Transcutaneous CO₂ versus end-tidal CO₂ in neonates and infants undergoing surgery: a prospective study

Arvind Chandrakantan¹
Ronald Jasiewicz²
Ruth A Reinsel³
Kseniya Khmara²
Jonathan Mintzer⁴
Joseph D DeCristofaro⁴
Zvi Jacob²
Peggy Seidman⁵

¹Department of Anesthesiology & Pediatrics, Texas Children’s Hospital, Houston, TX, USA; ²Department of Anesthesiology, Stony Brook University Hospital, Stony Brook, NY, USA; ³Department of Neurology, Stony Brook University Hospital, Stony Brook, NY, USA; ⁴Department of Neonatology & Pediatrics, Stony Brook University Hospital, Stony Brook, NY, USA; ⁵Department of Anesthesiology & Pediatrics, UH Rainbow Babies and Children’s Hospital, Cleveland, OH, USA

Aim: End-tidal CO₂ (EtCO₂) is the standard in operative care along with pulse oximetry for ventilation assessment. It is known to be less accurate in the infant population than in adults. Many neonatal intensive care units (NICU) have converted to utilizing transcutaneous CO₂ (tcP₂CO₂) monitoring. This study aimed to compare perioperative EtCO₂ to tcP₂CO₂ in the pediatric perioperative population specifically below 10 kg, which encompasses neonates and some infants.

Methods: After IRB approval and parental written informed consent, we enrolled neonates and infants weighing less than 10 kg, who were scheduled for elective surgery with endotracheal tube under general anesthesia. P₂CO₂ was monitored with EtCO₂ and with tcP₂CO₂. Venous blood gas (PvCO₂) samples were drawn at the end of the anesthetic. We calculated a mean difference of EtCO₂ minus PvCO₂ (ΔEtCO₂) and tcP₂CO₂ minus PvCO₂ (ΔtcP₂CO₂) from end-of-case measurements. The mean differences in the NICU and non-NICU patients were compared by t-tests and Bland–Altman analysis.

Results: Median age was 10.9 weeks, and median weight was 4.4 kg. NICU (n=6) and non-NICU (n=14) patients did not differ in PvCO₂. Relative to the P₂CO₂, the ΔEtCO₂ was much greater in the NICU compared to the non-NICU patients (~28.1 versus ~9.8, t=3.912, 18 df, P<0.001). ΔtcP₂CO₂ was close to zero in both groups. Although both measures obtained simultaneously in the same patients agreed moderately with each other (r =0.444, 18 df, P=0.05), Bland–Altman plots indicated that the mean difference (bias) in EtCO₂ measurements differed significantly from zero (P<0.05).

Conclusions: EtCO₂ underestimates P₂CO₂ values in neonates and infants under general anesthesia. TcP₂CO₂ closely approximates venous blood gas values, in both the NICU and non-NICU samples. We, therefore, conclude that tcP₂CO₂ is a more accurate measure of operative P₂CO₂ in infants, especially in NICU patients.

Keywords: infant, newborn, end-tidal CO₂, blood gas monitoring-transcutaneous, intensive care monitoring- neonatal, ASA monitoring standards

Introduction

Transcutaneous CO₂ monitoring (tcP₂CO₂) is a well-described non-invasive method to trend ventilation in neonates and is validated as accurate through all age groups. Recent literature has evaluated the relative efficacy of transcutaneous CO₂ (tcP₂CO₂) compared to end-tidal CO₂ (EtCO₂) monitoring as a reflection of arterial CO₂ (P₂CO₂). Publications relating to use in infants and children with respiratory failure,¹ congenital heart disease,² and one lung ventilation³ have demonstrated improved correlation...
between $P_{aCO_2}$ with $tcP_{CO_2}$ as compared to correlation of $P_{aCO_2}$ with $Et_{CO_2}$; however, controversy exists. Two recent reviews suggest that $tcP_{CO_2}$ should be used as an adjunct to end-tidal $CO_2$.\(^4,5\) One study which showed close correlation of $Et_{CO_2}$ with $P_{aCO_2}$ recommends $Et_{CO_2}$ usage for longitudinal monitoring in the neonatal intensive care unit (NICU);\(^6\) data from a more heterogeneous intraoperative cohort suggest that $tcP_{CO_2}$ may be more accurate.\(^7\) This non-invasive infant study uses $P_{vCO_2}$ as the surrogate for $P_{aCO_2}$.

