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DISPARITY BETWEEN MAINSTREAM AND SIDESTREAM END TIDAL CARBON DIOXIDE VALUES AND ARTERIAL CARBON DIOXIDE LEVELS

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Abstract

Background: Measuring and monitoring end-tidal carbon dioxide ($ETCO_2$) is an important aspect of care of critical patient. The two methods used for $ETCO_2$ measurement were mainstream and sidestream methods. The aim of the study was assessment of agreement between $ETCO_2$ measurements performed by mainstream and sidestream methods with the partial arterial carbon dioxide pressure ($PaCO_2$) values.

Methods: This was a prospective observational study. Total of 114 patients were enrolled in the study. $ETCO_2$ measurements using mainstream and sidestream methods were performed simultaneously with the arterial blood sampling in patients who were observed in the emergency department (ED) and required arterial blood gas (ABG) analysis. Agreement between the $ETCO_2$ measurements and the $PaCO_2$ values obtained from ABG analysis were evaluated using Bland-Altman method.

Results: Sixty (52.6%) of them were females and the mean age was 60.9 years (95% CI, 58.3-63.6). The mean $PaCO_2$ level was 35.16 (95% CI, 33.81-36.51), mainstream $ETCO_2$ was 22.11 (95% CI, 21.05-23.18), and sidestream $ETCO_2$ was 25.48 (95% CI, 24.22-26.75). Bland-Altman analysis showed an average difference between mainstream $ETCO_2$ and $PaCO_2$ values as 13 (95% limits of agreement -0.6 – 25.5) and moderate correlation ($r=0.548$, $p<0.001$) and an average difference between sidestream $ETCO_2$ and $PaCO_2$ values as 9.7 (95% limits of agreement -5.4 – 24.7) and poor correlation ($r=0.407$, $p<0.001$).

Conclusion: $ETCO_2$ values obtained from measurements by mainstream and sidestream methods were found to be significantly lower compared to the $PaCO_2$ values. There is essentially no agreement between the measurements obtained by two different methods and the $PaCO_2$ values.

Key words: end tidal carbon dioxide, noninvasive, mainstream, sidestream, arterial carbon dioxide

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Introduction

Measuring and monitoring end-tidal carbon dioxide ($ETCO_2$) is an important aspect of care of critical patient. While $ETCO_2$ monitorization were initially used by clinicians to confirm the place of the endotracheal tube and monitoring mechanically ventilated patients in the emergency departments (EDs), today there is a greater utilization of it for purposes such as monitoring the quality of cardiopulmonary resuscitation (CPR) and evaluating causes of bronchospasm (1, 2, 3, 4, 5). Furthermore, $ETCO_2$ measurement has been studied to predict partial arterial carbon dioxide ($PaCO_2$) or bicarbonate levels (6, 7).

$ETCO_2$ value is detected by measuring the amount of carbon dioxide (CO_2) in 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 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 patient's air passage and the sensor directly performs CO_2 readings, it is then called mainstream method (8, 9). Sidestream method 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. 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 non-invasively on non-intubated patients through reduced size and weight of sensors.

Studies evaluating the agreement between the $PaCO_2$ and sidestream $ETCO_2$ values yielded no favorable results (6, 11, 12). On the other hand, there is no sufficient information on the degree of agreement between $PaCO_2$ values and mainstream $ETCO_2$ measurements

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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.

Aim: Assessment of agreement between non-invasive $ETCO_2$ measurements performed by mainstream and sidestream methods with the $PaCO_2$ values.

Material and Methods

Study design and setting: We conducted a prospective observational trial in an academic emergency department which has an annual census of 30,000 patient visits between February and May 2011. The study was approved by the institutional review board and informed consent was obtained from all participants. (Project No: 2011/25, KAEK 2/10).

