Is continuous transcutaneous monitoring of \( P_{\text{CO}_2} \) (TcP\( \text{CO}_2 \)) over 8 h reliable in adults?

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Monitoring of non-invasive ventilation (NIV) in a non-intensive care unit (non-ICU) setting requires a method of evaluating nocturnal \( P_{a\text{CO}_2} \), such as transcutaneous CO\(_2\) monitoring (TcP\( \text{CO}_2 \)). However, changing the probe site after 4 h and recalibrating (as recommended) is time-consuming and impractical. Continuous (8-h) TcP\( \text{CO}_2 \) monitoring at a lower electrode temperature (43\( ^\circ \)C) in this setting has never been formally studied.

Patients under intermittent NIV were studied (\( n = 28 \), aged 69 \( \pm \) 9 years, \( P_{a\text{O}_2} : 71 \pm 13 \text{ mmHg}, P_{a\text{CO}_2} : 49 \pm 9 \text{ mmHg} \)). After calibration and stabilization of TcP\( \text{CO}_2 \) (Radiometer \( ^\circ \)Tina TCM3 capnograph), arterial blood gases (ABG) were measured and compared with transcutaneous readings. In 10 patients who underwent continuous 8-h TcP\( \text{CO}_2 \) recording, ABGs were also measured after 4 and 8 h.

The correlation between TcP\( \text{CO}_2 \) and \( P_{a\text{CO}_2} \) was highly significant (\( r^2 = 0.92, P < 0.0001 \)). Mean (TcP\( \text{CO}_2 – P_{a\text{CO}_2} \)) gradient (bias) was: \(-2.8 \pm 3.8 \text{ mmHg}; \) limits of agreement were: \((-10.4; +4.8 \text{ mmHg}) \). TcP\( \text{CO}_2 – P_{a\text{CO}_2} \) gradient was lowest (i.e. within-bias \( \pm 2 \text{ mmHg} \)) between 40 and 54 mmHg, increasing below and above these values. Over 8 h, no significant drift of the TcP\( \text{CO}_2 \) signal occurred (ANOVA). No discomfort or skin lesion was noted.

In conclusion, with an electrode temperature of 43\( ^\circ \)C, 8-h continuous monitoring of TcP\( \text{CO}_2 \) was well tolerated, without any local side-effects or significant drift of TcP\( \text{CO}_2 \) signal; when compared to previous reports, lowering the electrode temperature did not decrease performance for CO\(_2\) monitoring.

**Key words:** blood gas monitoring; transcutaneous; carbon dioxide tension; intermittent positive pressure ventilation.

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**Introduction**

Non-invasive ventilation (NIV) aims to improve arterial blood gases (ABGs) in patients with hypercapnic respiratory failure. Monitoring of NIV outside of an intensive care unit (ICU) requires measuring ABGs by arterial puncture, to ensure that NIV improves daytime hypoxia and hypercapnia. However, daytime ABG measurements may poorly reflect the quality of ventilation during sleep (1). Pulse oximetry is valuable for adjusting Fi\( \text{O}_2 \), and may be helpful in detecting desaturations related to air leaks, ventilation-perfusion mismatch or hypoventilation, although it may be of limited value in patients under oxygen and NIV. Monitoring of arterial carbon dioxide (CO\(_2\)) is necessary to detect either nocturnal hyperventilation or hypoventilation (1,2). Measuring transcutaneous \( P_{a\text{O}_2} \) has been described as unreliable for clinical use in adults (1,2), but transcutaneous measurement of CO\(_2\) (TcP\( \text{CO}_2 \)) is well correlated with arterial measurements (3). There are however a few reported drawbacks to the method such as the necessity of changing the skin site of the probe after 4 h and recalibrating, to avoid skin burning (a time-consuming procedure) (3,4).

Although used in previous publications for overnight studies (5–8), TcP\( \text{CO}_2 \) monitoring has never been validated for continuous 8-h monitoring. The present study aims to show whether TcP\( \text{CO}_2 \) recordings can be performed continuously for 8 h, at a low electrode temperature of 43\( ^\circ \)C, without recalibration, to avoid skin burning (a time-consuming procedure) (3,4).

Patients and methods

Patients treated by NIV for acute or chronic respiratory failure at our institution were considered for the present study. To be included, they had to be haemodynamically stable (systolic blood pressure > 100 mmHg and diastolic
blood pressure > 60 mmHg), without any vasopressor treatment, and willing to participate to the study protocol.

