Iran J Pediatr. 2015 February; 25(1):e184. DOI: 10.5812/ijp.184

Published online 2015 January 19. **Research Article**

Agreement of Mixed Venous Carbon Dioxide Tension ($PvCO_2$) and Transcutaneous Carbon Dioxide ($PtCO_2$) Measurements in Ventilated Infants

Sinan Uslu [1,*]; Ali Bulbul [1]; Mesut Dursun [1]; Umut Zubarioglu [1]; Ebru Turkoglu [1]; Omer Guran [1]

[1]Division of Neonatology, Sisli Hamidiye Etfal Educational and Research Hospital, Istanbul, Turkey

*Corresponding author: Sinan Uslu, Division of Neonatology, Sisli Hamidiye Etfal Educational and Research Hospital, Istanbul, Turkey. Tel: +90-5327370015, E-mail: sinanuslumd@hotmail.com

Received: May 19, 2014; **Accepted:** September 24, 2014

Background: Noninvasive transcutaneous carbon dioxide monitoring has been shown to be accurate in infants and children, limited data are available to show the usefulness and limitations of partial transcutaneous carbon dioxide tension ($PtCO_2$) value.

Objectives: The current study prospectively determines the effectiveness and accuracy of $PtCO_2$ measurements in newborns.

Materials and Methods: Venous blood gas sampling and monitoring of the $PtCO_2$ level (TCM TOSCA, Radiometer) were done simultaneously. All measurements are performed on mechanically ventilated infants. Partial venous carbon dioxide tension ($PvCO_2$) values divided into three groups according to hypocapnia (Group 1: < 4.68 kPa), normocapnia (Group 2: 4.68–7.33 kPa), hypercapnia (Group 3: > 7.33 kPa) and then $PvCO_2$ and $PtCO_2$ data within each group were compared separately.

Results: A total of 168 measurements of each $PvCO_2$ and $PtCO_2$ data were compared in three separated groups simultaneously (13 in Group 1, 118 in Group 2, and 37 in Group 3). A bias of more than ± 0.7 kPa was considered unacceptable. $PtCO_2$ was related to $PvCO_2$ with acceptable results between the two measurements in hypocapnia (mean difference 0.20 ± 0.19 kPa) and normocapnia (0.002 ± 0.30 kPa) groups. On the other hand in hypercapnia group $PtCO_2$ values were statistically significant ($P < 0.001$) and lower than $PvCO_2$ data (mean difference 0.81 ± 1.19 kPa)

Conclusions: $PtCO_2$ measurements have generally good agreement with $PvCO_2$ in hypocapnic and normocapnic intubated infants but there are some limitations especially with high level of CO_2 tension. Monitoring of $PtCO_2$ is generally a useful non-invasive indicator of $PvCO_2$ in hypocapnic and normocapnic infants.

Keywords: Blood Gas Monitoring, Transcutaneous; Infant, Newborn; Blood Gas Analysis

1. Background

Maintenance of normocarbia may reduce the incidence of mortality and morbidity such as intraventricular hemorrhage, periventricular leukomalacia and bronchopulmonary dysplasia in newborns especially premature infants (1, 2). The measurement of blood gas carbon dioxide (CO_2) level is critical tool in the assessment and principal aspect of monitoring the respiratory status specially for neonates, in particular those receiving mechanical ventilation.

Hence acid-base information obtained from blood gas samples taken from an indwelling arterial catheter appears to be the gold standard but it is difficult to obtain a sample and has important complications. Capillary and venous blood gas samplings are easier to obtain and a less invasive way of evaluating acid-base status. Both avoid the risks of arterial punctures. Several studies have shown good correlation between capillary blood, venous blood, and arterial blood gas values (3, 4). Therefore partial venous carbon dioxide tension ($PvCO_2$) is an alternative to assess the blood carbon dioxide status in sick newborn. Obtaining venous blood sample is invasive and painful method with some complications (infections, significant blood loss). Also it provides only a single measurement of CO_2 tension which is often a rapidly changing parameter (5).

The partial pressure of transcutaneous CO_2 ($PtCO_2$) is considered as an accurate estimate of both arterial and venous CO_2 tension in infants and children and estimates better than end tidal carbon dioxide ($ETCO_2$) (5, 6).

