Monitoring of end tidal carbon dioxide and transcutaneous carbon dioxide during neonatal transport

D G Tingay, M J Stewart, C J Morley

Objective: To assess the accuracy of measurements of end tidal carbon dioxide (CO₂) during neonatal transport compared with arterial and transcutaneous measurements.

METHODS

Ventilated infants requiring road transport to a level 3 neonatal intensive care unit during March to August 2002 were recruited if the paediatrician involved in the transport was specifically trained to use both PetCO₂ and TcPCO₂ monitors, an arterial catheter was being used, endotracheal tube position could be confirmed by chest radiograph before transport, and both TcPCO₂ and PetCO₂ monitoring could be started before the first arterial blood gas was measured by the NETS team. Because of the effects of barometric pressure on PetCO₂ infants transported by air were not studied. Informed parental consent was obtained for each infant before transport.

Infants were not studied if they were older than 28 days, had a capillary refill time of greater than two seconds, or PetCO₂ or TcPCO₂ readings could not be made or were lost during transport.

Arterial blood gases and TcPCO₂ are commonly used to monitor ventilation. The aim of this study was to assess the accuracy and reliability of PetCO₂ monitoring during neonatal transport.

Transcutaneous CO₂ monitoring is the most commonly used non-invasive CO₂ monitoring system in neonatal intensive care and has been shown to accurately predict PaCO₂ and monitor CO₂ trends. Calibrated transcutaneous partial pressure of carbon dioxide (TcPCO₂) has been shown to reliably approximate PaCO₂ during neonatal transport and has been recommended as an alternative to frequent PaCO₂ measurements. However, TcPCO₂ devices are difficult to use, bulky, and weigh between 2 and 6 kg, thus limiting their use during neonatal transport.

End tidal CO₂ (PetCO₂) monitors are lightweight and may indirectly monitor PaCO₂. Hence, PetCO₂ may be more useful during transportation than TcPCO₂ monitoring. Studies of PetCO₂ monitoring in newborn infants have had mixed results, primarily because of the effects of ventilation perfusion mismatching on PetCO₂, failure to reach an expiratory plateau during rapid respiratory rates, and the technical limitations of PetCO₂ devices to interpret CO₂ in small tidal volume states. Recent technological advances in PetCO₂ monitoring, such as smaller sample volumes and sample cells calibrated to neonatal tidal volumes, have attempted to overcome the limitations. Some authors advocate PetCO₂ as an acceptable method of approximation of PaCO₂ trends in newborn infants.

The Newborn Emergency Transport Service of Victoria (NETS) is the largest neonatal transport service in Australasia. More than 900 infants a year are transported, with approximately one third ventilated. Monitoring of TcPCO₂ and oxygen saturation have been standard practice for five years to indicate ventilation adequacy during transport, and previous unpublished data have shown a close correlation between TcPCO₂ and PaCO₂.
The Australian Therapeutics Goods Administration has approved both devices for use in newborn infants. A specialist neonatal transport nurse and neonatal paediatrician escorted all infants.

After calibration of the TcPCO₂ and PetCO₂ monitors, paired CO₂ measurements were recorded every 20 minutes, starting at stabilisation and continuing throughout the transport. The initial recordings were calibrated with a simultaneous PaCO₂. The NETS team was not blinded to the TcPCO₂ or PetCO₂ values; any ventilator changes were based on the TcPCO₂ or PaCO₂ values.

The severity of each baby’s lung disease was determined by calculating the alveolar to arterial oxygen tension ratio (PAO₂/PaO₂ ratio) where PAO₂ = (Barometric pressure – 47) × (FIO₂ × PaO₂). Severe lung disease was defined as a PAO₂/PaO₂ ratio <0.3. A PAO₂/PaO₂ ratio of <0.3 has been associated with less precision of PetCO₂ measurements to estimate PaCO₂.

The parents of all infants enrolled in the study provided written and signed informed consent for their infants to be transported by NETS and this involved specific consent to the use of all devices used in the study. This study was discussed with the Royal Women’s Hospital Ethics in Human Research Committee. It was decided that formal ethics approval was not required as the above written informed consent adequately informed the parents and addressed the ethical issues of the study.

Statistical analysis
The differences between PaCO₂, TcPCO₂, and PetCO₂ (expressed as P(a-Tc)CO₂, P(a-Et)CO₂, and P(Tc-Et)CO₂ respectively) were analysed using a Student’s paired t test, and their correlations were calculated. The Bland-Altman technique was used to assess agreement and repeatability. A bias of less than ±0.7 kPa was considered clinically acceptable. Intrasubject P(Tc-Et)CO₂ variability over time was calculated.

RESULTS
Twenty six infants were enrolled, but five were excluded because the PetCO₂ could not be continuously measured in three, both TcPCO₂ and PetCO₂ could not be measured in another, and in the fifth infant the initial blood gas was venous. Table 1 summarises the characteristics of the 21 infants. A total of 21 P(a-Tc)CO₂ and P(a-Et)CO₂ differences and 82 P(Tc-Et)CO₂ differences (median recordings per subject 4.0 (range 2–10)) were calculated.

