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Evaluation of the Relationship between Transcutaneous Carbondioxide Monitorization and End-tidal Carbondioxide and Partial Carbondioxide Monitorization

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Abstract

Non-invasive methods have replaced invasive methods in line with developments in pediatric intensive care units. (Especially methods that enable continuous monitoring) Although arterial carbon dioxide measurement is still the gold standard for the evaluation of alveolar ventilation, the need for continuous monitoring of $PaCO_2$ and the invasive nature of this method have led to the investigation of alternative methods. To evaluate the correlation of transcutaneous CO_2 ($TcCO_2$) monitoring with $PaCO_2$ and $ETCO_2$ in mechanically ventilated patients in peditaric intensive care units. Single-center, prospective, observational cohort study. We enrolled 60 patients between the age of 1 month-18 years who were mechanically ventilated in pediatric intensive care unit for this single-center, prospective, observational cohort study from February 2019 through March 2019. Correlation analysis was performed for arterial $PaCO_2$, end-tidal CO_2, $TcCO_2$ parameters. $P<0.05$ values were considered significant. The Bland-Altman plot was created for determining the agreement between the methods. The correlation of transcutaneous CO_2 and end-tidal CO_2 with arterial $PaCO_2$ was evaluated, both parameters were found to be positively and highly correlated ($r=0.864$, $p<0.001$, $r:0.962$, $p<0.001$, respectively). The mean bias between the arterial carbondioxide mesaurement and transcutaneous measurement was 5.5, and limits of agreement (bias ±1.96 SD) ranged from -13.9 to 2.9. The mean bias between the arterial carbondioxide mesaurement and end-tidal carbondioxide measurement was 2.3, and limits of agreement (bias ±1.96 SD) ranged from -4.1 to 8.6. In 44 measurements (88%), the $TcCO_2$ was ±7.5 mm Hg of the $PaCO_2$. $TcCO_2$ seems to be a good alternative for carbon dioxide measurement, as it is non-invasive and allows continuous monitoring in view of today's intensive care conditions, but arterial $PaCO_2$ measurement is still the gold standard method. Continuous $TcCO_2$ monitoring provides a promising alternative to repeated blood sampling in subjects requiring mechanical ventilation for critically ill children.

Keywords: Transcutaneous, carbondioxide, pediatric intensive care

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Introduction

In recent years, non-invasive methods have replaced invasive methods in line with developments in pediatric intensive care units. (Especially methods that enable continuous monitoring) Although arterial carbon dioxide measurement is still the gold standard for the evaluation of alveolar ventilation, the need for continuous monitoring of $PaCO_2$ and the invasive nature of this method have led to the investigation of alternative methods. Therefore, transcutaneous CO_2 ($TcCO_2$) measurement, which is a painless procedure and allows continuous monitoring, is used in intensive care units with increasing frequency.[1,2] Many studies have also shown that $TcCO_2$ measurement is a good alternative to arterial CO_2 measurement.[1-5]

End-tidal CO_2 ($ETCO_2$) monitoring has been known, heretofore, as a useful tool to follow carbondioxide levels in mechanically ventilated patients. However, several factors affect $ETCO_2$, such as pulmonary edema, obstruction of the airway and low cardiac output which are often found in critically ill patients in peditaric intensive care units.

Highlights

- $TcCO_2$ seems to be a good alternative for carbon dioxide measurement, as it is non-invasive and allows continuous monitoring in view of today's intensive care conditions, but arterial $PaCO_2$ measurement is still the gold standard method.
- Although arterial carbon dioxide measurement is still the gold standard for the evaluation of alveolar ventilation, the need for continuous monitoring of $PaCO_2$ and the invasive nature of this method have led to the investigation of alternative methods.
- End-tidal CO_2 ($ETCO_2$) monitoring has been known, heretofore, as a useful tool to follow carbondioxide levels in mechanically ventilated patients.

