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SHORT COMMUNICATION

Transcutaneous carbon dioxide measurements in anesthetized apneic patients with BMI > 35 kg/m^2

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Abstract

Transcutaneous carbon dioxide measurement ($TcCO_2$) offers the ability to continuously and non-invasively monitor carbon dioxide (CO_2) tensions when end-tidal monitoring is not possible. The accuracy of $TcCO_2$ has not been established in anesthetized apneic patients with obesity. In this secondary publication, we present a methods comparison analysis of $TcCO_2$ with the gold standard arterial PCO_2, in adult patients with body mass index (BMI) > 35kg/m^2 who were randomized to receive high flow or low flow nasal oxygenation during post-induction apnea. Agreement between $PaCO_2$ and $TcCO_2$ at baseline, the start of apnea and the end of apnea were assessed using a non-parametric difference plot. Forty-two participants had a median (IQR) BMI of 52 (40–58.5) kg/m^2. The mean (SD) $PaCO_2$ was 33.9 (4.0) mmHg at baseline and 51.4 (7.5) mmHg at the end of apnea. The bias was the greatest at the end of apnea median (95% CI, 95% limits of agreement) 1.90 mmHg (−2.64 to 6.44, −7.10 to 22.90). Findings did not suggest significant systematic differences between the $PaCO_2$ and $TcCO_2$ measures. For a short period of apnea, $TcCO_2$ showed inadequate agreement with $PaCO_2$ in patients with BMI > 35 kg/m^2. These techniques require comparison in a larger population, with more frequent sampling and over a longer timeframe, before $TcCO_2$ can be confidently recommended in this setting.

Keywords Apneic oxygenation · Carbon dioxide · High flow nasal oxygen · Obesity · Transcutaneous monitoring

Introduction

Transcutaneous CO_2 monitoring ($TcCO_2$) has been shown to give a reliable estimation of the arterial partial pressure of carbon dioxide ($PaCO_2$) in healthy volunteers [1]. The use of high-flow nasal oxygen delivery facilitates short laryngeal procedures but risks carbon dioxide (CO_2) retention during apnea and precludes accurate end-tidal CO_2 monitoring. $TcCO_2$ monitoring offers a potential benefit in this context but has not been studied in apneic obese patients.

Studies comparing the accuracy and precision of $TcCO_2$ with $PaCO_2$ in patients with body mass index (BMI) > 35 kg/m^2 in a perioperative setting have reported good accuracy and precision [2] when compared against the accepted clinical range of agreement ± 7.5 mmHg [3]. In this secondary publication, we present data obtained during a study of patients with BMI > 35 kg/m^2, comparing safe apnea time between those administered high flow nasal oxygen and those with standard nasal prongs [4]. We aimed to measure the agreement of CO_2 measurements obtained from arterial blood samples ($PaCO_2$) and transcutaneous monitoring ($TcCO_2$) at three time points in obese patients under apneic conditions.

Methods

This report comprises a secondary publication based on additional data that were collected during a single-center randomized controlled trial undertaken between September

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2018 and May 2019 at the Royal Brisbane and Women's Hospital [4]. The trial was ethics-approved (HREC-18-QPCH-9 approved 21-03-2018), registered (ANZCTR 12618000445279) and participants provided written informed consent. Measurement of $TcCO_2$ was stated in the trial registration and included in the initial ethical approval. We tested the hypothesis that the use of Optiflow THRIVE™ (Fisher & Paykel Healthcare, Auckland, New Zealand) at 70 L/min would increase the time to hypoxia and increase carbon dioxide elimination in apneic obese patients, when compared with 4 L/min oxygen administered via standard nasal prongs. The 42 participants were undergoing laparoscopic bariatric surgery, had BMI ranging from 38 to 68 kg/m^2 and a mean (SD) $PaCO_2$ at the end of apnea of 51.4 mmHg (7.5) (range 27.2–64.8 mmHg). The full inclusion and exclusion criteria and detailed methodology are available [4].