2. Objectives

The purpose of this study was to compare the $PvCO_2$ and $PtCO_2$ data based on separated three $PvCO_2$ value groups (hypocapnia, normocapnia, and hypercapnia) and to understand the usefulness and limitations of $PtCO_2$ monitoring in neonatal care.

3. Materials and Methods

This prospective and observational study was conducted in the neonatal intensive care unit (NICU) at the Sisli Hamidiye Etfal Educational and Research Hospital, Istanbul during September to December 2012. The local ethics committee approved the study and informal parental consent was obtained for each infant. Inclusion criteria were clinical indication of blood gas sampling and transcutaneous monitoring, and absence of an umbilical or radial arterial catheter. Examination was done within the first 6 to 28 days of life. All measurements were performed on mechanically ventilated infants. Infants were not studied if they were older than 28 days, had anemia, edema, hypotension requiring vasoactive drugs, hypothermia and capillary refill time of greater than two seconds, or if transcutaneous readings could not be made for any reason.

All newborns were monitored by using transcutaneous monitor (TCM TOSCA, Radiometer Medical ApS, Denmark). Once the site was cleaned with soap, 1-2 drops of contact gel was placed inside the ring and sensor fixation ring was placed on upper chest (parasternal anterior chest wall which is a highly vascularized area). The electrode was always placed on the anterior thorax, and its surface temperature was maintained at 44°C, according to manufacturer's instructions and previous literature. Sensor calibration was automatically done after every monitoring and the membrane was changed every 14 days according to manufacturer's instructions because the electrolytes between the sensor and the membrane became depleted.

Venous blood gas sampling and monitoring of the $PtCO_2$ level were done simultaneously. Within 5 min the venous blood gas determinations were performed using an automatic blood gas analyzer (Roche Omni C blood gas analyzer, Roche Diagnostic, Diamond diagnostics, USA). At the end of the monitoring, the transcutaneous sensors were removed and the underlying skin examined.

After collection of data, $PvCO_2$ values were divided into three groups: hypocapnia (Group 1: < 4.68 kPa, normocapnia (Group 2: 4.68–7.33 kPa), hypercapnia (Group 3: >7.33 kPa) and then $PvCO_2$ and $PtCO_2$ data within each group were compared separately. The differences between $PvCO_2$ and $PtCO_2$ were analyzed using a Student's paired t test. Agreement was illustrated by Bland-Altman plots with 95% limits of agreement. P-value < 0.05 was accepted to be statistically significant. A bias of more than ± 0.7 kPa was considered unacceptable (7). Data were analyzed and visualized using MedCalc program.

4. Results

Among the patients included in the study, 9 were term and 26 preterm newborns. The median gestational age was 32 (25-41) weeks, median birth weight was 1700 (780-3400) g and median age at measurement was 13 (6-25) days. Primary diagnoses of infants were prematurity with RDS (n = 19), respiratory failure (n = 11), persistent pulmonary hypertension of the newborn (n = 2), birth asphyxia (n = 2) and pneumothorax (n = 1). A total of 168 measurements of each $PvCO_2$ and $PtCO_2$ data were compared in three separated groups (13 readings in hypocapnia group, 118 in normocapnia group, and 37 in hypercapnia group). No infants were excluded due to instability since this was part of the study.

A comparison of $PvCO_2$ and $PtCO_2$ levels in kPa according to study groups and gestational weeks (whether term or preterm) of neonates are shown in Table 1. Although a statistical difference was detected, there was clinically a good relation between $PvCO_2$ and $PtCO_2$ in preterm, term, Group 1, Group 2 and all infants. On the other hand, only 37.8% of $PtCO_2$ recordings were within 0.7 kPa of the paired $PvCO_2$ in hypercapnia group. The difference between $PvCO_2$ and $PtCO_2$ ($P(v\text{-}Tc)CO_2$) against average CO_2 in the three Groups are illustrated in Figure 1. $PtCO_2$ was related to $PvCO_2$ with laboratory acceptable results between the two measurements in hypocapnia and normocapnia groups. All $PtCO_2$ values were statistically significant and lower than $PvCO_2$ data in hypercapnia group (Table 1 Figure 1). The mean pH values were 7.37 ± 0.07, 7.32 ± 0.04 and 7.25 ± 0.05 in Groups 1, 2 and 3, respectively. The mean warm-up period was 9.4 ± 0.3 minutes for all patients. No serious skin lesions or any other adverse events were detected except transient mild erythema after 4 (2.3%) measurements.