Transcutaneous gas exchange monitors measure PaO_2 and $PaCO_2$ on the skin surface to estimate arterial carbon dioxide and oxygen pressure. These monitors provide local warming of the skin. Heat from the sensor expands the capillaries and increases local blood flow. Transcutaneous CO_2 monitors measure $PaCO_2$ emitted throughout the skin by the application of a sensor heated 38°C above body temperature (typically between 40°C and 44°C) to ensure arterialization in the area where the probe is connected. So transcutaneous CO_2 pressure and oxygen saturation are electrochemically measured by the sensor. It should not be forgotten that the deterioration of the patient's ventilation status may result in false positive or false negative results, and this should not be allowed to lead to delay or inaccuracy in the orientation of the patient's treatment. In addition to studies showing good and high compatibility between transcutaneous and arterial blood gas values, studies have also been published that have low compatibility.[6-8] This controversy could be explained by the severity and the heterogenity of the diagnosis.

In this study, it was planned to evaluate the correlation of transcutaneous CO_2 ($TcCO_2$) monitoring with $PaCO_2$ and $ETCO_2$ in mechanically ventilated patients in peditaric intensive care units.

Material and Method

Study design

We enrolled 60 patients between the age of 1 month-18 years who were mechanically ventilated in pediatric intensive care unit for this single-center, prospective, observational cohort study from 1 February 2019-31 March 2019. The exclusion criterias were: Hypotension, using inotropic agent, skin condition that does not allow probe to settle. This study was approved by Clinical Research Ethics Committee of Erciyes Universtiy Hospital (Date: 09.02.2018, Decision No: 2018/78). Informed consent was obtained from the parents of the patients.

Data collection and procedures

$PaCO_2$, end-tidal CO_2 and $TcCO_2$ were measured simultaneously and correlation between these measurements were investigated. $PaCO_2$, end-tidal CO_2 and $TcCO_2$ were measured 4 times from all the patients.

$PaCO_2$: Arterial blood sample is taken from the patients which we follow in intensive care and measured with RAPIDLAB 1265 brand blood gas device in our unit.

End-tidal CO_2: End-tidal CO_2 measurement was performed by micro-side stream method (Capnostream® 20p/Covidien) in patients who were mechanically ventilated in intensive care.

Capno-oxymetry: $TcCO_2$ levels were measured with the help of a probe (V-Sign™ VS-A/P) and a device (SenTec digital Monitor System).

Statistical Analysis

In G-power 3.1.9.2 programme, efect size 0.25 type 1 error was received as 5%, power as 80%. According to this, the number of samples to be taken was calculated as 43. The study was planned to be conducted with 50 patients considering 10% data loss. All statistical analyses were performed using SPSS 22.0 (SPSS Inc., Chicago, IL, ABD) and MedCalc 13.3 (MedCalc Software Inc., Mariakerke, Belgium), with the statistical significance set at $p<0.05$. Frequency distributions were evaluated as number and percentage, continuous variables (measurements) were evaluated as mean±standard deviation. The distribution of the data (normal or not) was determined by performing a Shapiro Wilk test. Pearson correlation analysis was performed for arterial $PaCO_2$, end-tidal CO_2, $TcCO_2$ parameters. $p<0.05$ values were considered significant. The Bland-Altman plot was created for determining the agreement between the methods. Bias was calculated as the main difference between both methods and limits of agreement as the range in which 95% of the differences between 2 methods are expected to lie.[9] An additional analysis was performed to calculate the percentage of data in the bias range, with the measurement percentage range being ±7.5 mmHg because the clinically acceptable agreement between $TcCO_2$ and $PaCO_2$ is ±7.5 mmHg.[10]

Results

A total of 60 patients who were admitted to the Pediatric Intensive Care Unit between 1 month and 18 years of age were included in the study. 10 patients who had measurement problems and impossible optimal monitoring were excluded from the study. Of the patients who participated in the study, 26 were boys (52%) and 24 (48%) were girls. The median age of the patients was 14 months. (min: 2-max: 168) According to the admission diagnoses of the patients, 6 (12%) patients due to respiratory, 10 (20%) patients due to neurological problems, 16 (32%) patients due to cardiac problems, 6 (12%) patients due to renal failure, and 12 (24%) patients due to endocrinological problems were admitted to intensive care (**Table 1**).

