Medical Devices: Evidence and Research

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ORIGINAL RESEARCH

Transcutaneous CO_2 versus end-tidal CO_2 in neonates and infants undergoing surgery: a prospective study

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Aim: End-tidal CO_2 (Et_{CO2}) 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 CO_2 (tcP_{CO2}) monitoring. This study aimed to compare perioperative Et_{CO2} to tcP_{CO2} 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. P_{CO2} was monitored with Et_{CO2} and with tcP_{CO2}. Venous blood gas (Pv_{CO2}) samples were drawn at the end of the anesthetic. We calculated a mean difference of Et_{CO2} minus Pv_{CO2} (Delta Et_{CO2}), and tcP_{CO2} minus Pv_{CO2} (Delta tcP_{CO2}) 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 Pv_{CO2}. Relative to the Pv_{CO2}, the Delta Et_{CO2} 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). Delta tcP_{CO2} 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 Et_{CO2} measurements differed significantly from zero (P<0.05).

Conclusions: Et_{CO2} underestimates Pv_{CO2} values in neonates and infants under general anesthesia. TcP_{CO2} closely approximates venous blood gas values, in both the NICU and non-NICU samples. We, therefore, conclude that tcP_{CO2} is a more accurate measure of operative Pv_{CO2} in infants, especially in NICU patients.

Keywords: infant, newborn, end-tidal CO_2, blood gas monitoring-transcutaneous, intensive care monitoring- neonatal, ASA monitoring standards

Introduction

Transcutaneous CO_2 monitoring (tcP_{CO2}) 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 CO_2 (tcP_{CO2}) compared to end-tidal CO_2 (Et_{CO2}) monitoring as a reflection of arterial CO_2 (Pa_{CO2}). Publications relating to use in infants and children with respiratory failure,[1] congenital heart disease,[2] and one lung ventilation[3] have demonstrated improved correlation

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between Pa_{CO2} with tcP_{CO2} as compared to correlation of Pa_{CO2} with
Et_{CO2}; however, controversy exists. Two recent reviews suggest that tcP_{CO2} should be used as an adjunct to end-tidal CO_2.[4,5] One study which showed close correlation of Et_{CO2} with Pa_{CO2} recommends Et_{CO2} usage for longitudinal monitoring in the neonatal intensive care unit (NICU);[6] data from a more heterogeneous intraoperative cohort suggest that tcP_{CO2} may be more accurate.[7] This non-invasive infant study uses Pv_{CO2} as the surrogate for Pa_{CO2}.

The standard of care for monitoring respiratory status during anesthesia has been end-tidal CO_2 (Et_{CO2}) and pulse oximetry. While this methodology is well established in operative care, Et_{CO2} is known to be less accurate in the neonatal population. The sampling flow rate on the Et_{CO2} in relation to the tidal volume and total flow used to ventilate extremely low birth weight infants provides ambiguous data. In addition, Et_{CO2} 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_{CO2} as a primary means of Pa_{CO2} 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_{CO2}. Estimation of the required sample size is complicated by the range of values seen in our preliminary observations. Pearson correlations between T_{CO2} and Et_{CO2} 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_{CO2}) 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_{CO2}) 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_{CO2} measurements were recorded with the V-Sign™ 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 mmx9 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_{CO2} data reported here were manually recorded from the SDMS visual display and do not reflect the tcP_{CO2} 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_{CO2} V-Sign™ 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 tcP_{CO2}, 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.

TcP_{CO2} was monitored concurrently with Et_{CO2}, with respiratory mode noted (spontaneous vs controlled). The anesthesiologist delivering anesthesia was blinded to the readings of the $tcPCO_2$ monitor and provided intraoperative care using standard monitors including Et_{CO2} 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 Pv_{CO2}. Blood gas parameters including pH, partial pressure of oxygen (p_vO_2), bicarbonate concentration (HCO_3-), and base excess (BE) were recorded.

Data analysis

For each patient, we calculated a mean difference of Delta Et_{CO2} (Et_{CO2} minus Pv_{CO2}), and Delta tcP_{CO2} (tcP_{CO2} minus Pv_{CO2}) 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 Et_{CO2} and tcP_{CO2} 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.

