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.

Design: Paired end tidal and transcutaneous CO₂ recordings were taken frequently during road transport of 21 ventilated neonates. The first paired CO₂ values were compared with an arterial blood gas. The differences between arterial CO₂ (PaCO₂), transcutaneous CO₂ (TcPCO₂), and end tidal CO₂ (PetCO₂) were analysed. The Bland-Altman method was used to assess bias and repeatability.

Results: PetCO₂ correlated strongly with PaCO₂ and TcPCO₂. However, PetCO₂ underestimated PaCO₂ at a clinically unacceptable level (mean (SD) 1.1 (0.70) kPa) and did not trend reliably over time within individual subjects. The PetCO₂ bias was independent of PaCO₂ and severity of lung disease.

Conclusions: PetCO₂ had an unacceptable under-recording bias. TcPCO₂ should currently be considered the preferred method of non-invasive CO₂ monitoring for neonatal transport.

METHODS

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.

Continuous non-invasive carbon dioxide (CO₂) monitoring has become an important bedside tool in neonatal intensive care. Transported sick neonates should receive full intensive care, but arterial blood gas monitoring is not possible. Assessing the efficacy of ventilation during neonatal transport is challenging. Continuous non-invasive CO₂ monitoring has been shown to increase the likelihood of the patient arriving at the receiving hospital with a normal pH and partial pressure of CO₂ (PaCO₂).

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.1–2 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.1 However, TcPCO₂ devices are difficult to use,1–3 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 PaCO₂.4–5 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.5–9–12 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.13–15 Some authors advocate PetCO₂ as an acceptable method of approximation of PaCO₂ trends in newborn infants.13–16

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.

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.

Abbreviations: PaCO₂, arterial partial pressure of carbon dioxide; TcPCO₂, transcutaneous partial pressure of carbon dioxide; PetCO₂, end tidal partial pressure of carbon dioxide; NETS, Newborn Emergency Transport Service (Victoria); PAO₂/PaO₂ ratio, alveolar-arterial oxygen tension ratio
(Hoekloos, Amsterdam, Netherlands). 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 PaCO2 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) 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 PaCO2.15

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.17 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>
</thead>
<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 enrollment (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>Mean (SD)</td>
<td>Range</td>
<td></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>
<tr>
<td>Primary diagnosis Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respiratory failure</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Cyanotic heart disease</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Persistent pulmonary hypertension of the newborn</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Severe anaemia</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Birth asphyxia</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Multiple congenital abnormalities</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FIO2, Inspired oxygen fraction; PAO2/PaO2 ratio, alveolar-arterial oxygen tension ratio.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 A comparison of CO2 (kPa) measured in three 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>
</tr>
<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 \( P(T_c-E_t)CO_2 \) readings were within 1 kPa of the paired \( Paco_2 \). There was no significant change in the difference between \( P(T_c-E_t)CO_2 \) and \( Paco_2 \) as the \( CO_2 \) level changed (fig 2).

When the initial \( P(T_c-E_t)CO_2 \) and \( PetCO_2 \) values for each subject were calibrated to the original \( Paco_2 \), there was a closer relation between \( PetCO_2 \) and \( TcPCO_2 \): 64% of \( PetCO_2 \) values were within 0.7 kPa of the paired \( P(T_c-E_t)CO_2 \) value (fig 3). Although the \( P(T_c-E_t)CO_2 \) 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 \( PetCO_2 \) accuracy and severity of lung disease (table 3), although there was a non-significant trend towards \( PetCO_2 \) values being more likely to reflect either \( Paco_2 \) or \( TcPCO_2 \) in infants with a \( PAO_2/PAO_2 \) ratio >0.3. Muscle relaxation did not alter the reliability of \( PetCO_2 \) to trend with \( TcPCO_2 \).

**DISCUSSION**

This study shows that, in neonates requiring ventilation during transport, \( TcPCO_2 \) monitoring more accurately reflected \( Paco_2 \) than \( PetCO_2 \) monitoring. Furthermore, \( PetCO_2 \) monitoring should be used with caution. Both \( PetCO_2 \) and \( TcPCO_2 \) were linearly related to \( Paco_2 \) 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, \( PetCO_2 \) was neither as precise nor reliable a method of assessing \( Paco_2 \) during the transport of ventilated neonates, whereas \( TcPCO_2 \) provided a more reliable method. The degree of bias demonstrated between \( PetCO_2 \) and \( Paco_2 \) (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 \( CO_2 \) is essential for safe delivery of ventilation. Frequent \( Paco_2 \) measurements are not practical during neonatal transport; a reliable non-invasive indicator of \( Paco_2 \) is essential. Calibrated \( TcPCO_2 \) is an acceptable surrogate for \( Paco_2 \) 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 \( TcPCO_2 \) is too slow (30–50 seconds) to allow monitoring of the respiratory pattern. \( TcPCO_2 \) 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 \( PetCO_2 \), \( TcPCO_2 \), and \( Paco_2 \) in newborn infants, but in only three studies that evaluated \( PetCO_2 \) was the relation assessed using the Bland-Altman technique. \( PetCO_2 \), and \( TcPCO_2 \) were calibrated to the original \( Paco_2 \), there was a closer estimate of \( Paco_2 \) by about 1.0 kPa, a clinically unacceptable difference. \( PetCO_2 \) was also unable to reliably reflect \( TcPCO_2 \) over time, therefore this study supports the use of \( TcPCO_2 \) as the preferred method of non-invasive \( CO_2 \) monitoring during neonatal transport.

**What is already known on this topic**

- \( TcPCO_2 \) has been shown to be an accurate and reliable method of indicating \( Paco_2 \) in neonates receiving intensive care.
- Although measurement of \( PetCO_2 \) can also indicate endotracheal tube position, in previous studies the ability to accurately reflect \( Paco_2 \) has been variable.

**What this study adds**

- This study shows that \( TcPCO_2 \) accurately reflects \( Paco_2 \) during neonatal transport, whereas \( PetCO_2 \) underestimates \( Paco_2 \) by about 1.0 kPa, a clinically unacceptable difference.
- \( PetCO_2 \) was also unable to reliably reflect \( TcPCO_2 \) over time, therefore this study supports the use of \( TcPCO_2 \) as the preferred method of non-invasive \( CO_2 \) monitoring during neonatal transport.

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**Figure 3** Bland-Altman plot of the difference between \( TcPCO_2 \) and \( PetCO_2 \) (\( P(T_c-E_t)CO_2 \)) against average \( CO_2 \).

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Table 3 Relation between PetCO2 values and severity of lung disease

<table>
<thead>
<tr>
<th></th>
<th>Severe (n = 12)</th>
<th>Mild-moderate (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD)</td>
<td>1.21 (0.76)</td>
<td>0.87 to 1.88</td>
</tr>
<tr>
<td>95% CI</td>
<td>&lt;0.001</td>
<td>0.99 (1.16)</td>
</tr>
<tr>
<td>p Value</td>
<td></td>
<td>0.61 to 1.37</td>
</tr>
<tr>
<td>PaCO2/PetCO2</td>
<td></td>
<td>0.013</td>
</tr>
</tbody>
</table>

All CO2 values in kPa. Severe lung disease, PaCO2/PetCO2 ratio < 0.3; mild-moderate lung disease, PaCO2/PetCO2 ratio ≥ 0.3.

**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**


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