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Transcutaneous monitoring as a replacement for arterial PCO_2 monitoring during nocturnal non-invasive ventilation☆

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KEYWORDS
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Summary
Background: Continuous, non-invasive assessment of alveolar ventilation achieved by transcutaneous PCO_2 ($PtcCO_2$) monitoring is clearly superior to intermittent, invasive blood gas analyses in patients receiving nocturnal non-invasive positive pressure ventilation (NPPV), but the reliability and accuracy of $PtcCO_2$-monitoring is still disputed. The present study was aimed at investigating the capability of modern $PtcCO_2$-monitoring to reliably assess alveolar ventilation during nocturnal NPPV.
Methods: Capillary blood gas measurements (11pm, 2am, 5am and 7am) and 8 h of continuous $PtcCO_2$-monitoring using three of the latest generation devices (SenTec Digital Monitor, Radiometer TCM4-TINA and Radiometer TOSCA500) were performed during polysomnography-proven sleep studies in 24 patients receiving NPPV (15 with COPD, 9 with restrictive disorders).
Results: The technical calibration drift for SenTec DM, TCM4-TINA and TOSCA500 was 0.1, −0.4 and −0.5 mmHg/h, respectively. Bland-Altman method comparison of $PaCO_2$/drift-uncorrected $PtcCO_2$ revealed a mean bias (limits of agreement) of 1.0 (−4.7 to 6.7), −1.5 (−15.6 to 12.5) and 0.8 (−6.8 to 8.3) mmHg, respectively. Continuous overnight $PtcCO_2$-monitoring detected variations in alveolar ventilation, with median ranges of 12.3 (10.7–14.5) mmHg

Abbreviations: ABG, arterial blood gas analysis; BE, base excess; BMI, body mass index; CI, confidence interval; COPD, chronic obstructive pulmonary disease; CO_2, carbon dioxide; EPAP, expiratory positive airway pressure; FEV_1, forced expiratory volume in 1 s; FVC, forced vital capacity; HCO_3^-, standard bicarbonate; HRF, hypercapnic respiratory failure; IPAP, inspiratory positive airway pressure; LTOT, long-term oxygen therapy; min, minutes; NF, normality test failed; NREM, non-rapid eye movement sleep; NPPV, non-invasive positive pressure ventilation; PCO_2, partial pressure of carbon dioxide; $PaCO_2$, arterial partial pressure of carbon dioxide; $PetCO_2$, end-tidal partial pressure of carbon dioxide; $PtcCO_2$, transcutaneous partial pressure of carbon dioxide; PaO_2, partial pressure of oxygen; REM, rapid eye movement sleep; RM-ANOVA, Repeated Measures Analysis of Variance; RR_{set}, preset respiratory rate; RV, residual volume; SaO_2, arterial oxygen saturation; SenTec DM, SenTec Digital Monitor; SD, standard deviation; TLC, total lung capacity; TST, total sleep time.

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for SenTec DM, 14.5 (12.5—17.0) mmHg for TCM4-TINA and 11.5 (11.0—13.0) mmHg for TOSCA500 (RM-ANOVA, $p < 0.001$). The four capillary $PaCO_2$ values ranged by a median of 6.3 (4.7—9.7) mmHg.

Conclusions: Modern $PtcCO_2$-monitoring is reliable, accurate and robust. Since $PtcCO_2$-monitoring is also non-invasive, does not disrupt sleep quality and provides a more complete picture of alveolar ventilation than intermittent capillary $PaCO_2$, $PtcCO_2$-monitoring should become the preferred technique for assessing alveolar ventilation during nocturnal NPPV.

Trial Registration: DRKS00000433 at http://apps.who.int/trialsearch/default.aspx.