Transcutaneous measurements were performed using a Radiometer Tina TCM3 capnograph (Radiometer®, Copenhagen, Denmark) with a combined TcPO2 (type Clark)/TcPCO2 (type Stow-Severinghaus) electrode (model E5280). The principle of the electrode has been previously described (2). Calibration of the electrode was performed before each new measurement, with a standard (5% CO2–O2) (5% CO2–20% O2) calibration gas. The electrode was positioned on the anterior chest wall, as suggested by the manufacturer, after thoroughly cleansing the skin with alcohol. Care was taken to avoid bony prominences, visible veins or any other interference with skin perfusion. The temperature of the electrode was set at 43°C which improves the permeability of the skin to gas diffusion, and ‘arterializes’ the capillary blood to obtain TcPCO2 readings closer to PaCO2 values, without inducing local skin reactions or skin burns. This temperature is lower than the recommended 44-45°C. The manufacturer suggests changing the site of the electrode every 4 h (and recalibrating). However, patient tolerance to 5 h of continuous monitoring (i.e. without changing the position of the probe) with the same electrode and capnograph, at 43°C, has been reported (9). Arterial blood gases (ABGs) were determined with a gas analyser (ABL 520; Radiometer®; Copenhagen, Denmark).

CORRELATIONS BETWEEN ARTERIAL AND TRANSCUTANEOUS VALUES OF PCO2 AND PO2 AT 43°C

A 20-min period was required to allow for stabilization of the signal before performing ABG measurements. After this period, arterial blood samples for ABG determination were obtained by puncture of the radial artery. Twenty-eight patients were studied.

DRIFT OF TCPPCO2 OVER AN 8-H CONTINUOUS RECORDING

In 10 patients who accepted serial arterial punctures, arterial blood samples were taken at the beginning of the TcPCO2 monitoring (after allowing for stabilization of signal), after 4 h and 8 h of continuous TcPCO2 monitoring (8 h is the maximal recording capacity of the capnograph tested).

All arterial measurements were performed in steady state situations (i.e. patients had been with or without non-invasive ventilation for at least 30 min, and transcutaneous signals were stable), to take into account the lag time of the capnograph (an estimation of the lag time, i.e. the time occurring between a change in PaCO2 and it’s transcutaneous recording is 5 ± 3 min; range: 1–9 min) (3).

STATISTICAL ANALYSIS

Comparisons between arterial and transcutaneous PO2 and PCO2 values are expressed as described by Bland et al. (10): the mean difference between transcutaneous and arterial values (TcPCO2–PaCO2) was calculated for PO2 and PCO2 (d: bias or accuracy), as well as the standard deviation of d (s: precision) and the ‘limits of agreement’ between both methods (d ± 2s; d ± 2s).

Ninety-five per cent of the values of d are expected to be within the limits of agreement. Transcutaneous and arterial values were correlated by linear regression, with calculation of Pearson’s coefficient of correlation (r), and r². Analysis of variance for repeated measurements was used for other comparisons (11).

StatView® software for Windows, version 5.0.1. (SAS Institute Inc, Cara, North Carolina, U.S.A.) was used for statistical analysis.

This study protocol was approved by the Ethics Committee of the University Hospital of Lausanne.

Results

PATIENTS

Twenty-eight patients (18 male, 10 female; age 69 ± 9 years, range, 46–85 years), treated by intermittent NIV, were studied. Diagnoses included COPD (n = 16), obesity–hyperventilation syndrome (n = 5), neuromuscular disorders (n = 2), sequelae of tuberculosis (n = 2), severe kyphoscoliosis (n = 2) and pneumoconiosis (n = 1). Mean body-mass index (BMI) was 27.3 ± 6.1 kg m⁻² (range, 17–40 kg m⁻²). Pulmonary function tests were: FEV1: 0.93 ± 0.371 (39–80% predicted); FVC: 1.8 ± 0.71 (60 ± 25% predicted); FEV1/FVC: 54 ± 17% (70 ± 22% predicted). Arterial blood gases were: PaO2: 70 ± 12 mmHg (range: 55–102 mmHg); PaCO2: 49 ± 8 mmHg (range: 32–66 mmHg).

