Disparity Between Mainstream and Sidestream End-Tidal Carbon Dioxide Values and Arterial Carbon Dioxide Levels

Murat Pekdemir MD, Orhan Cinar MD, Serkan Yılmaz MD, Elif Yaka MD, and Melih Yuksel MD

BACKGROUND: Measuring and monitoring end-tidal carbon dioxide (P_{ETCO_2}) is an important aspect of caring for critically ill patients. The 2 methods used for P_{ETCO_2} measurement are the mainstream and sidestream methods. OBJECTIVE: To assess the agreement between P_{ETCO_2} measurements performed by mainstream and sidestream methods with the P_{aCO_2} values. METHODS: This was a prospective observational study. A total of 114 subjects were enrolled in the study. P_{ETCO_2} measurements using mainstream and sidestream methods were performed simultaneously with the arterial blood sampling in subjects who were observed in the emergency department and required arterial blood gas analysis. Agreement between the P_{ETCO_2} measurements and the P_{aCO_2} values obtained from arterial blood gas analysis were evaluated using the Bland-Altman method. RESULTS: Sixty subjects (52.6%) were female, and the mean age was 60.9 years (95% CI 58.3–63.6). The mean P_{aCO_2} was 35.16 mm Hg (95% CI 33.81–36.51), the mainstream P_{ETCO_2} was 22.11 (95% CI 21.05–23.18), and the sidestream P_{ETCO_2} was 25.48 (95% CI 24.22–26.75). Bland-Altman analysis showed an average difference between mainstream P_{ETCO_2} and P_{aCO_2} values of 13 mm Hg (95% limits of agreement −0.6 to 25.5) and moderate correlation (r = 0.55, $P < .001$). The average difference between the sidestream P_{ETCO_2} and P_{aCO_2} values was 9.7 mm Hg (95% limits of agreement −5.4 to 24.7) and poor correlation (r = 0.41, $P < .001$). CONCLUSIONS: P_{ETCO_2} values obtained by mainstream and sidestream methods were found to be significantly lower than the P_{aCO_2} values. There was essentially no agreement between the measurements obtained by 2 different methods and the P_{aCO_2} values. *Key words: end-tidal carbon dioxide; noninvasive; mainstream; sidestream; arterial carbon dioxide.* [Respir Care 2013;58(7):1152–1156. © 2013 Daedalus Enterprises]

Introduction

Measuring and monitoring end-tidal carbon dioxide (P_{ETCO_2}) is an important aspect of caring for critically ill patients. While P_{ETCO_2} monitoring was initially used by clinicians to confirm the place of the endotracheal tube and mechanically ventilated patients in the emergency department (ED), today there is a greater utilization of it for purposes such as monitoring the quality of cardiopulmonary resuscitation and evaluating the causes of bronchospasm.[1-5] Furthermore, P_{ETCO_2} measurement has been studied to predict P_{aCO_2} or bicarbonate levels.[6,7]

P_{ETCO_2} measures the amount of CO_2 in the patient's exhaled air by a sensor. Depending on the location of the sensor, the measurement method is called sidestream or mainstream. The method is called sidestream if the air exchange is taking place via a circuit placed in the patient's air passage and the sensor is reading CO_2 values from a sampling port connected to this circuit. If, on the other hand, the sensor is directly placed on the patient's air passage and the sensor directly performs CO_2 readings, it is then called mainstream method.[8,9] The sidestream method

The authors are affiliated with the Department of Emergency Medicine, Faculty of Medicine, Kocaeli University, Kocaeli, Turkey, with the exception of Dr Cinar, who is affiliated with the Department of Emergency Medicine, Gülhane Military Medical Academy, Ankara, Turkey.

Dr Pekdemir presented a version of this paper at the 7th Türkiye Acil Tıp Kongresi, held October 13–16, 2011, in Trabzon, Turkey.

The authors have disclosed no conflicts of interest.