Table 1. A Comparison of $PvCO_2$ and $PtCO_2$ (kPa) Measurements in Different Groups [a,b]

	$PvCO_2$, kPa	$PtCO_2$, kPa	Mean difference, kPa	95 % CI	P Value
Premature infants, (n = 138)	6.60 ± 1.70	6.39 ± 1.39	0.21 ± 0.75	0.08-0.33	0.001
Term infants, (n = 30)	5.83 ± 0.99	5.71 ± 0.87	0.11 ± 0.28	0.01-0.22	0.03
Hypocapnia group, (n = 13) $PvCO_2$ (< 4.68 kPa)	4.33 ± 0.29	4.23 ±0.33	0.20 ± 0.19	0.09-0.12	0.03
Normocapnia group, (n = 118) $PvCO_2$ (4.68–7.33 kPa)	5.94 ± 0.64	5.93 ± 0.72	0.002 ± 0.30	-0.06-0.05	0.938
Hypercapnia group, (n = 37) $PvCO_2$ (> 7.33 kPa),	8.86 ± 1.56	8.05 ± 0.72	0.81 ± 1.19	0.41-1.20	< 0.001
All patients (n = 168)	6.46 ± 1.62	6.27 ± 1.26	0.19 ± 0.69	0.08-0.29	0.001

[a] Abbreviations: CI, confidence interval.
[b] Data are presented as mean ± SD.

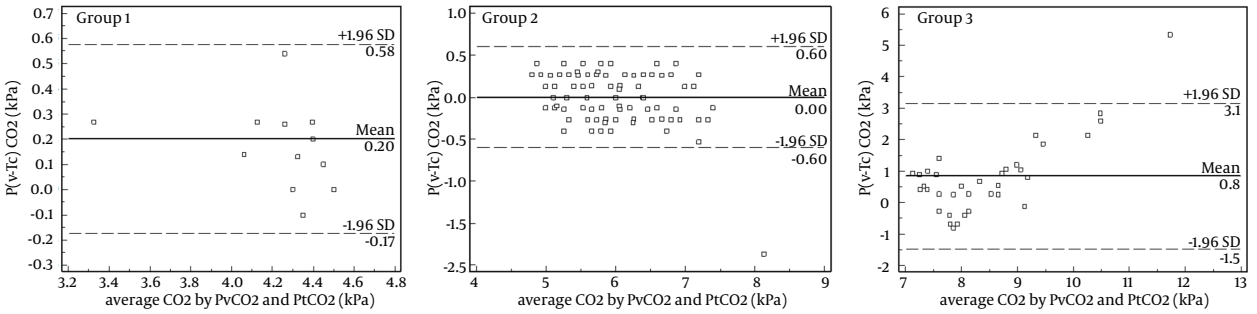

Figure 1. Bland-Altman Plot of the Difference Between $PvCO_2$ and $PtCO_2$ ($P(v\text{-}Tc)CO_2$) Against Average CO_2

5. Discussion

Although $PaCO_2$ remains the gold standard and $PvCO_2$ is preferred alternative method, $PtCO_2$ monitoring is a non-invasive technology and very valuable adjunct for respiratory management and also allows continuous monitoring (5). It is suggested that new generation transcutaneous monitors provide safe and useful carbon dioxide monitoring in newborns (8, 9). In this study close correlation was demonstrated between $PvCO_2$ and $PtCO_2$ values in hypocapnic and normocapnic $PvCO_2$ level whereas for hypercapnic $PvCO_2$ level was not.

As far as we know, this is the first study to demonstrate the relationship between $PvCO_2$ and $PtCO_2$. Several studies have shown a good agreement between $PtCO_2$ and $PaCO_2$ in newborn (10-14), although their accuracy diminished when the CO_2 tension increased especially when the increase was greater than 56 mmHg (15, 16). According to our results which are similar to those reports, we cannot assume that the CO_2 variations could reliably reflect $PvCO_2$ variations in hyperkapnic newborns. Acidosis negatively affects the ability to correlate transcutaneous and venous CO_2 values (5, 13, 17). In hypercapnia group mean pH value was lower than that in the other groups. So, we speculated that the capillary blood flow and gas diffusion of the skin may be even impaired when the pH decreases. This condition impairs the transcutaneous measurements and may alter the $PtCO_2$ correlation with $PvCO_2$.