The standard of care for monitoring respiratory status during anesthesia has been end-tidal $CO_2$ ($Et_{CO_2}$) and pulse oximetry. While this methodology is well established in operative care, $Et_{CO_2}$ is known to be less accurate in the neonatal population. The sampling flow rate on the $Et_{CO_2}$ in relation to the tidal volume and total flow used to ventilate extremely low birth weight infants provides ambiguous data. In addition, $Et_{CO_2}$ is not feasible in high-frequency oscillators or jet ventilators as the volume of each breath is less than dead space. Many neonatal intensive care units and pediatric intensive care units (PICU) utilize $tcP_{CO_2}$ as a primary means of $P_{aCO_2}$ monitoring. Adequate direct comparisons of the two monitors are not available. Based on preliminary data in neonates, our null hypothesis was that there would be no difference between venous $CO_2$ as measured by end-tidal and transcutaneous methods.

## Methods

### IRB approval and informed consent

This study was approved by the Stony Brook University Committee on Research Involving Human Patients. Parents were approached in person or by telephone by a physician or the study coordinator at least one day in advance of scheduled operative procedures. All study procedures were further explained and written informed consent was obtained on the day of surgery.

### Research site

This study was conducted in the main operating room of an academic tertiary care university hospital with a level 3 NICU (Regional Perinatal Center) between April 2015 and October 2016.

### Sample size requirements

The estimated sample size is based on a correlational analysis. We assume a relationship of at least moderate magnitude between the two techniques for estimation of $P_{aCO_2}$. Estimation of the required sample size is complicated by the range of values seen in our preliminary observations. Pearson correlations between $T_{CO_2}$ and $Et_{CO_2}$ ranged from $+0.59$ to $−0.74$. Disregarding the direction of the relationship (direct or inverse), the absolute values of 0.6 to 0.7 suggest a “large” effect size. We can thus estimate sample sizes under the assumption of a large effect size, $\rho = 0.5$. For 80% power at alpha level = 0.05 using a 2-tailed analysis, 26 subjects would be required.

### Study sample

Infants up to 12 months of age and under 10 kg in weight who required an elective surgery with general anesthesia were eligible for the study. Patients were excluded if they required emergency surgery, if they were receiving anesthesia without an endotracheal tube (ETT) or if the parents were unable to read or understand the consent form in either English or Spanish.

### Equipment

End-tidal $CO_2$ ($Et_{CO_2}$) was measured via the sidestream (diverting) sampling device (Medline 3m 0.06 ID) on the anesthesia machine (GE Aisys Datex-Ohmeda). Transcutaneous $CO_2$ ($tcP_{CO_2}$) was measured using the SenTec Digital Monitoring System (SDMS) manufactured by SenTec AG (Therwil, Switzerland; www.sentec.com). This is an FDA-approved clinical monitoring device that is used in NICUs globally. $TcP_{CO_2}$ measurements were recorded with the V-Sign\(^TM\) Sensor 2, under software version MPB-SW:V05.03.02/SMB-SW:V07.03.1. The sensor head is extremely lightweight (less than 2.9 g) and small (14 mm x 9 mm) and is applied to the skin using an adhesive ring specially designed for sensitive, fragile skin. $O_2$ saturation and pulse rate were obtained from our standard intraoperative monitor. $TcP_{CO_2}$ data reported here were manually recorded from the SDMS visual display and do not reflect the $tcP_{CO_2}$ values corrected for residual drift (obtainable via retrospective data download), as would be seen in real-time. The monitor was warmed up and calibrated by the study team the morning that an appropriate OR case was identified and consented. Membranes were changed per routine maintenance following manufacturer guidelines every 40 days.

### Procedures

In the OR, the $tcP_{CO_2}$ V-Sign\(^TM\) Sensor 2 with Multi-Site Attachment Ring was applied along with standard ASA monitors which are 3 lead electrocardiogram (EKG),
non-invasive blood pressure cuff (NIBP), pulse oximetry, and temperature probe. In most cases, the sensor was placed on the forehead. If that site was not available, it was placed as close to the core of the body as the surgical site and surgical preparation allowed in concordance with manufacturer recommendations. To ensure optimal recording of tcPCO₂, every effort was made to follow manufacturer recommendations for sensor placement (see Figure 1).