Correspondence: Murat Pekdemir MD, Department of Emergency Medicine, Kocaeli University, Kocaeli, Turkey. E-mail: mpekdemir@yahoo.com.

DOI: 10.4187/respcare.02227

can be used in both intubated and non-intubated patients. However, the accuracy of this method is diminished due to increase in dead space resulting from suction catheters or blocking of the catheter by fluids and secretions. The mainstream method has advantages by directly performing the measurement through the air passage, and therefore is reported to yield more accurate results.[10] While the mainstream methods were performed only on intubated patients, due to the size and weight of the sensors in the past, it is now practiced noninvasively on non-intubated patients through reduced size and weight of sensors.

Studies evaluating the agreement between the P_{aCO_2} and sidestream P_{ETCO_2} values yielded no favorable results.[6,11,12] On the other hand, there is insufficient information on the degree of agreement between P_{aCO_2} values and mainstream P_{ETCO_2} measurements performed on non-intubated patients. The future benefit of establishing such a correlation will lie in the reduced need for obtaining blood samples through invasive and painful arterial procedures. The aim of this study was to assess the agreement between noninvasive P_{ETCO_2} measurements performed by the mainstream and sidestream methods with P_{aCO_2} values.

QUICK LOOK

Current knowledge

Monitoring end-tidal carbon dioxide (P_{ETCO_2}) is a standard of care in the operating room, and can provide useful information in the ICU. The relationship between P_{ETCO_2} and P_{aCO_2} is affected by cardiac output, minute ventilation, and ventilation/perfusion matching. Both mainstream and sidestream sampling are used by capnometers.

What this paper contributes to our knowledge

The relationship between P_{aCO_2} and P_{ETCO_2} was poor in patients with and without lung pathology. The type of gas sampling (sidestream versus mainstream) did not impact the P_{aCO_2}/P_{ETCO_2} relationship.

Methods

Study Design and Setting

We conducted a prospective observational trial in an academic ED that has an annual census of 30,000 patient visits. The study was between February and May 2011. The study was approved by the institutional review board, and informed consent was obtained from all subjects (project 2011/25, KAEK 2/10).

Selection of the Subjects

We enrolled ED adult patients who required arterial blood gas (ABG) analysis for their diagnostic evaluation. Patients with trauma, altered mental status, mechanical ventilation, and those who did not provide consent were excluded from the study.

Study Protocol, Measurements, and Data Collection

Once informed consent was obtained, subjects' demographic and clinical data were recorded on the standardized study forms. P_{ETCO_2} measurements were conducted by both methods, simultaneously with the ABG sampling. One researcher (MY), with the requisite experience with the relevant equipment, performed all of the measurements. Subjects were asked to breathe normally. The highest P_{ETCO_2} value on the capnometer was recorded. A Nihon Kohden TG-921T3 sensor kit (Nihon Kohden, Tokyo, Japan) was used for mainstream measurements. Original adapters obtained from the manufacturer were used for mainstream measurements (Fig. 1). The P_{ETCO_2} module on the Mindray BeneView T5 monitor (Shenzen Mindray Bio-Medical Electronics, Nanshan, Shenzhen, China) was used for sidestream readings. Sidestream measurements were conducted by a sampling port adapted to a simple oxygen mask (Fig. 2). ABG samples were analyzed using a Roche Cobas 121 device (F Hoffmann-La Roche, Basel, Switzerland) in a central laboratory.

Primary Outcome Measure

The primary outcome measure was agreement between the P_{aCO_2} measurements and the noninvasive P_{ETCO_2} measurements performed by the mainstream and sidestream methods.

Statistical Analyses

Software (MedCalc 12.1.4, MedCalcTurkey, Ankara, Turkey) was used for statistical analyses. Normal distribution was tested by the D'Agostino Pearson test. Continuous variables are represented by mean and 95% CI or median and 95% CI, whereas the categorical variables were represented with percentages. The independent *t* test was used for comparing mean values of subgroups. Pearson correlation analysis was conducted for testing linear relationship for each P_{ETCO_2} value obtained through noninvasive methods and P_{aCO_2} value obtained by ABG analysis. Bland-Altman analysis was used to analyze agreement between the measurements.

