



# Accuracy of a battery-powered portable capnometer in premature infants

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## Abstract

Carbon dioxide measurement is useful for confirmation of successful tracheal intubation and ensuring adequate ventilation. There are two types of CO<sub>2</sub> detectors, i.e., single-use-only colorimetric devices and capnometers. Although portable capnometers are widely used for resuscitation, there have been no reports regarding their clinical utility in neonates. The correspondence between end-tidal CO<sub>2</sub> (PetCO<sub>2</sub>) level determined using a battery-powered portable capnometer and arterial CO<sub>2</sub> (PaCO<sub>2</sub>) was investigated using paired data obtained simultaneously from 26 neonates weighing 1262 ± 589 g at examination on mechanical ventilation. PetCO<sub>2</sub> level and PaCO<sub>2</sub> showed a strong correlation ( $r=0.839$ ,  $P<0.001$ ), and the correlation equation was:  $\text{PetCO}_2 = 0.8 \times \text{PaCO}_2 + 1.1$ . Therefore, PetCO<sub>2</sub> readings obtained with a battery-powered portable capnometer were likely to be underestimated. This became more pronounced with decreasing infant body weight at examination as the net difference in measurements of PaCO<sub>2</sub> and PetCO<sub>2</sub> was significantly positively correlated with infant body weight at examination ( $r=0.451$ ,  $P<0.001$ ). The observations presented here may be helpful in the use of battery-powered portable capnometers in neonates requiring controlled ventilation with tracheal intubation.

**Keywords** End-tidal CO<sub>2</sub> · Capnometer · Premature infants

## 1 Introduction

Measurement of carbon dioxide (CO<sub>2</sub>) using a CO<sub>2</sub> detector is a useful method for confirming airway clearance [1]. However, colorimetric devices are qualitative rather than quantitative. It is important to control CO<sub>2</sub> in premature infants, especially during the acute phase, such as resuscitation, during transportation from the delivery room to the neonatal intensive care unit (NICU). However, during transportation after birth or resuscitation, ventilation is manually supported. Considering that cerebral blood flow (CBF) correlates directly with PaCO<sub>2</sub>, continuous management of ventilation based on the monitoring of CO<sub>2</sub> is capable of limiting fluctuation in PaCO<sub>2</sub> and CBF [2]. It is important to visually and continuously confirm the end-tidal CO<sub>2</sub> using a capnometer, which also helps the respiratory therapist to

determine the appropriate initial settings when switching to a ventilator from a manual support. The capnometer, which measures CO<sub>2</sub> expired from the lung alveoli as PetCO<sub>2</sub> and generally installed in anesthesia machines, is used to identify early airway incidents and to ensure adequate ventilation in the operating room, out of hospital, and during transport of critically ill patients [3–5]. However, conventional capnometer devices are challenging to monitor CO<sub>2</sub> correctly due to the dead volume at the sensor in neonates, especially in premature infants. Neonatal resuscitation is usually conducted in the delivery room or operation room, after which the infant is transported to NICU. Therefore, there is a need for a portable capnometer that can be used easily and monitor correctly at resuscitation or during transportation in emergency, delivery, and operation rooms. The EMMA™ capnograph (EMMA, Masimo, Danderyd, Sweden) is small, light (5.2 × 3.9 × 3.9 cm and 59.5 g with batteries), is readily portable, does not require routine calibration before use, can be warmed up in a short time, 1 ml of the dead volume as small as possible, and can be used for continuous monitoring of CO<sub>2</sub> [6].