Table 1
Characteristics of study subjects

Characteristics	Values
Age, mean±SD (month)	14±11.3
Male, sex n (%)	26 (52)
Body weight (min-max)	13.7 (10.2-35)
BMI (min-max)	24.7 (18.4-31.2)
Body Temperature oC (min-max)	36.6 (36.1-37.2)
Diagnosis at the admission n (%)	
Respiratory problems	6 (12%)
Neurological problems	10 (20%)
Cardiac problems	16 (32%)
Renal problems	6 (12%)
Endocrinological problems	12 (24%)
Blood gases, mean±SD	
pH	7.32±0.9
$PaCO_2$, mmHg	51±3.7
$TcCO_2$, mmHg	45.1±4.2

When the correlation of transcutaneous CO_2 and end-tidal CO_2 with arterial $PaCO_2$ was evaluated, both parameters were found to be positively and highly correlated (r=0.864, p<0.001, r:0.962, p<0.001, respectively) (**Figure 1,2**).

The median $PaCO_2$ was 41 mmHg (IQR 35–51 mmHg), with a range 21–76 mmHg. The median $PTcCO_2$ was 43 mmHg (IQR 32–49 mmHg) with a range of 27–74 mmHg. The median end-tidal CO_2 was 38 mmHg (IQR 28–47 mmHg), with a range 18–66 mmHg.

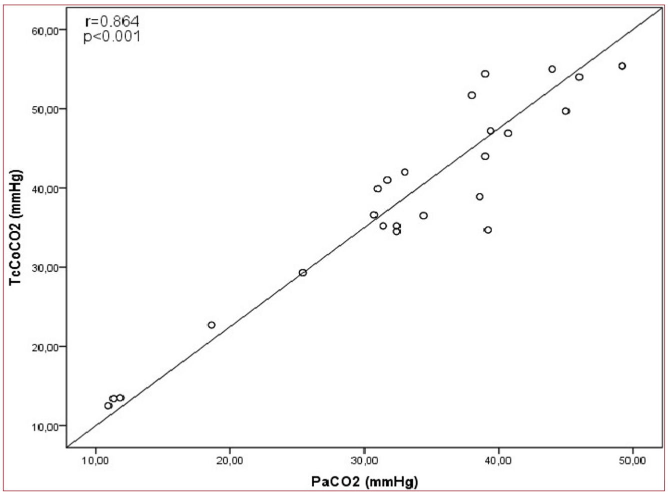

Figure 1. Correlation graphic between $PaCO_2$ and $TcCO_2$

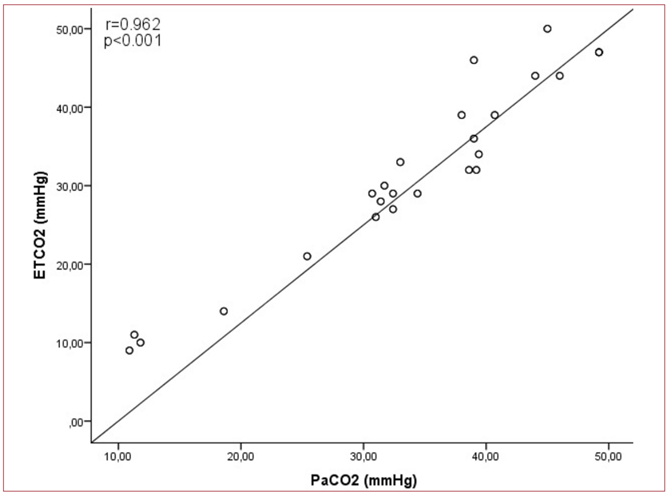

Figure 2. Correlation graphic between $PaCO_2$ and $ETCO_2$

The mean bias between the arterial carbondioxide mesaurement and transcutaneous measurement was 5.5, and limits of agreement (bias ±1.96 SD) ranged from -13.9 to 2.9. (**Figure 3**) The mean bias between the arterial carbondioxide mesaurement and end-tidal carbondioxide measurement was 2.3, and limits of agreement (bias ±1.96 SD) ranged from -4.1 to 8.6. (**Figure 4**) In 44 measurements (88%), the $TcCO_2$ was ±7.5 mmHg of the $PaCO_2$.