Selection of the participants: We enrolled ED adult patients who required 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, patients' demographic and clinical data was recorded on the standardized study forms. $ETCO_2$ 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. Patients were asked to breathe normally. The highest $ETCO_2$ value on capnometer was recorded. Nihon Kohden TG-921T3 sensor kit (Nihon Kohden Corp., Japan) was used for mainstream measurements. Original adapters obtained from the manufacturer were used for mainstream measurements (Figure 1). $ETCO_2$ module on Mindray BeneView T5 monitor (Shenzen Mindray Bio-Medical Electronics Co., Ltd., Nanshan, Shenzhen, PRC) was used for sidestream readings. Sidestream measurements were conducted by a sampling port adapted to a simple oxygen mask (Figure 2). ABG samples were analyzed using Roche Cobas 121 device (F. Hoffmann-La Roche Ltd, Basel, Switzerland) in central laboratory.

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Primary outcome measure: Agreement between non-invasive $ETCO_2$ measurements performed by mainstream and sidestream methods with the $PaCO_2$ values.

Statistical analyses: Medcalc 12.1.4 (MedcalcTurkey, Ankara) software program was used for statistical analyses. Normal distrubution was tested by D'Agostino Pearson test. Continuous variables were represented by mean and 95% confidence interval (CI) or median and 95% confidence interval (CI), whereas the categorical variables were represented with percentages. Independent t-test was used for comparing mean values of subgroups. Pearson correlation analysis was conducted for testing linear relationship for each $ETCO_2$ value obtained through non-invasive methods and $PaCO_2$ value obtained by ABG analysis. Bland-Altman analysis was used to analyze agreement between the measurements.

Clinically acceptable limit of agreement was determined to be ±5 mmHg for this study. G*Power 3.1.3 software (Franz Faul, Universitat 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). p value less than 0.05 was considered as statistically significant.

Results

The study was conducted on 119 patients. Five patients with outlying values in $PaCO_2$ variable were excluded from the study and statistical analyses were performed on 114 patients. Of those, 60 (52.6%) were females and the mean age was 60.9 years (95% CI, 58.3-63.6). Nineteen (16.7%) patients were diagnosed as pneumonia in the ED and 18 (15.8%) had cancer. Thirty eight (33.3%) of the patients were admitted to the wards. Demographic and clinical characteristics of patients are presented in Table 1.

The mean $PaCO_2$ level was 35.16 (95% CI, 33.81-36.51), mainstream $ETCO_2$ was 22.11 (95% CI, 21.05-23.18), and sidestream $ETCO_2$ was 25.48 (95% CI, 24.22-26.75).

Bland-Altman analysis showed an average difference between mainstream $ETCO_2$ and $PaCO_2$ values of 13 (95% limits of agreement -0.6 – 25.5) with moderate correlation ($r=0.548$, $p<0.001$) between measurements (Figure 3). Similarly, the average difference between sidestream $ETCO_2$ and $PaCO_2$ values was found to be 9.7 (95% limits of agreement -5.4 – 24.7) with poor correlation ($r=0.407$, $p<0.001$) was noted (Figure 4). Five (5.3%) $ETCO_2$ measurements with the mainstream method and 31 (27.2%) with the sidestream method were found to be within the previously determined ±5 mmHg limits of agreement.

Study patients were compared based on the presence of lung pathology. Mean values for $PaCO_2$, mainstream $ETCO_2$ and sidestream $ETCO_2$ were similar (Table 2).

Discussion

This study revealed no agreement between non-invasive $ETCO_2$ measurements with the mainstream and sidestream methods and $PaCO_2$ values.

While the acceptable difference caused by the alveolar dead space had been set at 5 mmHg prior to the study, the actual difference was found to be 1 mmHg following the data analysis (13). The mean bias in sidestream $ETCO_2$ and $PaCO_2$ values was reported to be between 3.5 mmHg (11) and 8.4 mmHg (6). The difference increased to 6 mmHg in patients with respiratory or metabolic acidosis; however the strong correlation continued to be present (11). In a study conducted on 162 patients presented to ED for complaints related to difficult breathing, a strong positive correlation was reported between the mainstream $ETCO_2$ and the $PaCO_2$ values. The mean bias was 0.5 mmHg and the limits of agreement were -10.5 mmHg and 9.5 mmHg. In this particular study, a mainstream capnometry device designed for invasive measurement was used non-invasively with an adapter (10). Although we used original mainstream sensor by the manufacturer, the bias was 13 mmHg in the current study. Sidestream measurement, even though conducted similar to other studies in the literature, yielded a bias of 9.7 mmHg. Unlike others, we enrolled patients without shortness of breath.