Respiratory function includes oxygenation of blood and expiration of CO<sub>2</sub>. Premature neonates often have difficulties

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in respiration and require tracheal intubation immediately after birth for controlled ventilation. SpO<sub>2</sub> monitoring is recommended during resuscitation and transportation of neonates with respiratory failure to the NICU [7]. However, SpO<sub>2</sub> monitoring alone without CO<sub>2</sub> monitoring is insufficient as SpO<sub>2</sub> is only an indicator of binding O<sub>2</sub> to hemoglobin. SpO<sub>2</sub> monitor provides no information about CO<sub>2</sub> levels and is not useful to estimate respiratory acidosis caused by hypercapnia due to inadequate respiration. In neonates, it is important to control CO<sub>2</sub> levels to prevent both hyper and hypocapnia although permissive hypercapnia may be used to protect the lungs, hypercapnia and subsequent respiratory acidosis, which occurs after birth, may exacerbate pulmonary hypertension and make it persistent [8]. On the other hand, hypocapnia is related to brain injury [9]. Hyperventilation with subsequent hypocapnia was widely practiced strategy in the past [10]. In the 1980s, hyperventilation was the only method available for the treatment of persistent pulmonary hypertension (PPHN). Inhalation of nitric oxide (NO) and extracorporeal membrane oxygenation (ECMO) were not commonly accepted as treatment options. However, artificially initiated hypocapnia by hyperventilation is now recognized as a major risk factor for intracranial intraventricular hemorrhage (IVH) or periventricular leukomalacia (PVL) [11]. Hypocapnia causes brain vasoconstriction, and thus reduces cerebral blood flow (CBF) [10]. The brain vasculature at watershed areas is particularly underdeveloped and vulnerable to hypoperfusion in premature infants at around 32 weeks of gestation, and PVL can occur in this area. IVH is caused by multiple reasons, one of which is hypocapnia [10–12]. Severe IVH is related to neurodevelopmental delay, and 48% of cases of IVH are observed within the first 6 h of life. Therefore, strict control of blood CO<sub>2</sub> levels in the acute phase is required [12, 13].

To our knowledge, there have been no studies focusing on the accuracy of the EMMA capnograph in neonates. This study was performed to assess the accuracy of the EMMA capnograph in neonates on mechanical ventilation by comparing end-tidal CO<sub>2</sub> measured using this device with PaCO<sub>2</sub>.

## 2 Materials and methods

This study was approved by the institutional review board (IRB) of Kagoshima City Hospital (KCH) (20150903). Neonates admitted to the NICU of KCH between July 2014 and February 2015 and requiring controlled ventilation were eligible for inclusion in the study. The parents of all patients provided written informed consent before participation in this study. Two mainstream capnographs are used for patients on mechanical ventilation in KCH, EMMA and CapONE™ (Nihon Kohden, Tokyo). Sidestream

capnography is not used. The EMMA was placed distal to the endotracheal tube using a neonatal adaptor with 1.0-mL dead space. PaCO<sub>2</sub> levels were measured using 100-μL arterial blood sample, and PetCO<sub>2</sub> levels were recorded at the same time as sampling as a number without a decimal point. Each participant underwent PetCO<sub>2</sub> measurement at least once a day. Participants on mechanical ventilation required repeated PetCO<sub>2</sub> measurements during their hospital stay when arterial blood samples were collected. PaCO<sub>2</sub> was measured using an ABL 800™ (Radiometer, Copenhagen, Denmark). All measurements were recorded with the patient in the supine position. Blood gas analysis was performed when ordered by the attending neonatologist depending on the condition of the patient.

Statistical analyses were performed using the JMP13© statistical software package (SAS, Cary, NC). The Wilcoxon/Kruskal–Wallis method was used for analysis of continuous variables. Fisher's exact probability test was used for analysis of categorical variables. Regression analysis was performed. In all analyses,  $P < 0.05$  was considered statistically significant.