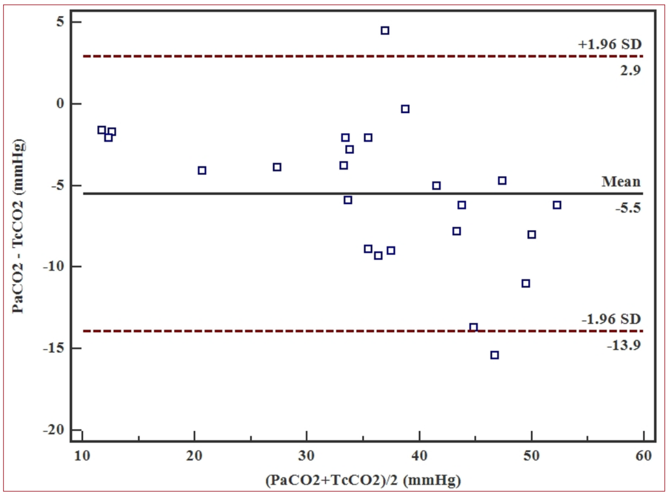

Figure 3. Blant-altman analysis for $TcCO_2$ versus $PaCO_2$. Bias (continous line), limits of agrement (bias±1.96, dashed lines) are shown in graph. Each square indicates the bias the bias of a single patient.

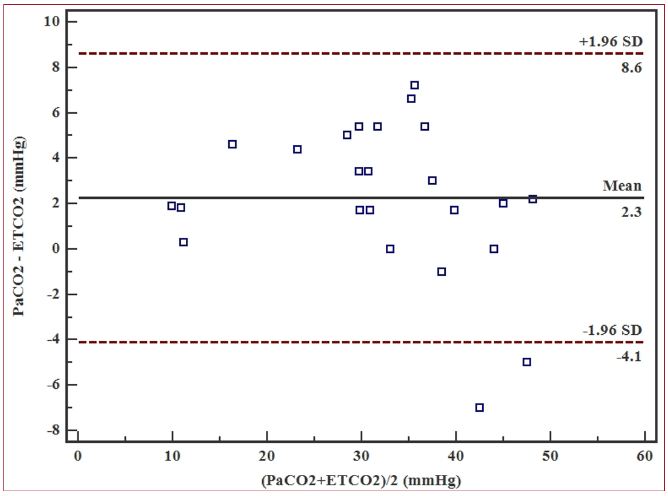

Figure 4. Blant-altman analysis for $ETCO_2$ versus $PaCO_2$. Bias (continous line), limits of agrement (bias±1.96, dashed lines) are shown in graph. Each ssquare indicates the bias the bias of a single patient.

Discussion

Arterial $PaCO_2$ is still the gold standard for the evaluation of alveolar ventilation but the desirable method for estimating $PaCO_2$ value in a critically ill child is the method that provides non-invasive, reliable and continuous monitoring.[5] This is one of the most detailed studies comparing two different non-invasive techniques for continuous carbon dioxide measurement with arterial blood gas carbon dioxide measurement (the gold standard method of alveolar ventilation) in patients undergoing mechanical ventilaiton in a pediatric intensive care unit. The main finding of the present study is that $TcCO_2$ monitoring is an appropriate method for continuously measuring PCO_2 in ventilated patients. In critical patients receiving respiratory support, closely monitoring cardiorespiratory changes and instantly recognizing clinical worsening are very important for follow-up and treatment. Therefore, continuous monitoring of CO_2 levels with $TcCO_2$ has the potential to prevent many of the known problems associated with end-tidal CO_2 monitorization in critically ill children.