All participants were monitored according to local standards, with the addition of invasive radial arterial catheters. Participants were randomized to Group T, in which they were administered high flow nasal oxygen using Optiflow THRIVE™ at 70 L/min, humidified using the Fisher & Paykel 950 humidifier, providing 70% relative humidity (oxygen concentration delivered at 100%); or to Group N, in which they were administered standard nasal prongs at 4 L/min (Salter Labs, Arvin, CA, USA). In both groups, pre-oxygenation occurred in the ramped position and with FiO_2 1.0 at 10 L/min.

Induction medications consisted of an opioid, propofol, and rocuronium with dosing at the discretion of the anesthetist. Anesthesia maintenance was achieved using propofol target controlled infusion. The patients were bag-mask ventilated to achieve an end-tidal oxygen fraction > 0.9. At this point, nasal oxygenation was applied according to group allocation and airway patency maintained using an oropharyngeal airway and two-handed airway maneuvers (chin lift, head tilt, jaw thrust).

Clinical observations and sampling occurred while the participants were anesthetized and apneic. $TcCO_2$ was measured using the TCM5 FLEX transcutaneous monitor TC Sensor 92 and 32mm TOSCA fixation ring (Radiometer Pacific Pty. Ltd., Waverley, Victoria, Australia). The device sensor was calibrated for each patient, to reach the required temperature of 43.5 degrees Celsius. The participant's skin was prepared with 70% isopropyl alcohol prior to placing the fixation ring over the clavicle and a small amount of contact gel applied before sensor attachment. Sensor membranes were replaced every three days. Arterial blood gas samples and $TcCO_2$ measurements were obtained at baseline (prior to induction to anesthesia), at the start of apnea (T0), and the end of apnea (Tend). Tend was defined as the time at which peripheral arterial oxygen saturations (measured by pulse oximetry) dropped to ≤ 95% or a total of 360s of apnea, whichever occurred first. Participant characteristics were collected and these included age, sex, BMI, and comorbidities including obstructive sleep apnea.

The sample size was a convenience sample of 42, determined according to the primary outcome of the original study [4]. The original analyses demonstrated no statistical differences between Group T and Group N in terms of the median $PaCO_2$ post apnea or the rate of increase of $PaCO_2$ during apnea. Therefore, for this methods comparison analysis, 42 participants were analyzed as one group. Agreement between $PaCO_2$ and $TcCO_2$ at the three time points was assessed using a non-parametric difference plot. Bias was reported as the median of the mean differences for each participant, with 95% confidence intervals (CI). The 95% limits of agreement (LOA) were estimated by the 2.5th and 97.5th percentiles with 90% CI, using quantile regression with cluster-robust bootstrap inference [5–7]. Analyses were run in R statistical package version 4.1.3.

Results

42 participants had a mean (SD) age of 50.4 (11.1) years, 33 (78.6%) were female and they had a median (IQR) BMI of 52 (40–58.5) kg/m^2. Twenty-two (52.4%) were diagnosed with obstructive sleep apnea. Additional characteristics are reported elsewhere.[4] In 14 (33.3%) participants, the apneic period lasted ≥ 360s. In the remaining 28, the mean (SD) time to desaturation to ≤ 95% (apneic period) was 190.3s (73.7). The mean (SD) $PaCO_2$ was 33.9 (4.0) mmHg at baseline and 51.4 (7.5) mmHg at the end of apnea.

The bias (95% CI, 95% LOA) at baseline was −1.00 mmHg (−2.47 to 0.47, −8.10 to 6.80), at T0 was 1.10 mmHg (−1.52 to 3.72, −6.10 to 11.30), and at Tend was 1.90 mmHg (−2.64 to 6.44, −7.10 to 22.90). Figure 1 shows the difference between the measurement techniques for each time point. The area between the limits of agreement indicates where 95% of the differences are expected to occur. Compared to $PaCO_2$, $TcCO_2$ had a small upward bias (measurement greater than $PaCO_2$) at baseline and small downward bias (measurement lower than $PaCO_2$) at time points T0 and Tend (Fig. 2). However, the 95% CI for the bias estimates all contain zero, suggesting no significant systematic differences between the $PaCO_2$ and the $TcCO_2$ measures.