## 3 Results

The study population consisted of 26 newborn infants (Table 1). The median (minimum–maximum) gestational age at birth was 27 (22–38) weeks and median birth weight was

**Table 1** Demographic characteristics of the 26 patients

Male/female	12 (46%)/14 (54%)
Gestational week at birth	27 (22–38)
22–26	12 (46%)
27–32	9 (35%)
33–	5 (19%)
Birth weight (g)	881 (420–2730)
≤ 999	15 (58%)
1000–1499	3 (11%)
1500–2499	7 (27%)
≥ 2500	1 (4%)
EMMA application	
Total no. of applications	63
No. of applications/infant	3 (1–5)
Once	8 (13%)
Twice	5 (16%)
Three times	9 (42%)
Four times	2 (13%)
Five or more	2 (16%)
Corrected age (weeks)	30 (22–38)
Body weight (g)	1151 (420–2730)
Tidal volume (mL/kg)	5.6 (3.3–7.4)

881 (420–2730) g. Tracheal tubes were selected according to birth weight as follows: < 1000 g, Fr. 2.5; 1000–1800 g, Fr. 3.0; and > 1800 g, Fr. 3.5. At the point of measurement, the ventilation mode was synchronized intermittent mechanical ventilation (SIMV) without volume guarantee and the leakage displayed on the ventilator was 0% in all patients. Simultaneous EMMA PetCO<sub>2</sub> and PaCO<sub>2</sub> measurements were performed 63 times in the 26 infants (median, three times per infant). Median values of corrected age, body weight, and tidal volume of those measured with EMMA were 30 (22–38) weeks of gestation, 1151 (420–2730) g, and 5.6 (3.3–7.4) mL/kg, respectively (Table 1). No adverse events associated with use of the EMMA capnograph occurred in the 26 infants.

### 3.1 Correlation between PetCO<sub>2</sub> and PaCO<sub>2</sub>

As shown in Fig. 1, the majority of PetCO<sub>2</sub> measurements were lower than those of PaCO<sub>2</sub>. However, the correlation coefficient (*r*) was 0.839 and the correlation equation was as follows for 63 paired data:  $\text{PetCO}_2 = 0.80 \times \text{PaCO}_2 + 1.17$ . Thus, the overall PetCO<sub>2</sub> measurements were approximately 20% lower than PaCO<sub>2</sub> measurements.

### 3.2 Effects of infant body weight on PetCO<sub>2</sub> measurements

The body weights of the infants showed no significant correlation with PaCO<sub>2</sub> measurements, but were significantly positively correlated with PetCO<sub>2</sub> measurements (Fig. 2, upper and middle panels). As most PetCO<sub>2</sub> measurements were lower than those of PaCO<sub>2</sub> (Fig. 1), these results suggested that PetCO<sub>2</sub> measurements were more likely to be underestimated in infants with lower body weight. This was the case, as shown in the lower panel of Fig. 2, where net differences between measurements of PaCO<sub>2</sub> and PetCO<sub>2</sub> increased as infant body weight decreased. However, the net differences were not significantly correlated with tidal volume (mL/kg) at the time of examination.

## 4 Discussion

In this study, PetCO<sub>2</sub> measured using an EMMA capnograph in neonates was correlated with PaCO<sub>2</sub>. This is the first report of the application of this device to neonates, including extremely infants with low birth weight. As shown in Fig. 1, correlations between PetCO<sub>2</sub> and PaCO<sub>2</sub> were observed over wide ranges; PaCO<sub>2</sub> [24.5–84.5] and PetCO<sub>2</sub> [18–79]. These observations also showed that the EMMA capnograph correctly tracked PaCO<sub>2</sub> over a wide range with PetCO<sub>2</sub> approximately 20% lower than PaCO<sub>2</sub>. The reason of this gap, especially in premature infants, was reported as