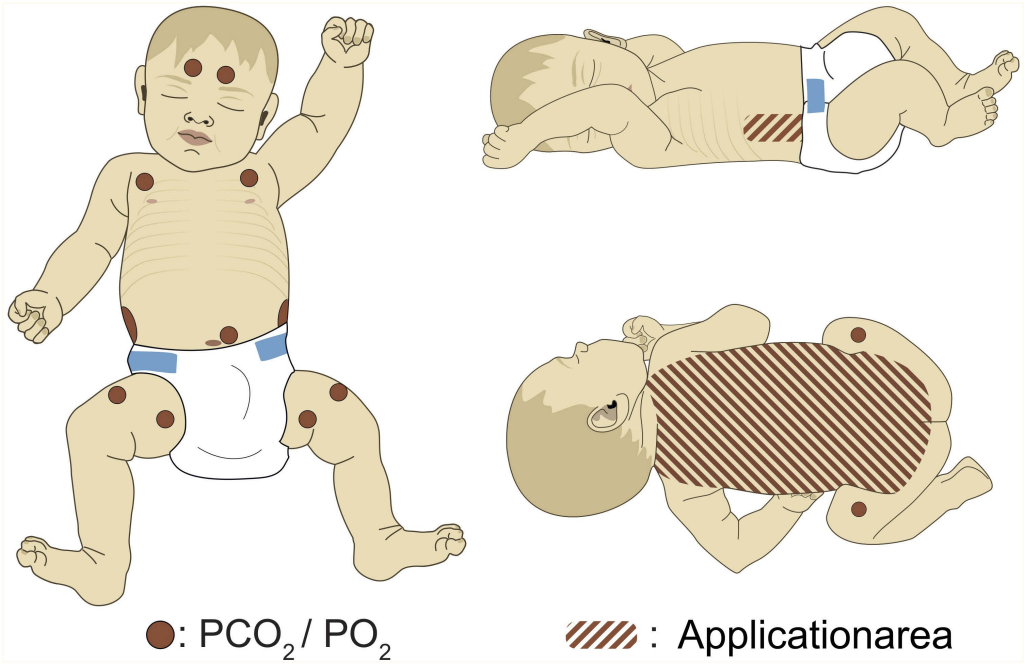

Figure 1 Manufacturer recommendations for sensor placement in infants, numbered in order of preference (1= high, 3= low). Source: SenTec AG, Therwil, Switzerland (www.sentec.com).

Agreement between methods of measurement

Et_{CO2} and TcP_{CO2} were compared to venous blood gas measure of P_{CO2} using the Bland–Altman technique.[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_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_{CO2}. This left 20 patients (6 NICU, 14 non-NICU) with concurrent end-tidal and transcutaneous CO_2 values for analysis. Characteristics of the patient cohort are given in Table 1. Thirteen out of the 20 patients were intubated with cuffed ETT. The leak was between 15 and 25 mm Hg in both groups and no difference in $EtCO_2$ was noted.

The median post-natal age on the day of surgery was 10.9 weeks (range 0.3–47 weeks). The median weight was 4.45 kg (range 1.8–9.8 kg). 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).

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	3 M, 3 F	9 M, 5 F
Premature at birth (n, %)	4 (66.7%)	4 (28.6%)
Post-natal age (weeks)	6.2+6.8	17.0±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)	165.3+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.

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 tcP_{CO2} 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 PvO_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).

Measurement of P_{CO2}. tcP_{CO2} levels were higher than Et_{CO2} in both populations (see Table 2). Et_{CO2} values in NICU patients did not differ significantly compared to older infants. The mean difference between Et_{CO2} and Pv_{CO2} 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 tcP_{CO2} and Pv_{CO2} 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

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_{CO2})	60.1±9.3	48.9 ±14.1	*P*=0.093
Transcutaneous CO_2 (tcP_{CO2})	59.4±12.7	51.9 ±13.1	*P*=0.251
End-tidal CO_2 (Et_{CO2})	32.0±12.4	39.1 ±10.8	*P*=0.215
Delta(tcP_{CO2}-Pv_{CO2})	−0.7±11.2	+3.0 ±9.8	*P*=0.473
Delta(Et_{CO2}-Pv_{CO2})	− 28.1±12.3	− 9.8 ±8.3	***P*=0.001**
pH	7.3±0.1	7.3±0.1	*P*=0.518
PvO_2	57.6±14.3	90.3 ±59.8	*P*=0.209
HCO_3-	26.6±3.1	22.5 ±2.9	***P*=0.012**
BE	−0.4±4.5	−4.0 ±2.6	***P*=0.034**