After baseline vital signs, the patients were anesthetized using either standard mask induction with sevoflurane and an IV was placed if one was not already in place or the patient was induced with the IV and then ETT placed after IV induction unless the child arrived intubated. Vital signs (cardiac rhythm, heart rate, respiratory rate, blood pressure, pulse oximetry, temperature) were recorded every 5 mins as per standard of care. Operative events were noted on the data sheet including: induction, intubation, neuraxial block, positioning for surgery, incision, closure, and extubation.

TcPCO₂ was monitored concurrently with EtCO₂, with respiratory mode noted (spontaneous vs controlled). The anesthesiologist delivering anesthesia was blinded to the readings of the tcPCO₂ monitor and provided intraoperative care using standard monitors including EtCO₂ to guide operative management. A separate data sheet was utilized to document the TCOM readings and note significant events and was blinded to the anesthesiology team caring for the patient.

Blood samples

Prior to extubation, a venous blood sample was obtained or a capillary blood gas was obtained from a heel or thumb stick and analyzed for PVCO₂. Blood gas parameters including pH, partial pressure of oxygen (pO₂), bicarbonate concentration (HCO₃⁻), and base excess (BE) were recorded.

Data analysis

For each patient, we calculated a mean difference of Delta EtCO₂ (EtCO₂ minus PVCO₂), and Delta tcPCO₂ (tcPCO₂ minus PVCO₂) from end-of-case measurements, matched as closely as possible to the time of venous blood gas sampling. Independent t-tests were used to compare the mean differences between NICU and non-NICU patients. In view of the small sample size, we repeated these tests with a nonparametric Mann–Whitney U-test, which is not dependent on normally distributed data. Within-patient comparisons between EtCO₂ and tcPCO₂ measures were made using the Wilcoxon signed ranks test. We considered a P-value of <0.05 as significant. All statistical testing was performed using IBM SPSS v22 (IBM, Armonk, NY). Continuous variables were analyzed using parametric and/or nonparametric testing based on the presence or absence of normal distributions, and were done on an individual variable basis to ensure scientific rigor. All values are in mm Hg unless otherwise indicated.

Figure 1  Manufacturer recommendations for sensor placement in infants, numbered in order of preference (1 = high, 3 = low). Source: SenTec AG, Therwil, Switzerland (www.sentec.com).
Agreement between methods of measurement

Et\textsubscript{CO\textsubscript{2}} and tc\textsubscript{P\textsubscript{CO\textsubscript{2}}} were compared to venous blood gas measure of P\textsubscript{CO\textsubscript{2}} using the Bland–Altman technique.\textsuperscript{8,9} This well-accepted graphical technique plots the mean of the two measures versus the difference of the two measures with 95% limits of agreement. If the two measures agree perfectly, all differences will be zero. The difference of the two measures is termed “bias”. One can calculate a 95% confidence interval around the mean difference (mean ±1.96*standard error of the mean). Statistical significance was defined a priori based on 95% confidence intervals of mean differences not including a determination of utility (bias of zero) between the two CO\textsubscript{2} measurement techniques.

Results

Patient sample

A total of 38 patients were enrolled with parental written informed consent. For six patients no data was obtained due to delay or cancellation of surgery, or lack of availability of study staff at the time of surgery. One patient was excluded from analysis due to a protocol deviation (use of laryngeal mask airway). Two patients came to the OR twice, each time as a separate consent, as allowed by our IRB protocol; but only one surgery was used in this analysis to meet statistical assumptions that the observations are independent. The choice of which patients to include was made based on availability of blood gas data at the end of the case. Insufficient data for venous blood gas analysis was obtained at the end of 5 additional cases, and in 4 patients the venous blood gas was obtained post-extubation, leaving no corresponding value for Et\textsubscript{CO\textsubscript{2}}. This left 20 patients (6 NICU, 14 non-NICU) with concurrent end-tidal and transcutaneous CO\textsubscript{2} values for analysis. Characteristics of the patient cohort are given in Table 1. Thirteen out of the 20 patients were intubated with cuffed laryngeal mask. Abdominal surgeries were the most frequent (n=9), followed by cleft lip/palate (n=3), neurological (n=2), orthopedic (n=2), bronchial (n=1), thoracic (n=1), urological (n=1), and central venous access (n=1). Within the NICU group (n=6), laparotomies were the most common procedure (n=3). As expected, NICU patients were significantly younger in gestational age (t=3.203, 17.3 df, P=0.001) and lower in weight (t=3.978, 18 df, P=0.001) than non-NICU patients (see Table 1). Anesthesia time did not differ between groups (see Table 1).