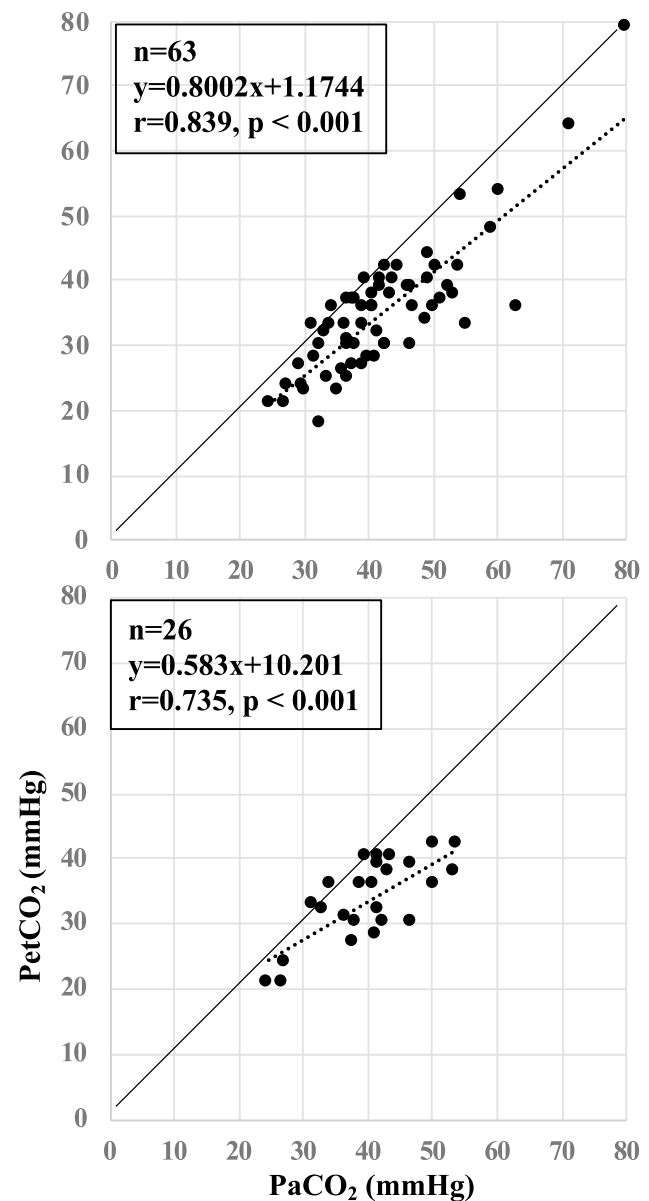
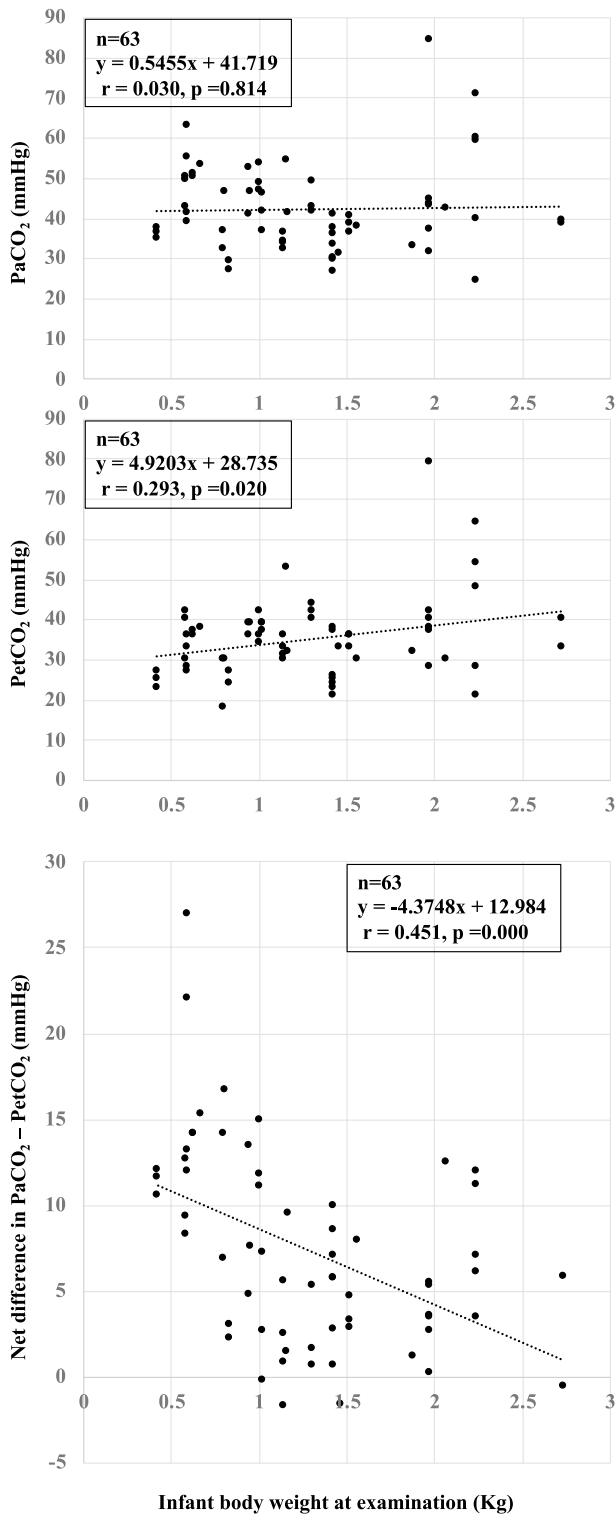