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

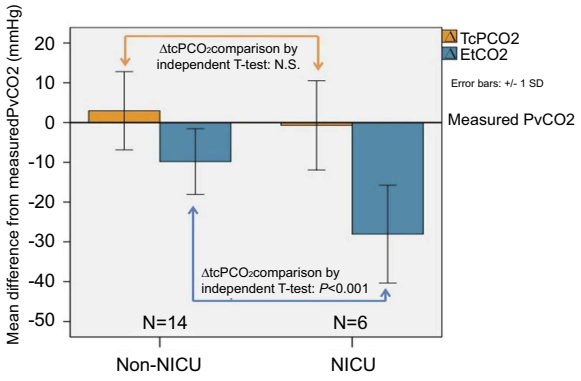

Figure 2 ΔEt_{CO2} and ΔTcP_{CO2} in NICU and non-NICU patients. Values are normalized to the measured Pv_{CO2} for each patient, indicated by the zero line on the vertical axis. TcP_{CO2} rather than Et_{CO2} levels closely approximated Pv_{CO2} in both populations. Dark bars: Et_{CO2}; light bars: tcP_{CO2}. Arrows indicate groups compared for independent-groups *t*-test. A nonparametric test for paired samples was also performed to compare measures of ΔEt_{CO2} and ΔTcP_{CO2} within each patient group. This test showed significant differences (*P*<0.05) between Et_{CO2} and tcP_{CO2} within both NICU and non-NICU patient groups.
Abbreviations: PV_{CO2}, venous blood gas; tcP_{CO2}, transcutaneous CO_2; Et_{CO2}, end-tidal CO_2; NICU, neo-natal intensive care unit; N.S., non significant.

samples showed that tcP_{CO2} and Et_{CO2} 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_{CO2}, tcP_{CO2} or Et_{CO2} at the end of the case. Delta Et_{CO2} 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_{CO2} was close to zero in both groups. TcP_{CO2} did not differ significantly from measured Pv_{CO2} in these two patient groups.

Comparison of methods by Bland–Altman analysis

Figure 3 and Table 3 show tcP_{CO2} and Et_{CO2} compared to the venous blood gas measurement (Pv_{CO2}) using the Bland–Altman technique. Comparing tcP_{CO2} to Pv_{CO2} (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_{CO2} to Pv_{CO2} (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_{CO2}+Pv_{CO2}) 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_{CO2} measurements, reflecting the higher values of the mean difference between Et_{CO2} and the venous blood gas. Notably, in Figure 3B, the 95% confidence limits for the sampling error of the mean difference of Et_{CO2} versus Pv_{CO2} (blue dashed lines) do not include zero. This indicates that the mean bias in Et_{CO2} 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_{CO2} measurements include zero, indicating lack of difference between tcP_{CO2} and Pv_{CO2} 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

