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Accuracy of Postoperative End-tidal P_{CO_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/m^2) without OSA, 20 obese patients (body mass index greater than 35 kg/m^2) 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 ($Etco_2$) is a breath-to-breath and noninvasive estimate of arterial carbon dioxide tension.[1,2] Monitoring $Etco_2$ during general anesthesia[3,4] is considered a standard of care and is believed to reduce ventilation-related complications.[5]

Postoperative respiratory monitoring is important because respiratory failure is the second most common postoperative morbidity after ischemic heart events.[6] 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.*,[7] more than 40% of patients whose pain is controlled with patient-controlled analgesia systems experience a bradypnea episode.

Currently, $Etco_2$ monitoring is not a standard procedure during postoperative recovery. Obese and obstructive sleep apnea (OSA) patients at risk for respiratory complications may benefit from $Etco_2$ monitoring, especially in the early postoperative period.[8] Although measuring $Etco_2$ 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 $Etco_2$ can be accurately measured *via* a nasal cannula during spontaneous ventilation in both adult and pediatric patients.[9–11] However, in spontaneously breathing, unintubated patients, sampling $Etco_2$ 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).[12,13] Furthermore in our experience, $Etco_2$ 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 $Etco_2$ 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 $Etco_2$ readings.[14] Two new capnometers designed for measurement of $Etco_2$ in unintubated patients have recently become available com-

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mercially. Nasal cannulas with an oral guide designed to capture expiratory flow from the mouth are available for both systems and may increase the accuracy of $Etco_2$ measurements during oral breathing.

The first new capnometer is a sidestream model, Microstream (Microcap, Oridion Capnography Inc., Needham, MA). Most capnometer technology has been based on nondispersive black body infrared radiation techniques; however, Microstream technology is based on molecular correlation spectroscopy (MCS) that generates an infrared emission, matching the absorption spectrum of the carbon dioxide molecule. The high emission efficiency and carbon dioxide specificity allows for a short light path and allows the use of a small 15-μl sample cell. Because the sample cell is so small, the gas flow rate can be reduced to 50 ml/min while maintaining adequate accuracy and response time. Obstructions in the pathway caused by moisture and humidity are reduced because of the low flow rate.[15] 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 sampling 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 obstructions are less likely to interfere with measurements.

Intermittent mouth breathing might also contribute to underestimated $Etco_2$ values. Exhaled flow distribution between the mouth and nose highly affects the accuracy of capnometry. Mouth breathing is common in obese patients, especially those with a history of OSA.[16,17] Nasal obstruction is associated with apneic episodes during sleep, and nasal airway resistance tends to be high in OSA patients.[18,19] 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 $Etco_2$ measurements in patients who breathe through their mouths.

It remains unknown whether mainstream capnography systems perform better than conventional sidestream 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 $Etco_2$ measurements in the PACU. We thus tested the following hypotheses: (1) the arterial-to-end-tidal partial pressure difference (Δco_2) is less with mainstream than sidestream devices; (2) Δco_2 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/m^2) without a diagnosis of OSA (Non-obese non-OSA), 20 were obese (body mass index greater than 35 kg/m^2) without a diagnosis of OSA (Obese non-OSA), and 20 were obese with OSA diagnosed 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,[20] a simple questionnaire to determine daytime sleepiness. Patients having an Epworth 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 indicated 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 restrictions on anesthetic management.

Measurements

Patients were extubated in the operation room and just after patients admitted to PACU, patients were randomly 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 Capnography Inc.) that incorporates an oral guide along with

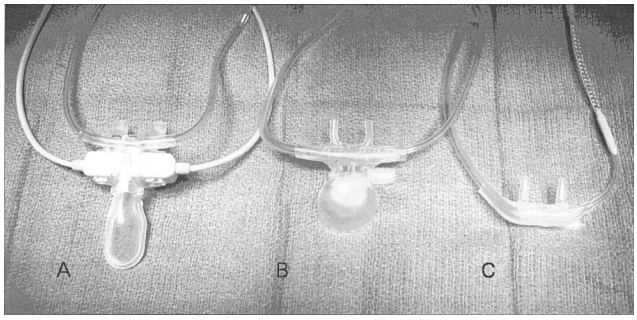

Fig. 1. (*A*) Cap-ONE (Nihon Kohden, Tokyo, Japan), mainstream capnometer system that includes an oral guided nasal cannula. (*B*) Smart CapnoLine Plus cannula (Oridion Capnography Inc., Needham, MA), a nasal cannula for sidestream Microcap capnometer with oral guide. (*C*) CapnoLine H cannula (Oridion Capnography Inc., Needham, MA), a conventional nasal cannula (with no oral guide) for sidestream Microcap capnometer.