There have been many studies in newborns, adults and children to demonstrate the relationship between $PaCO_2$ and $TcCO_2$, but there are still studies that show that there is correlation, as well as studies that suggest otherwise.[11-17] In a study of patients admitted to the emergency department with respiratory problems, the mean difference between $PaCO_2$ and $TcCO_2$ was 1 mmHg with limits of agreement of -3.4 to 5.6 was found by Delerme et al.[5] Perrin et al.[18] found a bias of 0.13 mmHg with limits of agreement of -3.9 and 3.7 mmHg in asthmatic patients. Different from previous studies, we found the mean bias between the arterial carbondioxide mesaurement and transcutaneous measurement was 5.5, and limits of agreement (bias ±1.96 SD) ranged from -13.9 to 2.9. We explain this worse results with the higher $PaCO_2$ levels of our patients. While mean $PaCO_2$ of our patients is 51 mmHg, mean $PaCO_2$ of previous studies are respectively 39 and 36 mmHg. Our findings are consistent with the findings of other authors, who argue that the reliability and accuracy of this method decreases in patients with high levels of $PaCO_2$.[2,19]

In previous studies, the predicted range for $TcCO_2$ was assumed to be ±7.5 mmHg and 81.2% of cases remained within this range.[13] Another study by Anoopindar et al.[20] found that 83.2% of cases remained within this range when the estimated range of ±7.5 mmHg was accepted. Our study also found that 88% of the cases were in this range consistent with the literature.

Anoopindar et al.[20] reported that they did not find a significant association between high lactate levels, high doses of inotropes (higher vasoactive inotrope scores) and $TcCO_2$ 5 mmHg higher than $PaCO_2$. In previous studies, a decreased correlation between $PaCO_2$ and $TcCO_2$ was observed at epinephrine doses as high as 0.3 ug/kg/min.[21] In our study, 5 of 12 patients with cardiac problems received such a high dose of inotrope, but we did not see this association in our subgroup. It is possible that most children with cardiac disease did not have low cardiac output at the time of measurement so they had enough cardiac output to ensure skin perfusion.

In a study on non-invasive carbon dioxide monitorization conducted by Tobias et al.[21] regression analysis revealed an r value of 0.9693 when comparing transcutaneous versus arterial $PaCO_2$ values and an r value of 0.8745 when comparing end-tidal versus arterial CO_2. Consistent with these findings, in our study the correlation of transcutaneous CO_2 and end-tidal CO_2 with arterial $PaCO_2$ were both found to be positively and highly correlated (R:0.864, p<0.001, r:0.962, p<0.001, respectively).

There are some limitations in our study. The first was that our number of patients was small. The second was although higher temperatures increased the reliability of the $TcCO_2$ measurement we use the V-Sign Sensor 2 (which heats up to 42°C) probe to avoid injury and burns. The third was that due to the low number of patients with respiratory problems, we were unable to obtain clear data on the differences from alveolar dead space between end-tidal CO_2 and $PaCO_2$/ $TcCO_2$. And also this is a single-centre study and one type of sensor device was used.

Conclusion

As a result, $TcCO_2$ seems to be a good alternative for carbon dioxide measurement, as it is non-invasive and allows continuous monitoring in view of today's intensive care conditions, but arterial $PaCO_2$ measurement is still the gold standard method. This study shows that continuous $TcCO_2$ monitoring provides a promising alternative to repeated blood sampling in subjects requiring mechanical ventilation for critically ill children. But further research is needed for the reliability of $TcCO_2$ measurement especially in special patient groups (tissue perfusion impaired, severe ARDS, shock, etc.)

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

Conflict of Interest: There are no conflicts of interest in connection with this paper, and the material described is not under publication or consideration for publication elsewhere.

Ethics Committee Approval: This study was approved by Clinical Research Ethics Committee of Erciyes Universtiy Hospital (Date: 09.02.2018, Decision No: 2018/78).

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Informed Consent: Informed consent was obtained from the parents of the patients.

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