Table 1 Characteristics of the 21 subjects enrolled in study

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Median</th>
<th>Range</th>
</tr>
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<tbody>
<tr>
<td>Gestational age (weeks)</td>
<td>35</td>
<td>26–40</td>
</tr>
<tr>
<td>Birth weight (g)</td>
<td>2260</td>
<td>930–4600</td>
</tr>
<tr>
<td>Age at enrolment (hours)</td>
<td>4.8</td>
<td>1.8–61.2</td>
</tr>
<tr>
<td>Transportation time (minutes)</td>
<td>65</td>
<td>20–180</td>
</tr>
<tr>
<td>pH</td>
<td>7.32 (0.12)</td>
<td>7.1–7.55</td>
</tr>
<tr>
<td>FIO₂</td>
<td>0.52 (0.24)</td>
<td>0.21–1.0</td>
</tr>
<tr>
<td>PAO₂/PaO₂ ratio</td>
<td>0.85 (1.3)</td>
<td>0.03–5.9</td>
</tr>
</tbody>
</table>

Primary diagnosis Number

<p>| | |</p>
<table>
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<tbody>
<tr>
<td>Respiratory failure</td>
<td>15</td>
</tr>
<tr>
<td>Cyanotic heart disease</td>
<td>2</td>
</tr>
<tr>
<td>Persistent pulmonary hypertension of the newborn</td>
<td>1</td>
</tr>
<tr>
<td>Severe anaemia</td>
<td>1</td>
</tr>
<tr>
<td>Birth asphyxia</td>
<td>1</td>
</tr>
<tr>
<td>Multiple congenital abnormalities</td>
<td>1</td>
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</tbody>
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FIO₂, Inspired oxygen fraction; PAO₂/PaO₂ ratio, alveolar-arterial oxygen tension ratio.

Table 2 A comparison of CO₂ (kPa) measured in three different ways

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean (SD)</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>P(a-Tc)CO₂</td>
<td>21</td>
<td>-0.13 (0.71)</td>
<td>-0.46 to 0.19</td>
<td>0.4</td>
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<tr>
<td>P(a-Et)CO₂</td>
<td>21</td>
<td>1.04 (0.98)</td>
<td>0.59 to 1.49</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>P(Tc-Et)CO₂</td>
<td>82</td>
<td>-0.07 (0.84)</td>
<td>-0.26 to 0.11</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Figure 1 Bland-Altman plot of the difference between PaCO₂ and PetCO₂ (P(a-Et)CO₂) against average CO₂.

Figure 2 Bland-Altman plot of the difference between PaCO₂ and TcPCO₂ (P(a-Tc)CO₂) against average CO₂.
and 81% of TcPCO2 readings were within 1 kPa of the paired PaCO2. There was no significant change in the difference between TcPCO2 and PaCO2 as the CO2 level changed (fig 2).

When the initial TcPCO2 and PetCO2 values for each subject were calibrated to the original PaCO2, there was a closer relation between PetCO2 and TcPCO2: 64% of PetCO2 values were within 0.7 kPa of the paired TcPCO2 value (fig 3). Although the P(a-Et)CO2 difference was not significant, the variability, as demonstrated by the Bland-Altman plot, was large (table 2, fig 3).

There was no significant relation between PetCO2 accuracy and severity of lung disease (table 3), although there was a non-significant trend towards PetCO2 values being more likely to reflect either PaCO2 or TcPCO2 in infants with a PaO2/PAO2 ratio >0.3. Muscle relaxation did not alter the reliability of PetCO2 to trend with TcPCO2.

**DISCUSSION**

This study shows that, in neonates requiring ventilation during transport, TcPCO2 monitoring more accurately reflected PaCO2 than PetCO2 monitoring. Furthermore, PetCO2 monitoring should be used with caution. Both PetCO2 and TcPCO2 were linearly related to PaCO2 and each other. However, a linear relation alone (or correlation coefficients—the method used in many of the previous reports) does not adequately describe the agreement between two clinical measurement techniques. Assessing agreement between two methods of clinical measurement is complex. The method described by Bland and Altman is a more informative technique for assessing agreement, reliability, and repeatability, and allows interpretation within a clinical context. With the use of this technique, PetCO2 was neither as precise nor reliable a method of assessing PaCO2 during the transport of ventilated neonates, whereas TcPCO2 provided a more reliable method. The degree of bias demonstrated between PetCO2 and PaCO2 (1.04 kPa) is clinically unacceptable.