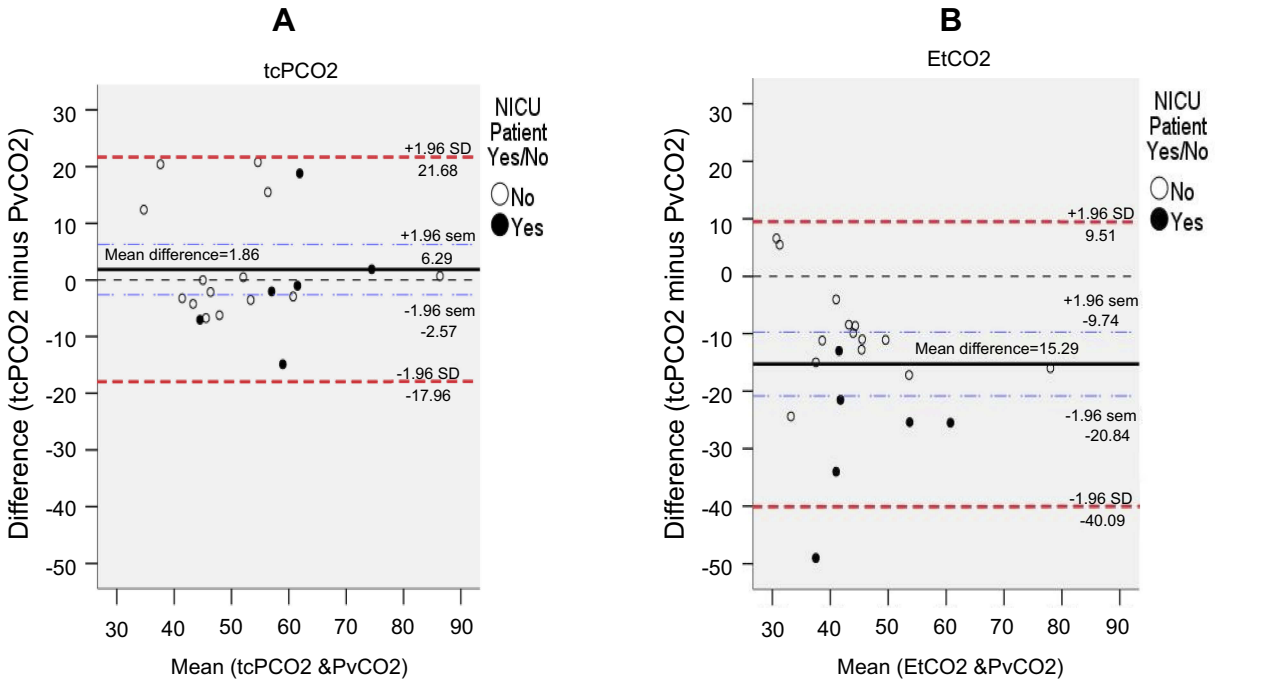

Figure 3 Bland–Altman plots showing mean difference (bias) for tcP_{CO2} **(A)** and Et_{CO2} **(B)** with 95% limits of agreement (red dashed lines). Blue dashed lines show the 95% confidence interval for the mean difference (bias). The bias is significant if the confidence interval does not include the line of equality (dashed line at zero). NICU patients, solid circles; non-NICU patients, open circles. Comparing tcP_{CO2} to Pv_{CO2} (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 tcP_{CO2} and Pv_{CO2} measurements comparing Et_{CO2} to Pv_{CO2} **(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 Et_{CO2} measurements is significantly different from zero ($P<0.05$) for the sample taken as a whole.
Abbreviations: PV_{CO2}, venous blood gas; tcP_{CO2}, transcutaneous CO_2; Et_{CO2}, end-tidal CO_2; NICU, neo-natal intensive care unit.

iatrogenic changes during surgery which can alter CO_2, and necessitates accurate CO_2 values to assure proper ventilation in the operative care. The inaccuracy of Et_{CO2} in this population compelled this study of the agreement between the monitors and the Pv_{CO2}. Since this study utilized children below 10 kg, which encompasses both neonates and infants, we were able to study the effects of both Et_{CO2} and TcP_{CO2} on both populations. Our study found that tcP_{CO2} correlates better with Pv_{CO2} in younger children, specifically in the neonatal population.

With long-term ventilator management in neonates and infants with respiratory failure, tcP_{CO2} is a viable alternative to Et_{CO2} in the NICU.[1] A more recent study demonstrated that tcP_{CO2} was correlated with venous CO_2, although the study was limited by small sample size.[10] In cases of infants with bronchiolitis, it was found that there was reasonable correlation between tcP_{CO2} and Pv_{CO2}, but the investigators felt the monitor was to be used as an adjunct rather than as a primary monitoring tool.[5] Long-term ventilator management in a larger study suggested moderate correlation of tcP_{CO2} with arterial CO_2 levels, although bias was greater when transcutaneous monitoring was employed in HFOV.[11] In addition, a recent study demonstrated poor correlation between Et_{CO2} and Pv_{CO2} in anesthetized neonates for general surgery.[12] Similar effects have been noted for Pa_{CO2} as well.[13] This is the same effect noted in our study; however, we were able to demonstrate improved agreement between Pv_{CO2} and tcP_{CO2} during the perioperative period as compared to Et_{CO2}.

Our study was limited to the perioperative period; however, the NICU literature suggests decreasing correlation with Pv_{CO2} with long-term mechanical ventilation.[11] 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 tcP_{CO2} as a stand-alone monitor, specifically for acute events resulting in large CO_2 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 CO_2 including those with abdominal insufflation

Table 3 Results of Bland–Altman analyses individually comparing tcP_{CO2} and Et_{CO2} to Pv_{CO2}. 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_{CO2} vs Pv_{CO2}	Et_{CO2} vs Pv_{CO2}
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: PV_{CO2}, venous blood gas; tcP_{CO2}, transcutaneous CO_2; Et_{CO2}, end-tidal CO_2; NICU, neo-natal intensive care unit.

(laparoscopy), neurosurgery with CO_2 manipulation to influence cerebral blood flow, and lengthy surgeries would benefit from an additional monitor with a stronger agreement with PV_{CO2}. This, in theory, would allow for a non-invasive calculation of M_{vO2} (mixed venous oxygen saturation) provided that Pa_{O2} is either known or calculated from the Sp_{O2}.

One drawback of this study was the inability to obtain Pv_{CO2} at the end of the surgery in all patients. This was due to a combination of difficult intravenous or heel sticks, vasoconstriction, and in some cases inadequate sample which was discovered only after the patient had left the OR.

Conclusions

End-tidal CO_2 underestimates venous blood gas CO_2 values in NICU and infant patients completing surgery. Transcutaneous CO_2 closely agrees with venous blood gas values, in both the NICU and non-NICU sample, but more closely in NICU patients. We conclude that transcutaneous CO_2 is a more accurate measure than Et_{CO2} of venous blood CO_2 levels in both NICU patients and infants. We postulate that utilizing tcP_{CO2} values will improve the ability to effectively guide ventilation in this population during operative care.

Quick look

Current Knowledge: Transcutaneous CO_2 has not been compared in the neonatal and infant perioperative population with Et_{CO2}.

What this paper contributes to our knowledge: The study demonstrates that transcutaneous CO_2 is better correlated with the venous CO_2 than standard Et_{CO2} 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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