$PtCO_2$ measurement is based on the observation that CO_2 has a high solubility and diffusion through the skin; local heat dilates blood vessel and enhances skin permeability (18). It is stated that $PtCO_2$ measurements provide accurate results in newborns because of their thin epidermis. The epidermal layer of preterm infants is advantageous in the accurate measurement of $PtCO_2$, but on the other hand disadvantages may cause heat induced skin damage (erythema, blisters, burns, skin tears) from the electrodes (19, 20). To achieve accurate measurements, the recommended skin prob temperature is 44°C (9). So transcutaneous CO_2 measurements were carried out at 44°C electrode temperature. According to recommendation for changing sites every 2 hours to avoid thermal injury (9), we monitored the patients no longer than 2 hours and no serious adverse effects were identified except for mild transient erythema after only 2.3% of measurements.

Transcutaneous monitoring systems have some other limitations such as difficulty in keeping them calibrated, preventing air trapping and taking up longer time to sufficiently warming the skin. The need for frequent changes in sensor sites was considered breach of minimal handling approach (21). The response time decreases with elevated electrode temperature (22). In present study we chose high electrode temperature, therefore the calibration problems did not occur in our application. The average time required to heat the skin was found to be 10 minutes. It is a long time, for this reason transcutaneous measurement of carbon dioxide is not useful during the early resuscitation in the delivery room (23). Transcutaneous measurements can be difficult to use in emergency situations and not appropriate to assess the use of instant carbon dioxide level (it requires time to calibrate and warm the skin), but is suitable for follow-up and an important method for monitoring CO_2 in neonates. We had no concern about the minimal handling approach, as the electrode location was not frequently altered. According to our results transcutaneous CO_2 monitoring would not create a serious complication in NICU.

Our study had some limitations; it was a single center study and acceptable limits of agreement of 0.7 kPa was chosen based on previous studies (7). The measurement of $PaCO_2$ which is considered the gold standard method was not used in our setting because of its practical difficulty. Instead of it we used $PvCO_2$ which is commonly used paramater in clinical practice.

The present study suggests that the relationship between $PvCO_2$ and $PtCO_2$ is deteriorated with hypercapnic level of $PvCO_2$. When the $PvCO_2$ levels increase, the difference of $PvCO_2$ and $PtCO_2$ values also increase. Transcutaneous PCO_2 measurements have generally good agreement with $PvCO_2$ in hypocapnic and normocapnic intubated infants but there are some limitations especially for high levels of CO_2 tension. We recommend that

transcutaneous readings to be confirmed with blood gas values in order to verify the hypercapnic transcutaneous values and persistent or unexpected changes in $PtCO_2$.

Acknowledgements

We would like to thank Raimeter Turkey Company for their help.

Authors' Contributions

Study conception and design: Sinan Uslu Acquisition of data: Mesut Dursun, Umut Zubarioglu, Ebru Turkoglu, Omer Guran Analysis and interpretation of data:Sinan Uslu, Ali Bulbul, Umut Zubarioglu, Ebru Turkoglu Drafting of manuscript: Sinan Uslu, Mesut Dursun Critical revision: Sinan Uslu, Ali Bulbul, Umut Zubarioglu Umut Zubarioglu