Introduction

Monitoring the partial pressure of carbon dioxide (PCO_2) is an essential means of assessing alveolar ventilation in patients with chronic hypercapnic respiratory failure (HRF), particularly in those receiving nocturnal non-invasive positive pressure ventilation (NPPV), which is aimed at improving for improved alveolar hypoventilation and sleep quality.[1—12] Although the measurement of arterial PCO_2 ($PaCO_2$) is regarded as the gold standard technique for PCO_2 assessment[3,13—16] it is an invasive and painful method requiring an arterial blood gas analysis (ABG) or, alternatively, a blood sample from the arterialized ear lobe.[16] Importantly, it also disrupts a patient's sleep structure if performed during the night, and only reflects a snap shot of the potentially varying ventilatory status of patients with chronic HRF.[14,15,17—20] Although the relevance of $PaCO_2$ assessment is undisputed for several conditions, including acute respiratory failure,[21] non-invasive and continuous PCO_2 monitoring is clearly preferable for monitoring the varying status of alveolar ventilation during sleep.[2,5,9,15]

In general, two different techniques for continuous non-invasive PCO_2 monitoring have been introduced into clinical practice; namely, end-tidal ($PetCO_2$) and transcutaneous ($PtcCO_2$) measurements.[9,17,20] However, according to an early study, neither $PetCO_2$ nor $PtcCO_2$-monitoring provided an accurate reflection of $PaCO_2$ during sleep.[15] $PetCO_2$ monitoring is known to have limitations in parenchymal lung disease and, importantly, also in the case of air leakage around the mask or via mouth, which regularly occurs in NPPV patients.[3,7,15,17,20,22,23] In contrast, $PtcCO_2$-monitoring is independent from both air leakage and the underlying disease, and has been shown to be more reliable than $PetCO_2$ monitoring in different conditions.[24—27]

An important limitation of $PtcCO_2$-monitoring is the reported occurrence of technical $PtcCO_2$ drifts, which can be particularly momentous if monitoring is performed over a period of several hours or throughout the whole night.[5,17] Interestingly, more recent daytime studies have reported a substantial improvement in $PtcCO_2$ drifts, likely due to technical refinements in $PtcCO_2$-monitoring[13,14,28—34]; however, overnight studies using modern techniques are still lacking.

Therefore, if continuous and non-invasive overnight $PtcCO_2$-monitoring are determined to be just as accurate as invasive, intermittent $PaCO_2$-measurements, this technique could become the preferred means for monitoring nocturnal alveolar ventilation in chronic HRF patients. Hence, the present study aims to assess the accuracy of modern technologies designed for $PtcCO_2$-monitoring in patients receiving overnight NPPV. Some of the results of these studies have been previously reported in the form of an abstract.[35]

Materials and methods

The study protocol was approved by the Institutional Review Board for Human Studies at the Albert-Ludwigs University, Freiburg, Germany, and was performed in accordance with the ethical standards laid down in the Declaration of Helsinki. Written informed consent was obtained from all subjects.

Patients

Stable NPPV patients without evidence of acute respiratory failure and severe obesity (BMI > 35 kg/m^2) were included in this study[23,36] [for details see Supplementary Material].

Measurements

Lung function parameters (Masterlab-Compact® Labor; Jaeger; Hochberg, Germany) were assessed in accordance with international guidelines.[37—39] Daytime ABG samples (AVL OMNI®; Roche Diagnostics GmbH; Graz, Austria) were taken simultaneously from both the radial artery and the arterialized earlobe during spontaneous breathing at 4pm. Patients were excluded from the study if the ABG samples each taken from the artery and the arterialized earlobe showed a $PaCO_2$ difference >2.5 mmHg.[16]

$PtcCO_2$ was monitored using the latest generation of three different devices, with the sensor temperature set to 42 °C[20,31,34,40]: 1) SenTec Digital Monitor (SenTec DM, Software 06.21.1, V04.04.04; SenTec AG; Therwil, Switzerland), 2) TCM4-TINA (Version 2.12; Radiometer Medical ApS; Brønshøj, Denmark) and 3) TOSCA500 (Main 1.30; Radiometer Medical ApS). Full polysomnography (SOMNOscreen™ plus; Somnomedics GmbH; Randersacker, Germany) was performed according to guidelines[41—43] [for details see Supplementary Material].

Study design

All $PtcCO_2$-monitors were activated and calibrated 4 h prior to the sleep study. For nocturnal measurements the sensors of all three $PtcCO_2$-monitors were placed 5 cm below either the right or left clavicle with fixation rings. All three sensors were placed under the same clavicle. Lateral to medial positioning of the three sensors was chosen in a randomized