate that both obesity and OSA reduce the correlation between Etco\textsubscript{2} and Paco\textsubscript{2} and accordingly increase Δ\textsubscript{CO}_2 unpredictably. Bland-Altman plots show that the mainstream capnogram was more accurate in predicting Paco\textsubscript{2} than the sidestream system, especially in patients with obesity and OSA.

In healthy young adults, Δ\textsubscript{CO}_2 is normally between 2 and 5 mmHg.\textsuperscript{22,23} Δ\textsubscript{CO}_2 tends to increase with age, obstructive lung disease, in situations where alveolar dead
space increases\textsuperscript{24} and results in a ventilation-perfusion mismatch, and with hemodynamic instability as well. Ventilation and perfusion mismatch is commonly increased immediately after endotracheal tube extubation because of transient atelectasis. Obesity is also considered to be a risk factor for postoperative atelectasis.\textsuperscript{25} Obese patients are therefore prime candidates for having a large $\Delta$CO$_2$ in during recovery. Takano et al.\textsuperscript{26} showed that $\Delta$CO$_2$ is highly dependent on tidal volume. $\Delta$CO$_2$ is expected to be high when the tidal volume is near dead space volume or when the respiratory rate gets too high to give an end-expiratory plateau, or patient’s airway is partially obstructed due to bronchospasm.\textsuperscript{27}

The determined $\Delta$CO$_2$ values in this study were greater than those previously reported. Bowe et al.\textsuperscript{9} reported a $\Delta$CO$_2$ of 2.1 $\pm$ 2.2 mmHg and a Paco$_2$ of 38.6 $\pm$ 3.8 mmHg by using a sidestream nasal cannula capnometer in preanesthetic patients getting 3 l/min oxygen. The most likely reason for the differences between the reported values is the dissimilarity of the circumstances under which the data were collected. Bowe et al. obtained their data before induction of anesthesia, whereas our results were obtained during recovery. This is an important distinction because hypoventilation or mouth breathing diminishes nasal expiratory flow rate, thereby increasing $\Delta$CO$_2$.

EtCO$_2$ is defined as partial pressure of carbon dioxide at the end of the expiratory phase of the respiratory cycle. However, dilution and a physiologic obstructed pattern often results in inconsistency of the expiratory plateau and slope of Phase 3 of the EtCO$_2$ waveform.\textsuperscript{28} Consequently, EtCO$_2$ values are especially misleading under the combination of severe obstructive pattern, low expiratory flow, low peak flow rates, and high fresh oxygen supply.

Given that the oxygen supply rate of 4 l/min was constant for all patients, the inconsistencies of $\Delta$CO$_2$ between patient groups likely resulted from differences in dead space and respiratory pattern for each patient group. Our results demonstrate that the arterial-to-end-tidal PaCO$_2$ gradient in spontaneously breathing postoperative patients depends on the patient population and type of capnometer. Oral guide devices proved to be more accurate measure of EtCO$_2$ as compared to a standard sidestream measurement. In non-obese and obese patients without OSA, readings from mainstream capnometers were both accurate and statistically significantly better than alternative approaches.

We note, though, that even in obese OSA patients—the most vulnerable patient population\textsuperscript{29}—the difference of mean $\Delta$CO$_2$ between mainstream device and sidestream with conventional cannula was only 4.3 mmHg. This difference is relatively small because many clinicians already assume that EtCO$_2$ underestimates arterial partial pressures by 2–5 mmHg. But an important factor is that the correlation between EtCO$_2$ and PaCO$_2$ was low without an oral guide in obese OSA patients ($r = 0.39$) and was markedly improved by addition of an oral guide ($r = 0.72$). Considering that OSA patients are at the high risk for adverse respiratory events and that intense respiratory monitoring is recommended, our results support using a cannula that includes an oral guide for OSA patients.

The cost of these systems is difficult to estimate because there are differences from country-to-country, and cost depends on use levels and negotiating power of specific hospitals. However, it appears that the nondisposable and disposable components for each tested system cost similar amounts. To the extent that this proves to be the case in any particular hospital, clinicians will presumably prefer the most accurate system.

In summary, mainstream capnometry performed best, and an oral guide improved the performance of sidestream capnometry. Accuracy in non-obese and obese patients, with and without OSA, was similar.

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References