The subgroup analysis showed no difference between the mean $ETCO_2$ values of the patients with and without lung pathology.

The first study in which the sidestream and the mainstream methods were compared was carried out on mechanically ventilated dogs with invasive techniques. In that study, bias between mainstream $ETCO_2$ and $PaCO_2$ was 3.15 mmHg while it was 5.65 mmHg with sidestream method. Regardless of measurement methods, the bias was reported to increase when $PaCO_2$ values exceeded 60 mmHg (14). In the first study comparing two non-invasive methods, sidestream and microstream techniques, Casati et al measured the mean difference between $ETCO_2$ and $PaCO_2$ as 4.4 mmHg by microstream method, which was increased to 7 mmHg with sidestream method (15). Our study compared sidestream and mainstream methods in the ED and there was no agreement found between the $PaCO_2$ and $ETCO_2$ values obtained by both methods. For comparison of $ETCO_2$ measurement techniques, types and localization of the sensors are important issues that can also affect the results. In a study which compared distal sidestream, proximal sidestream and mainstream methods, reported differences were 6.6, 25.5 and 9.25, respectively (16). Despite we performed our study in a standardized condition; we measured significantly different $PaCO_2$ and $ETCO_2$ values obtained through both methods.

$PaCO_2$ prediction with $ETCO_2$ values has been diminished in patients with lung disease (17). Furthermore, structural defects of the lung (e.g., hyaline membrane disease or meconium aspiration) in newborns have led to poor correlation between $ETCO_2$ and $PaCO_2$ values (18). In our study, we found poor correlation and no agreement between the $PaCO_2$ values and $ETCO_2$ values obtained through two separate methods in patients with lung pathologies. Since the same lack of agreement and poor correlation was 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 $ETCO_2$ and $PaCO_2$ 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 is heterogenous since consisted of patients requiring ABG analysis. However, the ABG analysis is performed in patients suffering from variety of conditions such as poisoning, metabolic disorders, respiratory problems, in the ED. In line with our initial goal of using non-invasive $ETCO_2$ measurements in place of invasive $PaCO_2$ readings, patients from different subgroups were included in the study to determine agreement between measurements. Since ability for deep breathing has an effect on $ETCO_2$ readings, measurements conducted on patients with various clinical conditions may not yield proper results. To overcome this disadvantage, we considered the highest $ETCO_2$ value obtained during our measurements. Besides, subgroup analyses showed no difference in $ETCO_2$ readings between patients with and without lung pathologies. For this reason, we believe there was no limitation inherent in our selection of study group.

Conclusion

Noninvasive $ETCO_2$ measurements performed both by mainstream and sidestream methods were found to yield significantly lower and unacceptable results compared to the $PaCO_2$ values. Thus, neither of these methods is recommended as a reliable predictor of PaCO2 values.

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Figure legends

Figure-1: Non-invasive mainstream measurement with capnometer.

Figure-2: Non-invasive sidestream measurement with capnograph. The arrow shows tip of the sidestream line in the space of the face mask.

Figure-3: Bland-Altman plot of mainstream end-tidal carbon dioxide compared with arterial carbon dioxide.

Figure-4: Bland-Altman plot of sidestream end-tidal carbon dioxide compared with arterial carbon dioxide.