Table 1. Patient Characteristics

	Non-obese Non-OSA (n = 20)	Obese Non-OSA (n = 20)	Obese OSA (n = 20)	*P* Value
Age, yrs	55.7 ± 11.0	49.6 ± 10.8	50.3 ± 14.1	0.23
Gender, male/female	13/7	4/16	5/15	0.005
Race				0.58
Caucasian	14	16	17	
African American	5	3	2	
Asian	1	1	0	
Latino	0	0	1	
BMI, kg/m^2	24.4 ± 2.7	40.2 ± 7.4*	40.1 ± 6.8*	< 0.001
Height, cm	168 ± 8	164 ± 6	166 ± 8	0.20
Weight, kg	69 ± 10	108 ± 20*	111 ± 24*	< 0.001
Philtrum, mm	17 ± 2	18 ± 3	18 ± 4	0.50
Epworth Sleepiness Scale	2.1 ± 1.8	2.3 ± 2.1	10.3 ± 3.3*†	< 0.001
Type of surgery				
Gynecological	3	13	8	
Orthopedic	1	1	3	
Spine	3	0	1	
Major vascular	2	3	4	
Thoracotomy	4	1	2	
Neurosurgical or neurointerventional	3	0	0	
Other major abdominal	4	2	1	
Mastectomy	0	0	1	

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/m^2) without a diagnosis of OSA; Obese non-OSA = obese patients (body mass index > 35 kg/m^2) without a diagnosis of OSA; Obese OSA = obese patients (body mass index > 35 kg/m^2) 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 $Etco_2$ 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. $Etco_2$ was determined breath-by-breath by each capnograph. The average $Etco_2$ 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 $Etco_2$ measurements with each capnometer system in the three patient groups. The mean $Etco_2$ value for each device/cannula combination measurements was subtracted from the arterial partial pressure of carbon dioxide ($Paco_2$) measurement that was measured simultaneously. This provided the difference between the $Etco_2$ and the $Paco_2$ (Δco_2), which defined accuracy.

An average Δco_2 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 Δco_2 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, $\alpha = 0.05$.

Our secondary outcome was oxygenation efficacy. $Etco_2$, Δco_2, and Pao_2 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, Sidestream 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

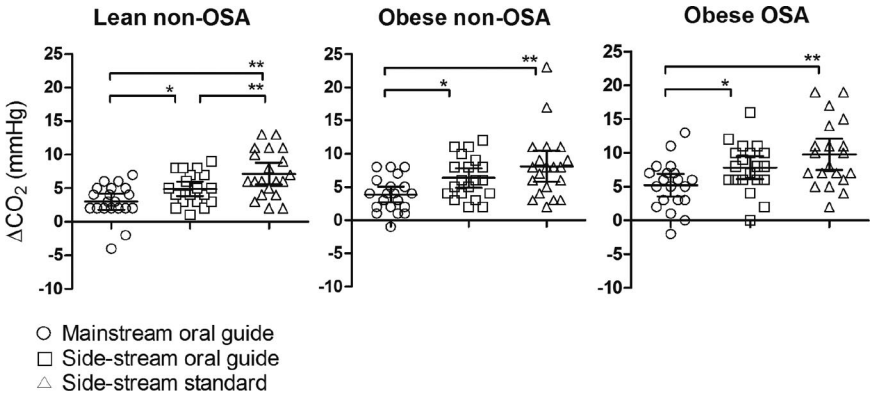

Fig. 2. The arterial-to-end-tidal partial pressure difference (Δco_2) for each device/cannula and patient group. Individual data points are plotted along with mean and 95% confidential interval for 20 normal weight patients (defined as a body mass index < 30 kg/m^2) without a diagnosis of obstructive sleep apnea (Non-obese non-OSA), 20 obese patients (body mass index > 35 kg/m^2) without a diagnosis of obstructive sleep apnea (Obese non-OSA), and 20 obese patients with polysomnography-diagnosed obstructive sleep apnea (Obese OSA). * P < 0.05; ** P < 0.01.

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 $Etco_2$–$Paco_2$ 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 in Δco_2 among the three device/cannula combinations in all three patient groups. Δco_2 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).