Discussion

To the best of our knowledge, these are the first published data describing $TcCO_2$ monitoring in apneic patients with obesity. Our results suggest that for a short period of apnea, $TcCO_2$ monitoring may be inaccurate when used to estimate $PaCO_2$ in patients with BMI > 35 kg/m^2. The bias LOA were outside the recommended range of ± 7.5 mmHg, with wide

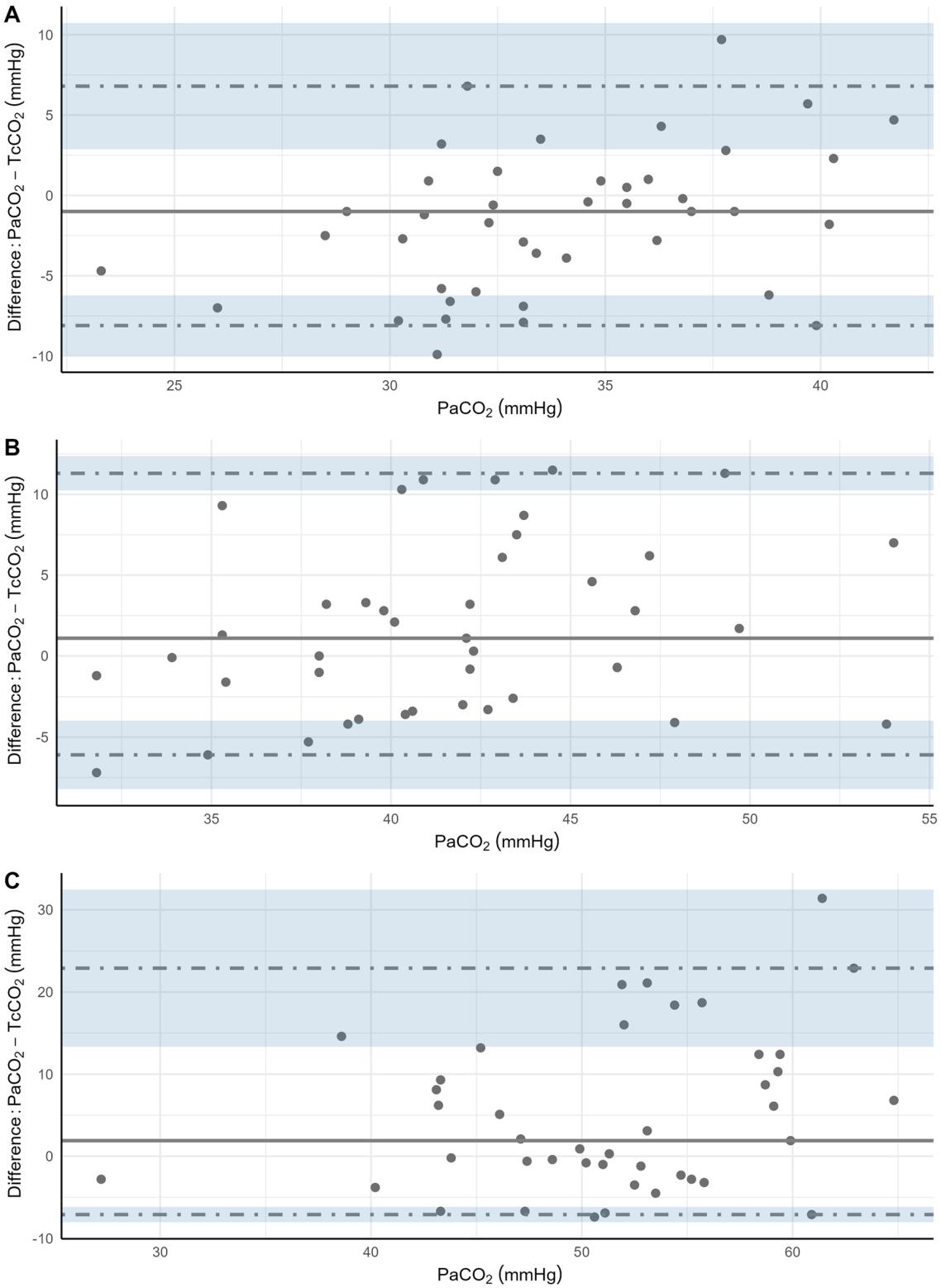

Fig. 1 Difference plot of $PaCO_2$ and $TcCO_2$ at **A** baseline, **B** start of apnea **C** end of apnea, showing bias estimated as the median of the differences (solid black line) and dashed lines displaying non-parametric 95% limits of agreement estimated using the 2.5th and 97.5th percentiles with 90% confidence intervals