Fig. 1 Correlations between PaCO<sub>2</sub> and PetCO<sub>2</sub>

ventilatory parameters, small airways, missing alveolar plateau, airway dead spaces, endotracheal tube leaks, apparatus dead space, response time and sampling rate [14]. Singh et al. have reported lower levels of PetCO<sub>2</sub> relative to PCO<sub>2</sub>, not PaCO<sub>2</sub>, in side stream device, meaning PetCO<sub>2</sub> is lower than PaCO<sub>2</sub> [15]. Several neonatal lung diseases affecting gas exchange subsequent to cause the gap between PCO<sub>2</sub> and PetCO<sub>2</sub> were also reported, and the effects of lung stiffness related with surfactant activity have a relation with the gap [16]. No infants with the diseases were included in the present study. Our data showed that the net difference of detected CO<sub>2</sub> was larger in infants with lower birth weight. As lower CO<sub>2</sub> values were observed in lower birth weight



**Fig. 2** Correlation between infant body weight and net difference in PaCO<sub>2</sub>-PetCO<sub>2</sub>

infants, higher dead space relative to tidal volume were considered. PetCO<sub>2</sub> was measured with a sensor set at the distal end of the tracheal tube, which was also the end of the entire

ventilation circuit. In management of mechanical ventilation, tidal volume per weight (TV mL/kg) is a score that ensures that the ventilator settings are adequate for the patient. The normal range of TV mL/kg in neonates is 4–6 mL/kg. Obviously, the net tidal volume (mL) is smaller in infants with lower birth weight. In this study, the median body weight and median TV mL/kg at the time of examination were 1151 (420–2730) g and 5.6 (3.3–7.4) mL/kg, respectively. TV mL/kg was adequate for each body weight. Low net tidal volume has been reported as a factor of the observed net differences between PaCO<sub>2</sub> and PetCO<sub>2</sub> due to the lack of alveolar plateau [17]. Our result indicates that a greater net tidal volume was required for accuracy of PetCO<sub>2</sub> measurement in premature infants. Therefore, net tidal volume affects PetCO<sub>2</sub> depending on the level of flow at the sensor. The differences also have been due to differences in the sizes of tracheal tubes. Use of a tracheal tube of inadequate size affect tidal volume, because the tracheal tubes used in neonates do not have a cuff, therefore tidal volume is affected by air leakage. In this study, air leakage displayed on the ventilator monitors was 0% at each examination.