COMPARISON BETWEEN TRANSCUTANEOUS AND ARTERIAL VALUES FOR PCO2

Correlation between TcPCO2 and PaCO2 values was highly significant (r = 0.96, P < 0.0001). The regression line (TcPCO2 = −15.1 + 1.25 PaCO2) was close to the identity line (Fig. 1). The value of r² was 0.92; i.e. 92% of the variability of TcPCO2 was explained by changes in PaCO2. The bias (or accuracy: d) was: −2 ± 8 mmHg; i.e. on average, TcPCO2 slightly underestimated PaCO2 values; precision (s) was: 3.8 ± 1.9 mmHg; limits of agreement were: −10–4; +4 ± 8 mmHg. There was a significant correlation between TcPCO2–PaCO2 values and the mean of transcutaneous and arterial CO2 values (r = 0.691, < 0.0001, regression equation shown in Fig. 2). The best TcPCO2 readings (i.e. TcPCO2–PaCO2 within ± 2 mmHg) were obtained between 40 and 54 mmHg; below and above these values, the TcPCO2–PaCO2 gradient increased (Fig. 2).

No significant correlation was found between the TcPCO2–PaCO2 gradient and BMI, age, or any of the functional parameters recorded (FEV1, FVC, FEV1/FVC).
Comparison between transcutaneous and arterial values for $P_O^2$

Correlation between arterial and transcutaneous values for $P_O^2$ was also significant ($r=0.636, P=0.0045$), although with a large variability around the regression line. Only 40% of the variability of $P_{tcO^2}$ was explained by changes in $P_{aO^2}$ ($r^2=0.40$). Bias (d: accuracy) was: $-10.9 \pm 9$ mmHg; precision (s) was: $10$ mmHg, i.e. $P_{tcO^2}$ underestimated $P_{aO^2}$ by $10.9 \pm 10$ mmHg; limits of agreement were: $-30.9 \pm 9$ mmHg; $+9.2$ mmHg. There was no significant correlation between $TcPO^2$ and the mean of transcutaneous and arterial $O^2$ values. As with $TcPO^2$, there was no significant correlation between the $TcPO^2$ gradient and BMI, age, or any of the functional parameters recorded (FEV1, FVC, FEV1/FVC).

**Discussion**

The present study shows that $TcPO^2$ can be measured continuously for 8 h in adults at a probe temperature of 43°C without recalibration or changing skin probe position, while maintaining a highly significant correlation between $PaCO^2$ and $TcPO^2$, without any discomfort for the patient, and with no significant drift or deterioration in the $TcPO^2$ signal.

**Performance of the capnograph at different electrode temperatures**

The lowest reported electrode temperature used for monitoring $TcPO^2$ with a Radiometer TCM-3 capnograph is, to our knowledge, 42°C; however, correlation with $PaCO^2$ was not reported (12). Albeit for the study by Rosner et al. (9), previously published values of correlations between $TcPCO^2$ and $PaCO^2$ with the Radiometer TCM-3 capnograph used probe temperatures of 44 or 45°C (4,
Accuracy and precision of Tc probe temperature to 45°C. Although Sridhar et al. showed that increasing probe temperature to 45°C significantly increases the accuracy and precision of TcPO2 and TcPCO2 measurements, this probe temperature cannot be used for several hours (16) (Table 1).

The reason for the higher bias and wider limits of agreement in the present study by Rosner et al. is unclear; particular attention was taken in the present study to recalibrate the capnograph before each new patient, to thoroughly cleanse the skin with alcohol, and to allow for stabilization of the TcPCO2 signal: indeed, time for TcPCO2 signal to stabilize increases at lower electrode temperature. In summary, the present data suggest that using a temperature of 43°C is not associated with a decreased electrode performance for TcPCO2 measurements, although decreasing probe temperature is associated with a prolonged response time (16). Interestingly, optimal performance (i.e., TcPCO2−PaCO2 gradient within bias±2 mmHg) of the capnograph was in the 40–54 mmHg range (i.e. in a normal to moderate hypercapnia range: Fig. 2), which is what one would require for monitoring and adjusting NIV; the TcPCO2−PaCO2 gradient increased for extreme values: lower values of TcPCO2 underestimated PaCO2 whilst higher TcPCO2 values overestimated PaCO2.

CLINICAL VALUE OF TcPO2

As previously described (17), and with the exception of the study by Sringhar et al. (16), TcPO2 values, although significantly correlated with PaO2, were unreliable for clinical use, with a large dispersion of values around the regression line. Decreasing the electrode temperature further decreases the precision of the TcPO2 signal.