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Table-1: Main characteristics of patients

	Study patients (n=114)
Demographic features	
Mean age	60.9 (95% CI 58.3 to 63.6)
Gender (Female/Male)	60/54
Clinical features	
Mean systolic blood pressure (mmHg)	132.25 (95% CI 127.61 to 136.88)
Mean diastolic blood pressure (mmHg)	78.73 (95% CI 75.62 to 81.84)
Mean heart rate (beats/min)	97.68 (95% CI 94.19 to 101.17)
Mean respiratory rate (breaths/min)	29.99 (95% CI 28.82 to 31.16)
Median fever (^{0}C)	36.2 (95% CI 36.0 to 36.4)
Mean $PaCO_2$ (mmHg)	35.16 (95% CI 33.81 to 36.51)
Mean MS $ETCO_2$ (mmHg)	22.11 (95% CI 21.05 to 23.18)
Mean SS $ETCO_2$ (mmHg)	25.48 (95% CI 24.22 to 26.75)
Final diagnosis	**n (%)**
Pneumonia	19 (16,7)
Cancer	18 (15,1)
Asthma/COPD	16 (14)
Heart failure	16 (14)
Chronic renal failure	9 (7,9)
Pulmonary embolism	5 (4,4)
Other	31 (27,2)

$PaCO_2$: Partial arterial carbondioxide pressure, MS $ETCO_2$: Mainstream end-tidal carbondioxide, SS $ETCO_2$: Sidestream end-tidal carbondioxide

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Table 2: Mean $ETCO_2$ and PaCO2 values in patients with and without lung pathologies

	Patients with lung pathology (n=68)	Patients without lung pathology (n=46)	P value
Mean $PaCO_2$	35.51 (95% CI 32.54 to 36.5)	34.64 (95% CI 32.69 to 36.59)	0.507
Mean MS $ETCO_2$	22.32 (95% CI 21.02 to 23.63)	21.8 (95% CI 19.93 to 23.68)	0.638
Mean SS $ETCO_2$	25.44 (95% CI 23.83 to 27.05)	25.54 (95% CI 23.42 to 27.67)	0.943

CI: Confidence interval, $PaCO_2$: Partial arterial carbondioxide pressure,

MS $ETCO_2$: Mainstream end-tidal carbondioxide, SS $ETCO_2$: Sidestream end-tidal carbondioxide

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Non-invasive mainstream measurement with capnometer.
197x70mm (96 x 96 DPI)

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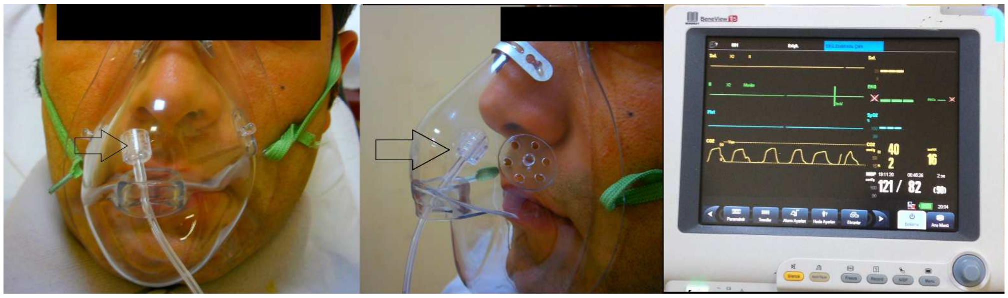

2133x620mm (96 x 96 DPI)