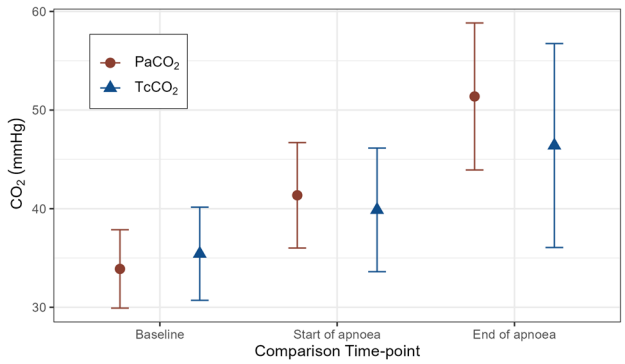

Fig. 2 $PaCO_2$ and $TcCO_2$ measures at the three time points. Values are mean (SD). $PaCO_2$ data have been published previously [4]

90% CIs at the start and end of apnea. The accuracy of $TcCO_2$ in anesthetized apneic patients has been previously reported, but in populations with normal BMI [8, 9]. Measuring $TcCO_2$ over longer apneic periods (median of 14 min [9] and up to 45 min [8]), these studies showed conflicting results. Based on Bland–Altman analysis, Pape et al. reported acceptable agreement, with a tendency for $TcCO_2$ to overestimate CO_2 tensions after 15 min of apnea, when $PaCO_2$ levels were the highest [9]. Schweizer et al. concluded these two methods were not interchangeable [8]. Their linear mixed model demonstrated a substantial bias of −19.1mmHg (95% CI −20.1 to −18.0) between arterial and TCM5 measurements [8].

$TcCO_2$ measurements offer a convenient and non-invasive method of detecting hypercapnia in non-obese, anesthetized, apneic patients. There remain limitations of the method that must be considered [3]. Correct calibration is required and should be undertaken according to manufacturer recommendations. Previous evaluations of $TcCO_2$ measurements in patients with obesity have placed the sensor on the forearm to avoid increased subcutaneous tissue [2], whereas we placed the sensor over the clavicle. Heating of the electrode prior to placement may be recommended by the manufacturer and this can lead to thermal injury of the skin, whereas failure to heat the electrode may cause invalid results. While our participants were demonstrably hypercapnic, our results pertain to a small number of samples from a relatively small population and over a short timeframe. Conditions of prolonged apnea in this population will be challenging to reproduce from an ethical and safety perspective. These measurement techniques should be evaluated in a larger population, with more frequent sampling over a longer timeframe, before $TcCO_2$ measurement can be confidently recommended for patients with obesity under apneic conditions.

Author contributions VE: concept development, protocol design, interpretation of statistical analysis, manuscript writing and review, manuscript revisions. LG: Initial concept, protocol design, ethics application, data collection, interpretation of statistical analysis and writing the manuscript; CW: protocol design, data collection, manuscript review; SL protocol design, statistical analysis, interpretation of analysis, manuscript review; AvZ: concept development, protocol design, manuscript writing and review; All authors: approval of the submitted version.

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Data availability Data are available on reasonable request, from the authors.

Declarations

Conflict of interest Equipment for measuring $TcCO_2$ was provided by Radiometer under a loan agreement with the Department of Anaesthesia and Perioperative Medicine, Royal Brisbane and Women's Hospital between 14/05/2018 and 25/10/2019. Radiometer were not involved in the design of the study, the analysis and interpretation of results, nor in writing the manuscript. Fisher & Paykel Healthcare provided loan equipment and consumables for the study. Fisher & Paykel Healthcare was not involved in the design of the study, the analysis and interpretation of results, nor in writing the manuscript.

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