References

1. Zhou W, Liu W. Hypercapnia and hypocapnia in neonates. *World J Pediatr.* 2008;**4**(3):192–6.
2. Subramanian S, El-Mohandes A, Dhanireddy R, Koch MA. Association of bronchopulmonary dysplasia and hypercarbia in ventilated infants with birth weights of 500-1,499 g. *Matern Child Health J.* 2011;**15 Suppl 1**:S17–26.
3. Yildizdas D, Yapicioglu H, Yilmaz HL, Sertdemir Y. Correlation of simultaneously obtained capillary, venous, and arterial blood gases of patients in a paediatric intensive care unit. *Arch Dis Child.* 2004;**89**(2):176–80.
4. Bilan N, Behbahan AG, Khosroshahi AJ. Validity of venous blood gas analysis for diagnosis of acid-base imbalance in children admitted to pediatric intensive care unit. *World J Pediatr.* 2008;**4**(2):114–7.
5. Goenka A, Bhoola R, McKerrow N. Neonatal blood gas sampling methods. *SAJCH.* 2012;**6**(1):3–9.
6. Tobias JD, Meyer DJ. Noninvasive monitoring of carbon dioxide during respiratory failure in toddlers and infants: end-tidal versus transcutaneous carbon dioxide. *Anesth Analg.* 1997;**85**(1):55–8.
7. Tingay DG, Stewart MJ, Morley CJ. Monitoring of end tidal carbon dioxide and transcutaneous carbon dioxide during neonatal transport. *Arch Dis Child Fetal Neonatal Ed.* 2005;**90**(6):F523–6.
8. Lacerenza S, De Carolis MP, Fusco FP, La Torre G, Chiaradia G, Romagnoli C. An evaluation of a new combined Spo2/PtcCO2 sensor in very low birth weight infants. *Anesth Analg.* 2008;**107**(1):125–9.
9. Restrepo RD, Hirst KR, Wittnebel L, Wettstein R. AARC clinical practice guideline: transcutaneous monitoring of carbon dioxide and oxygen: 2012. *Respir Care.* 2012;**57**(11):1955–62.
10. Sandberg KL, Brynjarsson H, Hjalmarson O. Transcutaneous blood gas monitoring during neonatal intensive care. *Acta Paediatr.* 2011;**100**(5):676–9.
11. Sivan Y, Eldadah MK, Cheah TE, Newth CJ. Estimation of arterial carbon dioxide by end-tidal and transcutaneous PCO2 measurements in ventilated children. *Pediatr Pulmonol.* 1992;**12**(3):153–7.
12. Geven WB, Nagler E, de Boo T, Lemmens W. Combined transcutaneous oxygen, carbon dioxide tensions and end-expired CO2 levels in severely ill newborns. *Adv Exp Med Biol.* 1987;**220**:115–20.
13. Hand IL, Shepard EK, Krauss AN, Auld PA. Discrepancies between transcutaneous and end-tidal carbon dioxide monitoring in the critically ill neonate with respiratory distress syndrome. *Crit Care Med.* 1989;**17**(6):556–9.
14. Aliwalas LL, Noble L, Nesbitt K, Fallah S, Shah V, Shah PS. Agreement of carbon dioxide levels measured by arterial, transcutaneous and end tidal methods in preterm infants < or = 28 weeks gestation. *J Perinatol.* 2005;**25**(1):26–9.
15. Cuvelier A, Grigoriu B, Molano LC, Muir JF. Limitations of transcutaneous carbon dioxide measurements for assessing long-term mechanical ventilation. *Chest.* 2005;**127**(5):1744–8.
16. Sorensen LC, Brage-Andersen L, Greisen G. Effects of the transcutaneous electrode temperature on the accuracy of transcutaneous carbon dioxide tension. *Scand J Clin Lab Invest.* 2011;**71**(7):548–52.
17. Bhat R, Kim WD, Shukla A, Vidyasagar D. Simultaneous tissue pH and transcutaneous carbon dioxide monitoring in critically ill neonates. *Crit Care Med.* 1981;**9**(10):744–9.
18. Eberhard P. The design, use, and results of transcutaneous carbon dioxide analysis: current and future directions. *Anesth Analg.* 2007;**105**(6 Suppl):S48–52.
19. Fanconi S, Tschupp A, Molinari L. Long-term transcutaneous monitoring of oxygen tension and carbon dioxide at 42 degrees C in critically ill neonates: improved performance of the tcpo2 monitor with topical metabolic inhibition. *Eur J Pediatr.* 1996;**155**(12):1043–6.
20. Tobias JD. Transcutaneous carbon dioxide monitoring in infants and children. *Paediatr Anaesth.* 2009;**19**(5):434–44.
21. Rudiger M, Topfer K, Hammer H, Schmalisch G, Wauer RR. A survey of transcutaneous blood gas monitoring among European neonatal intensive care units. *BMC Pediatr.* 2005;**5**:30.
22. Nishiyama T, Nakamura S, Yamashita K. Effects of the electrode temperature of a new monitor, TCM4, on the measurement of transcutaneous oxygen and carbon dioxide tension. *J Anesth.* 2006;**20**(4):331–4.
23. Rubortone SA, De Carolis MP, Lacerenza S, Bersani I, Occhipinti F, Romagnoli C. Use of a combined SpO(2)/PtcCO(2) sensor in the delivery room. *Sensors (Basel).* 2012;**12**(8):10980–9.