The clinically acceptable limit of agreement was determined to be ± 5 mm Hg for this study. Software

Fig. 1. Noninvasive mainstream measurement with capnometer.

Fig. 2. Noninvasive sidestream measurement with capnograph. The arrow points to tip of the sidestream line in the space of the face mask.

(G*Power 3.1.3, Franz Faul, Universitat Kiel, Kiel, Germany) was used to determine the sample size. During linear correlation analysis, the sample size was determined to be 111 for effect size = 0.3, alpha = 0.05 and power = 0.95. Furthermore, the sample size was determined to be 54 for mean differences of paired measurements (effect size = 0.3, alpha = 0.05 and power = 0.95). A P value < .05 was considered as statistically significant.

Results

The study was conducted with 119 subjects. Five subjects with outlying P_{aCO_2} values were excluded from the study, and statistical analyses were performed on 114 subjects. Of those, 60 (52.6%) were female, and the mean age was 60.9 years (95% CI 58.3–63.6 y). Nineteen (16.7%) subjects were diagnosed with pneumonia in the ED, and 18 (15.8%) had cancer. Thirty-eight (33.3%) subjects were admitted to the wards. Demographic and clinical characteristics of subjects are presented in Table 1.

The mean P_{aCO_2} was 35.16 mm Hg (95% CI 33.81–36.51 mm Hg), mainstream P_{ETCO_2} was 22.11 mm Hg (95% CI 21.05–23.18 mm Hg), and sidestream P_{ETCO_2} was 25.48 mm Hg (95% CI 24.22–26.75 mm Hg). Bland-Altman analysis showed an average difference between mainstream P_{ETCO_2} and P_{aCO_2} values of 13 mm Hg (95% limits of agreement −0.6 to 25.5 mm Hg) with moderate correlation (r = 0.55, P < .001) between measurements (Fig. 3). Similarly, the average difference between sidestream P_{ETCO_2} and P_{aCO_2} values was found to be 9.7 (95% limits of agreement −5.4 to 24.7); poor correlation (r = 0.41, P < .001) was noted (Fig. 4). Five (5.3%) P_{ETCO_2} measurements with the mainstream method and 31 (27.2%) with the sidestream method were found to be within the previously determined ± 5 mm Hg limits of agreement.

Table 1. Main Characteristics of Subjects

n	114
Age, mean (95% CI) y	60.9 (58.3–63.6)
Female/male, no.	60/54
Systolic blood pressure, mean (95% CI) mm Hg	132.25 (127.61–136.88)
Diastolic blood pressure, mean (95% CI) mm Hg	78.73 (75.62–81.84)
Heart rate, mean (95% CI) beats/min	97.68 (94.19–101.17)
Breathing frequency, mean (95% CI) breaths/min	29.99 (28.82–31.16)
Temperature, median (95% CI) °C	36.2 (36.0–36.4)
P_{aCO_2}, mean (95% CI) mm Hg	35.16 (33.81–36.51)
Mainstream P_{ETCO_2}, mean (95% CI) mm Hg	22.11 (21.05–23.18)
Sidestream P_{ETCO_2}, mean (95% CI) mm Hg	25.48 (24.22–26.75)
Final diagnoses, no. (%)	
Pneumonia	19 (16.7)
Cancer	18 (15.8)
Asthma/COPD	16 (14)
Heart failure	16 (14)
Chronic renal failure	9 (7.9)
Pulmonary embolism	5 (4.4)
Other	31 (27.2)