Two infants arrived from the NICU already intubated and were returned to the NICU in the same condition. Three additional neonates were not extubated after surgery and were returned to the NICU intubated. Vasoactive agents were not utilized for any of the patients.

Sensor placement

For the NICU group, all but one had the V-Sign Sensor 2 placed on the forehead (n=3) or abdomen/chest (n=2). A single baby had the sensor placed on the lower leg, which is a less favorable but accepted position for tc\textsubscript{P\textsubscript{CO\textsubscript{2}}} measurement. Among the non-NICU patients, 8 had the sensor placed on the forehead, 2 on the abdomen/chest, and 4 on the shoulder/back.

Blood gas analysis

As shown in Table 2, the difference between blood pH and Pv\textsubscript{O\textsubscript{2}} was not statistically significant. However, NICU patients had higher levels of bicarbonate (t=−2.813, 18 df, P=0.012) and lower base excess (t=−2.298, 18 df, P=0.034).

\textbf{Measurement of P\textsubscript{CO\textsubscript{2}}.} tc\textsubscript{P\textsubscript{CO\textsubscript{2}}} levels were higher than Et\textsubscript{CO\textsubscript{2}} in both populations (see Table 2). Et\textsubscript{CO\textsubscript{2}} values in NICU patients did not differ significantly compared to older infants. The mean difference between Et\textsubscript{CO\textsubscript{2}} and Pv\textsubscript{CO\textsubscript{2}} was significantly greater in NICU patients (−28.1 ±12.3) vs non-NICU patients (9.8±8.3) (t=3.912, 18 df, P=0.001, see Figure 2; P-value confirmed by Mann–Whitney U-test). The mean difference between tc\textsubscript{P\textsubscript{CO\textsubscript{2}}} and Pv\textsubscript{CO\textsubscript{2}} between NICU (−0.7±11.2) and non-NICU patients (3.0±9.8) was not significantly different (t=−0.733, 18 df, P=0.473). However, Wilcoxon signed rank tests for related

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**Table 1 Characteristics of NICU and non-NICU subjects.** For continuous variables, values are mean±standard deviation

|                      | NICU (n=6) | Non-NICU (n=14) |
|----------------------|------------|------------------|
| ASA (I/II/III/IV)    | 0/0/2/4    | 2/7/5/0          |
| Gender               | M: 3 F: 3  | M: 9 F: 5        |
| Premature at birth   | 4 (66.7%)  | 4 (28.6%)        |
| Post-natal age (weeks)| 6.2±6.8    | 17±10.8          |
| Gestational age (weeks)| 38.7±4.8  | 51.9±9.5         |
| Weight on DOS (kg)   | 2.6±0.5    | 5.4±1.7          |
| Anesthesia time (mins)| 163.3±43.8| 147.3±78.7       |

Notes: Data presented as mean ± SD unless otherwise indicated.

Abbreviations: ASA, American Society of Anesthesiologists; DOS, day of surgery; NICU, neo-natal intensive care unit.
Table 2 Blood gas analysis (mean±standard deviation) for NICU and non-NICU subjects. Venous blood gas samples were taken at the end of the case.