Pao_2 was similar in all groups during all device/cannula combinations, except for the obese non-OSA patients who had a higher Pao_2 during the period when they were measured by sidestream standard device (fig. 3). All other blood gas measurements, including pH, bicarbonate, base excess, and $Paco_2$, were similar among device/cannula combinations in all patient groups.

The correlations between $Etco_2$ and $Paco_2$ 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 $Etco_2$ and $Paco_2$ 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 $Etco_2$ measured with a mainstream capnometer produces better correlation between

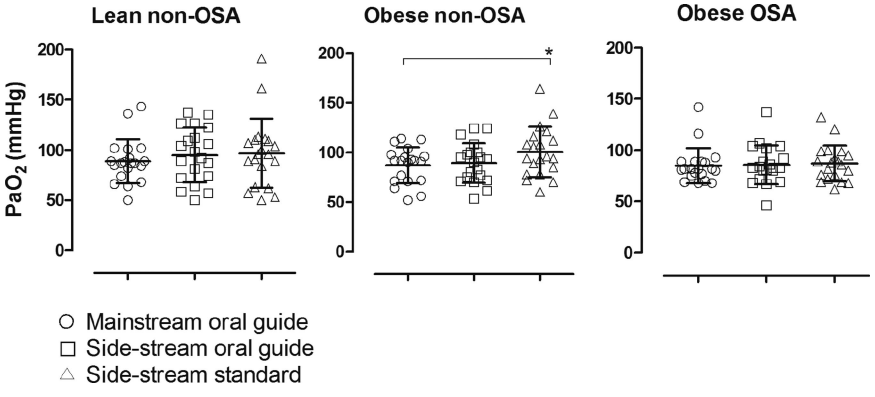

Fig. 3. Arterial oxygen partial pressure (Pao_2) with each device/cannula and patient group. Individual data points are plotted along with means and SDs for 20 normal weight patients (defined as a body mass index < 30 kg/m^2) without a diagnosis of obstructive sleep apnea (Non-obese non-OSA), 20 obese patients (body mass index > 35 kg/m^2) without a diagnosis of obstructive sleep apnea (Obese non-OSA), and 20 obese patients with polysomnography-diagnosed obstructive sleep apnea (Obese OSA). * P < 0.05.

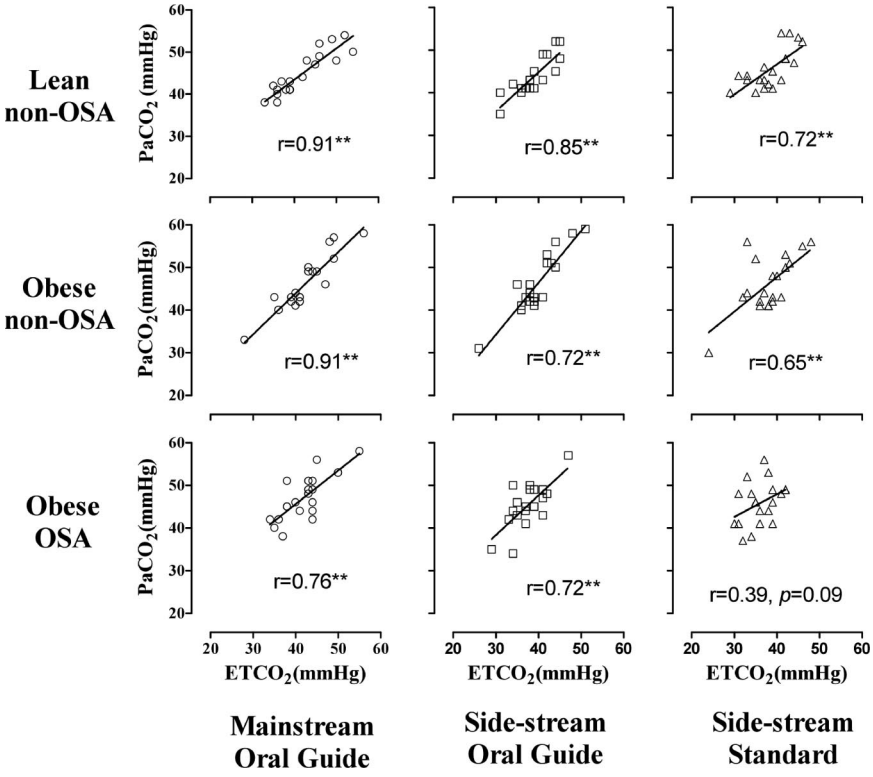

Fig. 4. Pearson correlation coefficients between end-tidal carbon dioxide pressure ($Etco_2$) and arterial carbon dioxide pressure ($Paco_2$) with each device/cannula and patient group. Patient groups are normal weight patients (defined as a body mass index < 30 kg/m^2) without a diagnosis of obstructive sleep apnea (Non-obese non-OSA), obese patients (body mass index > 35 kg/m^2) without a diagnosis of obstructive sleep apnea (Obese non-OSA), and obese patients (body mass index > 35 kg/m^2) with obstructive sleep apnea (Obese OSA). ** P < 0.01.