P_{ETCO_2} = end-tidal carbon dioxide

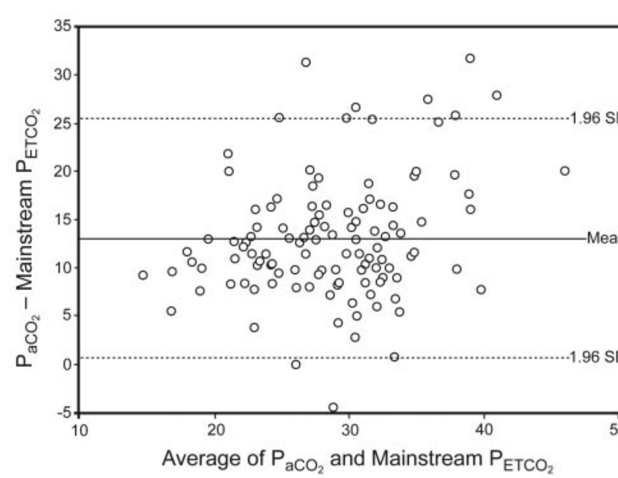

Fig. 3. Bland-Altman plot of mainstream end-tidal carbon dioxide (P_{ETCO_2}) compared with arterial carbon dioxide (P_{aCO_2}).

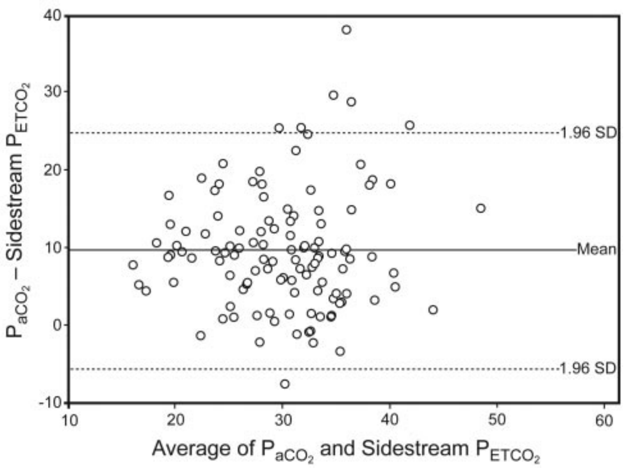

Fig. 4. Bland-Altman plot of sidestream end-tidal carbon dioxide (P_{ETCO_2}) compared with arterial carbon dioxide (P_{aCO_2}).

Table 2. Mean P_{ETCO_2} and P_{aCO_2} in Subjects With and Without Lung Pathologies

	Subjects With Lung Pathology n = 68		Subjects Without Lung Pathology n = 46		P
	Mean mm Hg	95% CI	Mean mm Hg	95% CI	
P_{aCO_2}	35.51	32.54–36.5	34.64	32.69–36.59	.51
Mainstream P_{ETCO_2}	22.32	21.02–23.63	21.8	19.93–23.68	.64
Sidestream P_{ETCO_2}	25.44	23.83–27.05	25.54	23.42–27.67	.94

P_{ETCO_2} = end-tidal carbon dioxide

Study subjects were compared based on the presence of lung pathology. Mean values for P_{aCO_2}, mainstream P_{ETCO_2}, and sidestream P_{ETCO_2} were similar (Table 2).

Discussion

This study revealed no agreement between noninvasive P_{ETCO_2} measurements with the mainstream and sidestream methods and P_{aCO_2} values. While the acceptable difference caused by the alveolar dead space had been set at 5 mm Hg prior to the study, the actual difference was found to be 1 mm Hg following the data analysis.[13] The mean bias in sidestream P_{ETCO_2} and P_{aCO_2} values was reported to be between 3.5 mm Hg[11] and 8.4 mm Hg.[6] The difference increased to 6 mm Hg in subjects with respiratory or metabolic acidosis; however, the strong correlation continued.[11] In a study conducted in 162 subjects who presented to the ED for complaints related to difficult breathing, a strong positive correlation was reported between the mainstream P_{ETCO_2} and the P_{aCO_2} values. The mean bias was 0.5 mm Hg and the limits of agreement were −10.5 mm Hg and 9.5 mm Hg. In this particular study, a mainstream capnometry device designed for invasive measurement was used noninvasively with an adapter.[10] Although we used the original mainstream sensor by the manufacturer, the bias was 13 mm Hg in the current study. Sidestream measurement, even though conducted similar to other studies in the literature, yielded a bias of 9.7 mm Hg. Unlike others, we enrolled subjects without shortness of breath. The subgroup analysis showed no difference between the mean P_{ETCO_2} values of the subjects with and without lung pathology.