|                      | Neonatal intensive care unit (NICU) (n=6) | Non-NICU (n=14) | P-value for independent t-test |
|----------------------|------------------------------------------|-----------------|-------------------------------|
| Venous blood gas (Pv\textsubscript{CO\textsubscript{2}}) | 60.1±9.3                                  | 48.9±14.1       | 0.093                         |
| Transcutaneous CO\textsubscript{2} (tcP\textsubscript{CO\textsubscript{2}}) | 59.4±12.7                                  | 51.9±13.1       | 0.251                         |
| End-tidal CO\textsubscript{2} (Et\textsubscript{CO\textsubscript{2}}) | 32.0±12.4                                  | 39.1±10.8       | 0.215                         |
| Δ(tcP\textsubscript{CO\textsubscript{2}}−Pv\textsubscript{CO\textsubscript{2}}) | −0.7±11.2                                  | +3.0±9.8        | 0.473                         |
| Δ(Et\textsubscript{CO\textsubscript{2}}−Pv\textsubscript{CO\textsubscript{2}}) | −28.1±12.3                                 | −9.8±8.3        | 0.001                         |
| pH                   | 7.3±0.1                                   | 7.3±0.1         | 0.518                         |
| PvO\textsubscript{2}  | 57.6±14.3                                  | 90.3±59.8       | 0.209                         |
| HCO\textsubscript{3}− | 26.6±3.1                                   | 22.5±2.9        | 0.012                         |
| BE                   | −0.4±4.5                                   | −4.0±2.6        | 0.034                         |

Notes: Indicates P<0.05 is generally considered to be statistically significant.

Figure 2 ΔEt\textsubscript{CO\textsubscript{2}} and ΔtcP\textsubscript{CO\textsubscript{2}} in NICU and non-NICU patients. Values are normalized to the measured Pv\textsubscript{CO\textsubscript{2}} for each patient, indicated by the zero line on the vertical axis. TcP\textsubscript{CO\textsubscript{2}} rather than Et\textsubscript{CO\textsubscript{2}} levels closely approximated Pv\textsubscript{CO\textsubscript{2}} in both populations. Dark bars: Et\textsubscript{CO\textsubscript{2}}; light bars: tcP\textsubscript{CO\textsubscript{2}}. Arrows indicate groups compared for independent-groups t-test. A nonparametric test for paired samples was also performed to compare measures of ΔEt\textsubscript{CO\textsubscript{2}} and ΔtcP\textsubscript{CO\textsubscript{2}} within each patient group. This test showed significant differences (P<0.05) between Et\textsubscript{CO\textsubscript{2}} and tcP\textsubscript{CO\textsubscript{2}} within both NICU and non-NICU patient groups.

Abbreviations: Pv\textsubscript{CO\textsubscript{2}}, venous blood gas; tcP\textsubscript{CO\textsubscript{2}}, transcutaneous CO\textsubscript{2}; Et\textsubscript{CO\textsubscript{2}}, end-tidal CO\textsubscript{2}; NICU, neo-natal intensive care unit; N.S., non significant.

samples showed that tcP\textsubscript{CO\textsubscript{2}} and Et\textsubscript{CO\textsubscript{2}} were significantly different within both groups (P=0.028 for NICU and P=0.001 for non-NICU patients).

Blood gas results are shown in Table 2. The nonparametric Mann–Whitney U-Test found that venous blood gas was significantly different between the two groups at both the start (P=0.036) and end (P=0.033) of the surgery. By paired-t-test, these differences were significant only at the start of the case (t=−2.620, 12 df, P=0.022). NICU and non-NICU patients did not differ in venous blood gas Pv\textsubscript{CO\textsubscript{2}}, tcP\textsubscript{CO\textsubscript{2}} or Et\textsubscript{CO\textsubscript{2}} at the end of the case. Delta Et\textsubscript{CO\textsubscript{2}} was much greater in the NICU babies compared to non-NICU patients (−28.1 versus −9.8, t=3.912, 18 df, P=0.001). Delta tcP\textsubscript{CO\textsubscript{2}} was close to zero in both groups. TcP\textsubscript{CO\textsubscript{2}} did not differ significantly from measured Pv\textsubscript{CO\textsubscript{2}} in these two patient groups.