Although widely used in neonatal and infant monitoring, in an adult population, pulse oximetry is far more reliable than TcPO2 monitoring (1,2). In fact, in adults, the strong influence of cutaneous blood flow on TcPO2 has led to the use of TcPO2 monitoring as a measure of local perfusion rather than an estimate of arterial PaO2 (2).

DRIFT OF TcPCO2 SIGNAL OVER TIME AND TOLERANCE TO PROLONGED CONTINUOUS MEASURING

There are few reports measuring the drift of the TcPCO2 signal in a clinical setting (3,5,9,18,19). Reported TcPCO2 signal drift ranges from non-significant to 1 mmHg h−1. Tolerance to continuous TcPCO2 measurement has been previously reported for up to 5 h at 43°C, using a Radiometer Tina TCM3 Capnograph (9), and up to 6 h, using a Kontron capnograph, without any local side-effects (5). Mahutte et al. (18) recorded TcPCO2 for 8 h at 43-5°C in 47 adult patients: mild erythema was frequent, resolving after 24–48 h; blisters developed in three patients (in whom the sensor had been left inadvertently in place for more than 8 h). A temperature of 43°C therefore appears to be the highest recommendable electrode temperature for a safe 6–8 h monitoring.

Despite the results presented, some important caveats must be kept in mind when using transcutaneous CO2 monitoring: there is a clear possibility of unpredictable errant values; occasional unexplained fluctuations in TcPCO2 occur without any clear technical explanation (although this was not the case in the patients studied, it is an occasional occurrence in current clinical practice) one must also bear in mind the lag time of transcutaneous measurements (average 5±3 min) which precludes the recording of brief ventilatory events such as obstructive apneas (3); regular recalibration and changing of probe membrane are mandatory for optimal transcutaneous

Table 1. Correlations between TcCO2 and PaCO2, bias and limits of agreement in previous publications and present study using the Radiometer TINA TCM-3 capnograph at different electrode temperatures

<table>
<thead>
<tr>
<th>First author (with reference no.)</th>
<th>No. of patients</th>
<th>Temperature of probe*</th>
<th>d</th>
<th>s</th>
<th>Limits of agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoffmann (13)</td>
<td>9</td>
<td>45</td>
<td>0.84</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Sridhar (16)</td>
<td>24</td>
<td>45</td>
<td>NA</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>Drummond (4)</td>
<td>64</td>
<td>44</td>
<td>0.88</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Kesten (14)</td>
<td>20</td>
<td>44</td>
<td>0.90</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Palmisano (15)</td>
<td>251</td>
<td>44</td>
<td>0.93</td>
<td>1.3</td>
<td>3.9</td>
</tr>
<tr>
<td>Lang (17)</td>
<td>54</td>
<td>44</td>
<td>NA</td>
<td>−0.3</td>
<td>8.5</td>
</tr>
<tr>
<td>Rosner (9)</td>
<td>10</td>
<td>43</td>
<td>NA</td>
<td>8.1</td>
<td>7.8</td>
</tr>
<tr>
<td>Present study</td>
<td>28</td>
<td>43</td>
<td>0.96</td>
<td>−2.8</td>
<td>3.8</td>
</tr>
</tbody>
</table>

NA: not available from original publication.
d: bias; s: sqd of bias; limits of agreement: d−2s; d+2s, as expressed by Bland and Altman (see ref. 10).
*Temperature in °C.
signals; also, transcutaneous measurements are adversely affected by cutaneous vasoconstriction due to hypovolemic or cardiogenic hypotension, vasoconstricting agents, and hypothermia which all markedly increase the $Tc\text{PCO}_2-\text{PaCO}_2$ gradient (2). Noteworthy is the fact that none of the patients studied in this report were haemodynamically unstable or receiving vasopressor treatment.

In summary, our results show that continuous monitoring of $Tc\text{PCO}_2$ for up to 8 h, at a probe temperature of 43°C, is well tolerated in patients during NIV, and is not associated with a significant drift of the $Tc\text{PCO}_2$ signal, or a decrease in electrode performance. The range of optimal performance of the electrode (40–54 mm Hg) is quite suitable for adjusting and monitoring NIV. However, these results apply only for adults and for the monitor tested. Taking into account the above-mentioned caveats and limitations, $Tc\text{PCO}_2$ is a reliable method of continuous monitoring of NIV, of estimating the average impact of NIV on nocturnal $\text{PaCO}_2$, and documenting periods of hypoventilation lasting more than a few minutes.

References