Most of the infants in this study had mechanical ventilation instigated by the transport team; knowledge of any changes in the CO2 is essential for safe delivery of ventilation. Frequent PaCO2 measurements are not practical during neonatal transport; a reliable non-invasive indicator of PaCO2 is essential. Calibrated TcPCO2 is an acceptable surrogate for PaCO2 trends over time. Transcutaneous gas monitoring is an established and validated practice in neonatology. Newborn infants are particularly suited to transcutaneous monitoring because of their thin skin. Although proper use is dependent on appropriate training and placement, the only practical limitations are skin perfusion (which may be altered by vasoconstrictive agents, hypovolaemia, and oedema) and the temperature produced by the device. The response time of TcPCO2 is too slow (30–50 seconds) to allow monitoring of the respiratory pattern. TcPCO2 monitoring in neonatal transport has previously been evaluated and shown to result in improved ventilation on arrival at the receiving institution.

Many authors have reported a good correlation between PetCO2, TcPCO2, and PaCO2 in newborn infants, but in only three studies that evaluated PetCO2 was the relation assessed using the Bland-Altman technique. Rozycki et al described a mean (SD) P(a-Et)CO2 bias of 0.92 (0.92) kPa in 45 newborn infants receiving mechanical ventilation, with only 36.9% of PetCO2 values falling within 0.67 kPa of the PaCO2. The authors concluded that despite the significant bias, PetCO2 provided a reliable estimate of PaCO2 trends. A similar mean P(a-Et)CO2 difference of 0.91 (0.68) kPa was reported by Tobias and Meyer in 25 infants and toddlers (up to 48 months of age) receiving mechanical ventilation for respiratory failure; the P(a-Tc)CO2 difference in this study was 0.31 (0.18) kPa. Sivan et al obtained a clinically acceptable P(a-Et)CO2 result, with a mean difference of 0.45 (0.88) kPa in a study involving 134 children (aged 2 days to 16 years) receiving mechanical ventilation. The mean P(a-Tc)CO2 in this group was −0.17 (0.96) kPa. The P(a-Tc)CO2 bias was related to skin perfusion but remained clinically acceptable. Primary diagnosis was not described in this study, nor was the proportion of the population who were newborn infants, making inference to the neonatal population difficult. Sivan and colleagues concluded that the degree of the P(a-Et)CO2 was reduced in children with mild lung disease, as defined by a PaO2/PAO2 ratio of >0.3. In the cohort with severe lung disease, the mean P(a-Et)CO2 1.04 (0.97) kPa was similar to our study.

Parenchymal lung disease with ventilation perfusion (V/Q) mismatching and a PaO2/PAO2 <0.3 is a feature of most causes of neonatal respiratory failure. During our study, only two infants did not require oxygen, and nearly all had parenchymal lung disease. Our study was not designed to assess the relation between degree of lung disease and PetCO2 accuracy.

PetCO2 monitoring has been validated in adult ventilated patients and healthy anaesthetised infants, but the infants in...
our study had respiratory failure. Petro2 is dependent on alveolar CO2 (Paco2) and the site of sampling. Non-uniform alveolar CO2 emptying patterns in patients with large ventilation perfusion mismatching result in Paco2 underestimating PETCO2.5–22 Technical limitations of end tidal analysis in patients with high rate, low tidal volume breathing would have contributed to the difference between PETCO2 and Paco2. To account for the fresh inhaled gas admixture during proximal PETCO2 sampling, a minimum sampling flow rate of 150 ml/min is required.4 The end tidal analyser used in our study sampled at 50 ml/min. Despite manufacturer assurances, this may have had an impact on our results. The response time of end tidal analysers must be less than the respiratory cycle. The response time of the end tidal analyser used was 190 milliseconds, which is adequate for the ventilation rates used during the study, although at high respiratory rates with a short expiratory time, all exhaled alveolar gas would not have migrated to a proximal end tidal sampling site on completion of each respiratory cycle.1

The relation between TcPCO2 and PETCO2 was not constant over time within individuals, even when both values were adjusted to PaCO2. In our opinion PETCO2 monitoring cannot be used to reliably monitor trends in PaCO2 over time in newborn infants with lung disease.

Despite our findings, PETCO2 monitoring may offer some benefits over TcPCO2 monitoring. Primarily the ability to rapidly and reliably confirm endotrachael tube position within the trachea, with either a capnograph or colorimetric end tidal CO2 indicator, is of great benefit within the noisy environment of neonatal transport.7 This study did not aim to assess the ability of PETCO2 or TcPCO2 to indicate endotrachael tube position. Inadvertent extubation is not a common occurrence in our transport population and did not occur in any of the neonates involved in this study. Further study is required to determine the role of PETCO2 in ensuring the endotracheal tube position during transport.

**CONCLUSIONS**

Owing to the bias of about −1 kPa and lack of consistency in measuring Paco2 over time, PETCO2 cannot be recommended during neonatal transport to monitor ventilation. TcPCO2 monitoring was generally more precise, reliable, and agreed with Paco2. TcPCO2 monitoring is the preferred method of non-invasive CO2 monitoring during neonatal transport.

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**REFERENCES**