Comparison of methods by Bland–Altman analysis

Figure 3 and Table 3 show tcP\textsubscript{CO\textsubscript{2}} and Et\textsubscript{CO\textsubscript{2}} compared to the venous blood gas measurement (Pv\textsubscript{CO\textsubscript{2}}) using the Bland–Altman technique. Comparing tcP\textsubscript{CO\textsubscript{2}} to Pv\textsubscript{CO\textsubscript{2}} (Figure 3A), these plots show agreement between measures, with a mean difference (bias) of 1.86 (95% CI −2.57 to 6.29), in the full sample of 20 patients. The value is similarly low in NICU (−0.70, 95% CI −9.68 to 8.28) and non-NICU patients (2.96, 95% CI −2.19 to 8.11). Comparing Et\textsubscript{CO\textsubscript{2}} to Pv\textsubscript{CO\textsubscript{2}} (Figure 3B), the plots show a much higher bias of −15.29 (95% CI −20.84 to −9.74) for the full sample, with high variability, especially among NICU patients. The mean bias is nearly three times as high among NICU patients (−28.07, 95% CI −37.91 to −18.23) as in the non-NICU group (−9.82, 95% CI −14.15 to −5.49). This variability seems to be most pronounced for the average measure of (Et\textsubscript{CO\textsubscript{2}}+Pv\textsubscript{CO\textsubscript{2}}) below 40 (see Figure 3B). The standard deviations of the bias are similar among the two patient groups on both methods of measurement.

The 95% limits of agreement (red dashed lines) are much wider for Et\textsubscript{CO\textsubscript{2}} measurements, reflecting the higher values of the mean difference between Et\textsubscript{CO\textsubscript{2}} and the venous blood gas. Notably, in Figure 3B, the 95% confidence limits for the sampling error of the mean difference of Et\textsubscript{CO\textsubscript{2}} versus Pv\textsubscript{CO\textsubscript{2}} (blue dashed lines) do not include zero. This indicates that the mean bias in Et\textsubscript{CO\textsubscript{2}} measurements is significantly different from zero (P<0.05) for both NICU and non-NICU patients, as well as for the sample taken as a whole (see Table 3). In contrast, all the corresponding confidence intervals for tcP\textsubscript{CO\textsubscript{2}} measurements include zero, indicating lack of difference between tcP\textsubscript{CO\textsubscript{2}} and Pv\textsubscript{CO\textsubscript{2}} measurements (see Figure 3A and Table 3).

Discussion

The limits of agreement for both measurements were wide in both age groups. There are many physiological and
iатrogenic changes during surgery which can alter CO₂ and necessitates accurate CO₂ values to assure proper ventilation in the operative care. The inaccuracy of EtCO₂ in this population compelled this study of the agreement between the monitors and the PvCO₂. Since this study utilized children below 10 kg, which encompasses both neonates and infants, we were able to study the effects of both EtCO₂ and TcPCO₂ on both populations. Our study found that tcPCO₂ correlates better with PvCO₂ in younger children, specifically in the neonatal population.

With long-term ventilator management in neonates and infants with respiratory failure, tcPCO₂ is a viable alternative to EtCO₂ in the NICU. A more recent study demonstrated that tcPCO₂ was correlated with venous CO₂, although the study was limited by small sample size. In cases of infants with bronchiolitis, it was found that there was reasonable correlation between tcPCO₂ and PvCO₂, but the investigators felt the monitor was to be used as an adjunct rather than as a primary monitoring tool. Long-term ventilator management in a larger study suggested moderate correlation of tcPCO₂ with arterial CO₂ levels, although bias was greater when transcutaneous monitoring was employed in HFOV. In addition, a recent study demonstrated poor correlation between EtCO₂ and PvCO₂ in anesthetized neonates for general surgery. Similar effects have been noted for PA CO₂ as well. This is the same effect noted in our study; however, we were able to demonstrate improved agreement between PvCO₂ and tcPCO₂ during the perioperative period as compared to EtCO₂.

Our study was limited to the perioperative period; however, the NICU literature suggests decreasing correlation with PvCO₂ with long-term mechanical ventilation. This suggests that in the short term, the utility of having a single accepted, correlated monitor for both the OR and the NICU cannot be overstated. Further, larger studies are needed to validate tcPCO₂ as a stand-alone monitor, specifically for acute events resulting in large CO₂ shifts, such as an accidental or intentional extubation, endobronchial intubation, or mucus plugging, which are seen in the intraoperative period. Answers to these questions require a greater number of neonates across a greater spectrum of surgeries. Specifically, surgeries in which there are greater shifts of CO₂ including those with abdominal insufflation.