The first study in which the sidestream and the mainstream methods were compared was carried out with invasive techniques on mechanically ventilated dogs. In that study, the bias between mainstream P_{ETCO_2} and P_{aCO_2} was 3.15 mm Hg, while it was 5.65 mm Hg with the sidestream method. Regardless of the measurement method, the bias was reported to increase when P_{aCO_2} values exceeded 60 mm Hg.[14] In the first study comparing 2 noninvasive methods, the sidestream and microstream techniques, Casati et al measured the mean difference between P_{ETCO_2} and P_{aCO_2} as 4.4 mm Hg by the microstream method, which was increased to 7 mm Hg with the sidestream method.[15] Our study compared the sidestream and mainstream methods in the ED, and there was no agreement found between the P_{aCO_2} and P_{ETCO_2} values obtained by both methods. For comparison of P_{ETCO_2} measurement techniques, the type and location of the sensor are important issues that can also affect the results. In a study that compared the distal sidestream, proximal sidestream, and mainstream methods, the reported differences were 6.6, 25.5, and 9.25 mm Hg, respectively.[16] Despite the fact that we performed our study in a standardized condition, we measured significantly different P_{aCO_2} and P_{ETCO_2} values obtained through both methods.

P_{aCO_2} prediction with P_{ETCO_2} values has been diminished in patients with lung disease.[17] Furthermore, structural defects of the lung (eg, hyaline membrane disease or meconium aspiration) in newborns have led to poor correlation between P_{ETCO_2} and P_{aCO_2} values.[18] In our study we found poor correlation and no agreement between the P_{aCO_2} values and P_{ETCO_2} values obtained through 2 separate methods in patients with lung pathologies. Since the same lack of agreement and poor correlation were found in patients with no lung pathology, we believe that these differences arise from measurement methods. Technological improvements in the future may result in increase in agreement between P_{ETCO_2} and P_{aCO_2} values.

Limitations

This study was conducted in a single center with one set of medical devices. All the devices used during the study had been calibrated by qualified technicians and all were functioning properly. However, errors resulting from functioning of devices can nonetheless affect the entire study results. Performing measurements by a single researcher minimizes the potential for variations that could be caused by an operator. Furthermore, the study group was heterogeneous, since it consisted of subjects requiring ABG analysis. However, the ABG analysis was performed in subjects suffering from a variety of conditions, such as poisoning, metabolic disorders, and respiratory problems, in the ED. In line with our initial goal of using noninvasive P_{ETCO_2} measurements in place of invasive P_{aCO_2} readings, subjects from different subgroups were included in the study to determine agreement between measurements. Since the ability for deep breathing has an effect on P_{ETCO_2} readings, measurements conducted on subjects with various clinical conditions may not yield proper results. To overcome this disadvantage we considered the highest P_{ETCO_2} value obtained during our measurements. Besides, subgroup analyses showed no difference in P_{ETCO_2} readings between the subjects with and without lung pathologies. For this reason we believe there was no limitation inherent in our selection of the study group.

Conclusions

Noninvasive P_{ETCO_2} measurements performed both by mainstream and sidestream methods were found to yield significantly lower and unacceptable results, compared to the P_{aCO_2} values. Thus, neither of these methods is recommended as a reliable predictor of P_{aCO_2} values.