$Etco_2$ and $Paco_2$ than other systems. Our results also indicate that both obesity and OSA reduce the correlation between $Etco_2$ and $Paco_2$ and accordingly increase Δco_2 unpredictably. Bland-Altman plots show that the mainstream capnogram was more accurate in predicting $Paco_2$ than the sidestream system, especially in patients with obesity and OSA.

In healthy young adults, Δco_2 is normally between 2 and 5 mmHg.[22,23] Δco_2 tends to increase with age, obstructive lung disease, in situations where alveolar dead

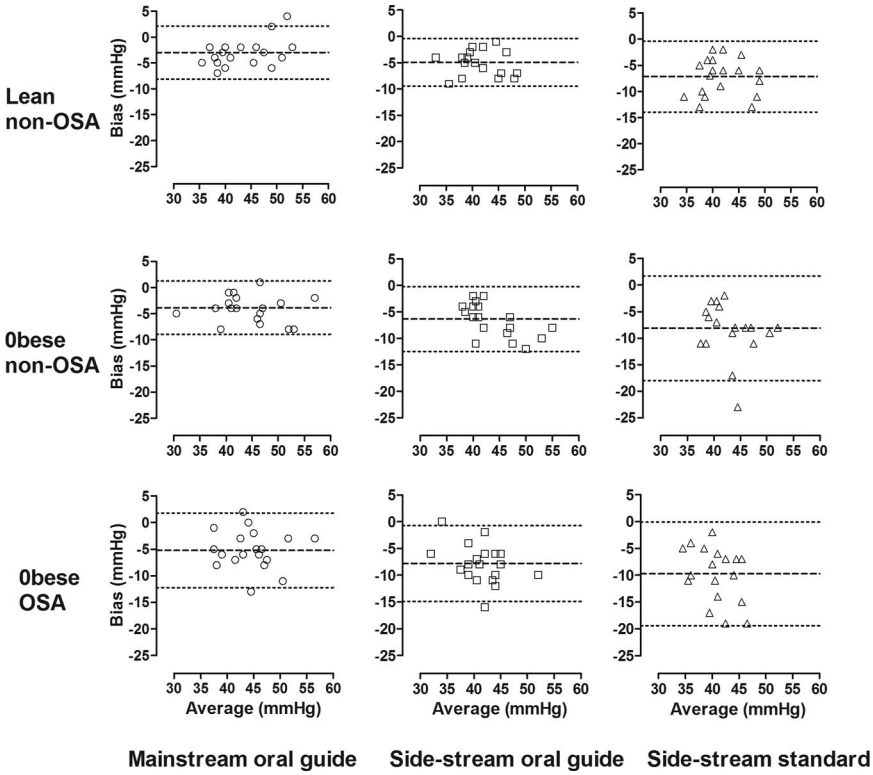

Fig. 5. Bland-Altman plot. Solid broken lines represent mean of the bias and thin broken lines represent 95% CI for 20 normal weight patients (defined as body mass index < 30 kg/m^2) without a diagnosis of obstructive sleep apnea (Non-obese non-OSA), 20 obese patients (body mass index > 35 kg/m^2) without a diagnosis of obstructive sleep apnea (Obese non-OSA), and 20 obese patients with polysomnography-diagnosed obstructive sleep apnea (Obese OSA).

space increases[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.[25] Obese patients are therefore prime candidates for having a large ΔPco_2 in during recovery. Takano *et al.*[26] showed that ΔPco_2 is highly dependent on tidal volume. ΔPco_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.[27]

The determined ΔPco_2 values in this study were greater than those previously reported. Bowe *et al.*[9] reported a ΔPco_2 of 2.1 ± 2.2 mmHg and a $Paco_2$ of 38.6 ± 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 ΔPco_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.[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 ΔPco_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 Pco_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[29]—the difference of mean ΔPco_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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