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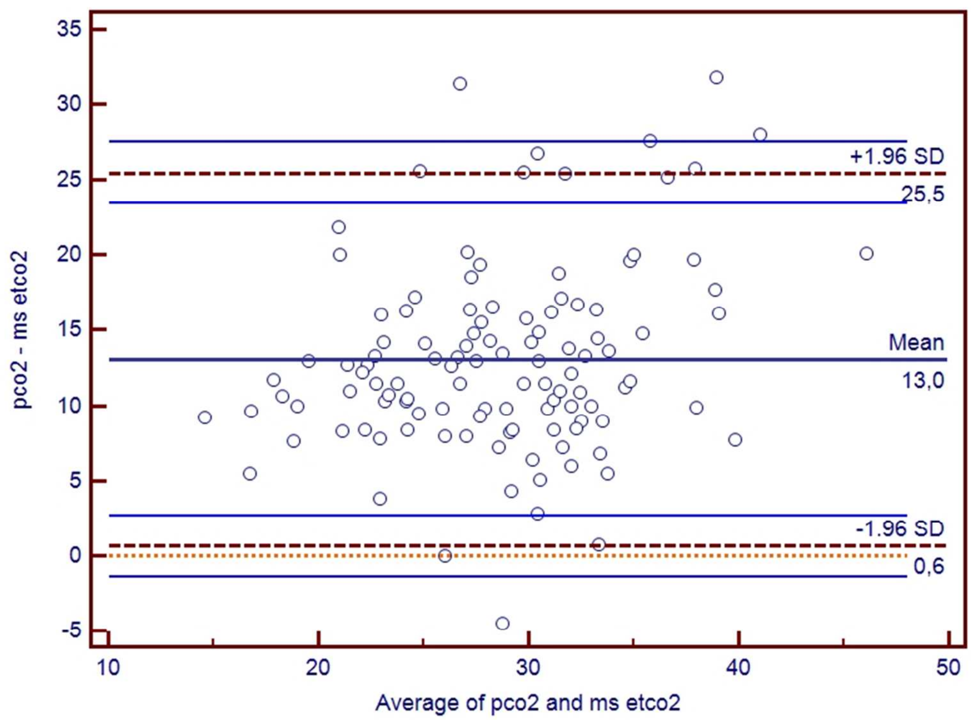

Bland-Altman plot of mainstream end-tidal carbon dioxide compared with arterial carbon dioxide.
211x158mm (96 x 96 DPI)

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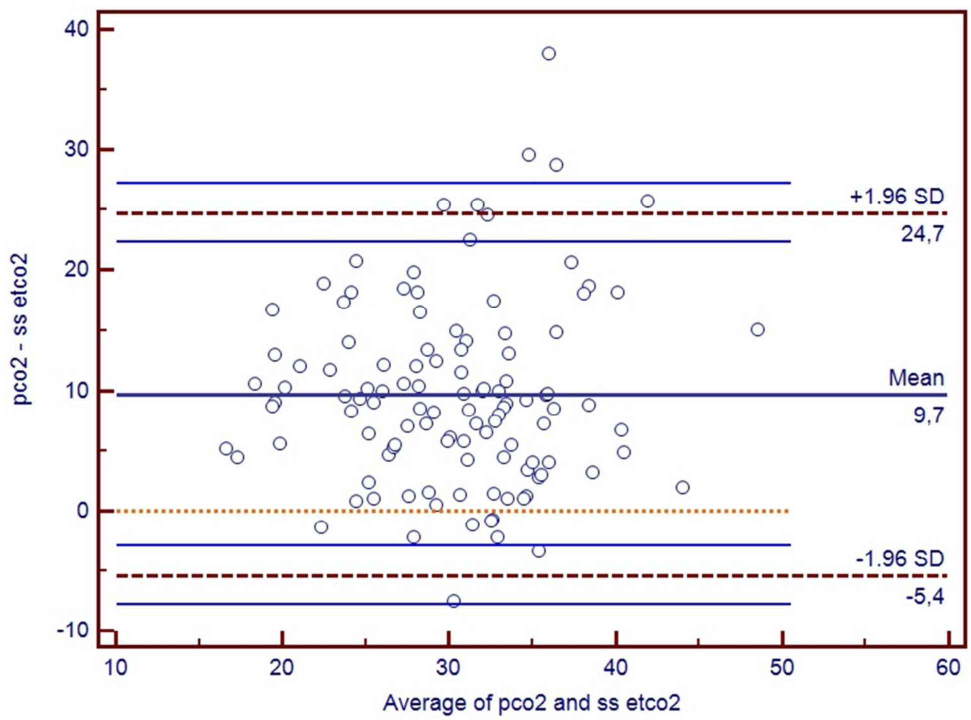

Bland-Altman plot of sidestream end-tidal carbon dioxide compared with arterial carbon dioxide.
211x158mm (96 x 96 DPI)