**Figure 3** Bland–Altman plots showing mean difference (bias) for tcPCO₂ (A) and EtCO₂ (B) with 95% limits of agreement (red dashed lines). Blue dashed lines show the 95% confidence interval for the mean difference (bias). The bias is significant if the confidence interval does not include the line of equality (dashed line at zero). NICU patients, solid circles; non-NICU patients, open circles. Comparing tcPCO₂ to PvCO₂ (Figure 3A), these plots show good agreement between measures, with a mean difference (bias) of 1.86, in the full sample of 20 patients. The 95% confidence interval for the mean difference (blue dashed lines) includes zero, indicating lack of meaningful difference between tcPCO₂ and PvCO₂ measurements comparing EtCO₂ to PvCO₂ (B), the plots show a much higher bias of −15.29 for the full sample, with high variability, especially among NICU patients. Notably, in (B), the 95% confidence limits for the mean difference (blue dashed lines) do not include zero. This indicates that the mean bias in EtCO₂ measurements is significantly different from zero (p<0.05) for the sample taken as a whole.

**Abbreviations:** PVCO₂, venous blood gas; tcPCO₂, transcutaneous CO₂; EtCO₂, end-tidal CO₂; NICU, neo-natal intensive care unit.
Table 3 Results of Bland–Altman analyses individually comparing tcP\textsubscript{CO}\textsubscript{2} and Et\textsubscript{CO}\textsubscript{2} to P\textsubscript{vCO}\textsubscript{2}. All measures were taken at the end of the surgery, as close as possible to the time of venous blood sampling. Values shown are bias (mean difference), the standard deviation (SD) of the bias, and 95% limits of agreement (mean ±1.96*SD). Also shown is the standard error of the mean (sem), which is the basis for calculation of the confidence interval (CI) for the sampling error of the mean (mean±1.96*sem).

| Group               | tcP\textsubscript{CO}\textsubscript{2} vs P\textsubscript{vCO}\textsubscript{2} | Et\textsubscript{CO}\textsubscript{2} vs P\textsubscript{vCO}\textsubscript{2} |
|---------------------|---------------------------------|---------------------------------|
| NICU (n=6)          |                                 |                                 |
| Bias                | −0.70                           | −28.07                          |
| Bias SD             | 11.23                           | 12.31                           |
| 95% limits          | −22.71 to 21.31                 | −52.20 to −3.94                 |
| Bias sem            | 4.58                            | 5.02                            |
| 95% CI for mean     | −9.68 to 8.28                   | −37.91 to −18.23                 |
| Non-NICU (n=14)     |                                 |                                 |
| Bias                | 2.96                            | −9.82                           |
| Bias SD             | 9.83                            | 8.26                            |
| 95% limits          | −16.31 to 22.23                 | −26.01 to 6.37                  |
| Bias sem            | 2.63                            | 2.21                            |
| 95% CI for mean     | −2.19 to 8.11                   | −14.15 to −5.49                  |
| Total sample (n=20) |                                 |                                 |
| Bias                | 1.86                            | −15.29                          |
| Bias SD             | 10.11                           | 12.66                           |
| 95% limits          | −17.96 to 21.68                 | −40.09 to 9.51                  |
| Bias sem            | 2.26                            | 2.83                            |
| 95% CI for mean     | −2.57 to 6.29                   | −20.84 to −9.74                  |

Notes: *95% CI does not include zero, indicating that measurements are significantly (P<0.05) different from zero.

Abbreviations: P\textsubscript{vCO}\textsubscript{2}, venous blood gas; tcP\textsubscript{CO}\textsubscript{2}, transcutaneous CO\textsubscript{2}; Et\textsubscript{CO}\textsubscript{2}, end-tidal CO\textsubscript{2}; NICU, neo-natal intensive care unit.

Current Knowledge: Transcutaneous CO\textsubscript{2} has not been compared in the neonatal and infant perioperative population with Et\textsubscript{CO}\textsubscript{2}.

Quick look

What this paper contributes to our knowledge: The study demonstrates that transcutaneous CO\textsubscript{2} is better correlated with the venous CO\textsubscript{2} than standard Et\textsubscript{CO}\textsubscript{2} in younger and smaller infants, specifically NICU patients.

Ethics

This study was approved by the Stony Brook University Committee on Research Involving Human Subjects (IRB), 5 August 2014, Ref. #2014-2629-R3. This study was performed in accordance with the Declaration of Helsinki.

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Disclosure

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