REFERENCES

1. Grmec S. Comparison of three different methods to confirm tracheal tube placement in emergency intubation. Intensive Care Med 2002; 28(6):701-704.
2. Krauss B, Hess DR. Capnography for procedural sedation and analgesia in the emergency department. Ann Emerg Med 2007;50(2): 172-181.
3. Levine RL, Wayne MA, Miller CC. End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest. N Engl J Med 1997;337(5): 301-306.
4. Steedman DJ, Robertson CE. Measurement of end-tidal carbon dioxide concentration during cardiopulmonary resuscitation. Arch Emerg Med 1990;7(3):129-134.
5. Howe TA, Jaalam K, Ahmad R, Sheng CK, Nik Ab Rahman NH. The use of end-tidal capnography to monitor non-intubated patients presenting with acute exacerbation of asthma in the emergency department. J Emerg Med 2011;41(6):581-589.
6. Kartal M, Goksu E, Eray O, Isik S, Sayrac AV, Yigit OE, Rinnert S. The value of $ETCO_2$ measurement for COPD patients in the emergency department. Eur J Emerg Med 2011;18(1):9-12.
7. Kartal M, Eray O, Rinnert S, Goksu E, Bektas F, Eken C. ETCO: a predictive tool for excluding metabolic disturbances in nonintubated patients. Am J Emerg Med 2011;29(1):65-69.
8. Jaffe MB. White paper: mainstream or sidestream capnography? Andover, MA: Philips Respironics; 2002. http://oem.respironics.com/Downloads/Main%20vs%20Side.pdf *Accessed April 17, 2013.*
9. Block FE, McDonald JS. Sidestream versus mainstream carbon dioxide analyzers. J Clin Monit 1992;8:139-141.
10. Cinar O, Acar YA, Arziman I, Kilic E, Eyi YE, Ocal R. Can mainstream end-tidal carbon dioxide measurement accurately predict the arterial carbon dioxide level of patients with acute dyspnea in ED. Am J Emerg Med 2012;30(2):358-361.
11. Barton CW, Wang ES. Correlation of end-tidal CO_2 measurements to arterial P_{aCO_2} in nonintubated patients. Ann Emerg Med 1994; 23(3):560-563.
12. Delerme S, Freund Y, Renault R, Devilliers C, Castro S, Chopin S, et al. Concordance between capnography and capnia in adults admitted for acute dyspnea in an ED. Am J Emerg Med 2010;28(6): 711-714.
13. Corbo J, Bijur P, Lahn M, Gallagher EJ. Concordance between capnography and arterial blood gas measurements of carbon dioxide in acute asthma. Ann Emerg Med 2005;46(4):323-327.
14. Teixeira Neto FJ, Carregaro AB, Mannarino R, Cruz ML, Luna SP. Comparison of a sidestream capnograph and a mainstream capnograph in mechanically ventilated dogs. J Am Vet Med Assoc 2002; 221(11):1582-1585.
15. Casati A, Gallioli G, Passaretta R, Scandroglio M, Bignami E, Torri G. End tidal carbon dioxide monitoring in spontaneously breathing, nonintubated patients. A clinical comparison between conventional sidestream and microstream capnometers. Minerva Anestesiol 2001; 67(4):161-164.
16. McEvedy BA, McLeod ME, Kirpalani H, Volgyesi GA, Lerman J. End-tidal carbon dioxide measurements in critically ill neonates: a comparison of side-stream and mainstream capnometers. Can J Anaesth 1990;37(3):322-326.
17. Plewa MC, Sikora S, Engoren M, Tome D, Thomas J, Deuster A. Evaluation of capnography in nonintubated emergency department patients with respiratory distress. Acad Emerg Med 1995;2(10):901-908.
18. Bhat YR, Abhishek N. Mainstream end-tidal carbon dioxide monitoring in ventilated neonates. Singapore Med J 2008;49(3):199-203.