## 5 Conclusion

The results of this study indicated that PetCO<sub>2</sub> measured using an EMMA capnograph was positively correlated to PaCO<sub>2</sub> even in preterm neonates. Thus, this device may be applicable even in preterm neonates. As shown in the correlation equation, PetCO<sub>2</sub> determined with the EMMA capnograph was approximately 20% lower than PaCO<sub>2</sub>. Therefore, this underestimation must be taken into account when assessing blood CO<sub>2</sub> level using this device.

**Author contributions** E.H., and S.I. contributed to the study design and writing the manuscript. All authors have seen and approved the final version of this manuscript.

## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

**Ethical Approval** The Institutional Review Board of the Kagoshima city hospital approved the protocol of the current studies (20150903).

**Informed consent** Written informed consent was obtained from each participant or authorized representative prior to study enrollment.

## References

1. Gavin A, Finn D, Mmoloki K, Livingstone V, O'Toole JM, Boylan GB, et al. *J Pediatr*. 2017;182:74–8.
2. Chandrasekharan PK, Rawat M, Nair J, Gugino SF, Koenigsnecht C, Swartz DD, et al. Continuous end-tidal carbon dioxide monitoring during resuscitation of asphyxiated term lambs. *Neonatology*. 2016;109(4):265–73.
3. Georgiou AP, Gouldson S, Amphlett AM. The use of capnography and the availability of airway equipment on Intensive Care Units in the UK and the Republic of Ireland. *Anaesthesia*. 2010;65:462–7.
4. Levine RL, Wayne MA, Miller CC. End-tidal carbon dioxide and outcome of out-of-hospital cardiac arrest. *N Engl J Med*. 1997;337:301–6.
5. Singh S, William D, Shekhar T, Mananda S. Utility of a novel quantitative handheld microstream capnometer during transport of critically ill children. *Am J Emerg Med*. 2006;24:302–7.
6. Heines SJH, Strauch U, Roekaerts PMHJ, Winkens B, Bergmans DCJJ. Accuracy of end-tidal CO<sub>2</sub> capnometers in post-cardiac surgery patients during controlled mechanical ventilation. *J Emerg Med*. 2013;45:130–5.
7. Finn D, Boylan GB, Ryan CA, Dempsey EM. Enhanced monitoring of the preterm infant during stabilization in the delivery room. *Front Pediatr*. 2016;4:30.
8. Noori S, Anderson M, Soleymani S, Seri I. Effect of carbon dioxide on cerebral blood flow velocity in preterm infants during post-natal transition. *Acta Paediatr*. 2014;103:e334–9.
9. Zhou W, Liu W. Hypercapnia and hypocapnea in neonates. *World J Pediatr*. 2008;4:192–6.
10. Laffey JG, Kavanagh BP. Hypocapnia. *N Engl J Med*. 2002;347:43–53.
11. Curley G, Kavanagh BP, Laffey JG. Hypocapnia and the injured brain: more harm than benefit. *Crit Care Med*. 2010;38:1348–59.
12. Ballabh P. Intraventricular hemorrhage in premature infants: mechanism of disease. *Pediatr Res*. 2010;67:1–8.
13. Al-Abdi SY, Al-Aamri MA. A systematic review and meta-analysis of the timing of early intraventricular hemorrhage in preterm neonates: clinical and research implications. *J Clin Neonatol*. 2014;3:76–88.
14. Schmalisch G. Current methodological and technical limitations of time and volumetric capnography in newborns. *Biomed Eng Online*. 2016;15(1):104.
15. Singh BS, Gilbert U, Singh S, Govindaswami B. Sidestream microstream end tidal carbon dioxide measurements and blood gas correlations in neonatal intensive care unit. *Pediatr Pulmonol*. 2013;48:250–6.
16. Bhat YR, Abhishek N. Mainstream end-tidal carbon dioxide monitoring in ventilated neonates. *Singap Med J*. 2008;49(3):199–203.
17. Tirosh E, Bilker A, Bader D, Cohen A. Capnography in spontaneously breathing preterm and term infants. *Clin Physiol*. 2001;21:150–4.

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