Weaning Mechanical Ventilation After Off-Pump Coronary Artery Bypass Graft Procedures Directed by Noninvasive Gas Measurements

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Objective(s): **Partial pressure of carbon dioxide and oxygen were transcutaneously measured in adults after off-pump coronary artery bypass (OPCAB) surgery. The clinical use of such measurements and interchangeability with arterial blood gas measurements for weaning patients from postoperative mechanical ventilation were assessed.**

Design: **This was a prospective observational study.**

Setting: **Tertiary referral heart hospital.**

Participants: **Postoperative OPCAB surgical patients.**

Interventions: **Transcutaneous oxygen and carbon dioxide measurements.**

Measurements and Main Results: **In this prospective observational study, 32 consecutive adult patients in a tertiary care medical center underwent OPCAB surgery. Noninvasive measurement of respiratory gases was performed during the postoperative period and compared with arterial blood gases. The investigator was blinded to the reports of arterial blood gas studies and weaned patients using a "weaning protocol" based on transcutaneous gas measurement. The number of patients successfully weaned based on transcutaneous measurements and the number of times the weaning process was held up were noted. A total of 212 samples (pairs of arterial and transcutaneous values of oxygen and carbon dioxide) were obtained from 32 patients. Bland-Altman plots and mountain plots were used to analyze the interchangeability of the data. Twenty-five (79%) of the patients were weaned from the ventilator based on transcutaneous gas measurements alone. Transcutaneous carbon dioxide measurements were found to be interchangeable with arterial carbon dioxide during 96% of measurements, versus 79% for oxygen measurements.**

Conclusion: **More than three fourths of the patients were weaned from mechanical ventilation and extubated based on transcutaneous gas values alone after OPCAB surgery. The noninvasive transcutaneous carbon dioxide measurement can be used as a surrogate for arterial carbon dioxide measurement to manage postoperative OPCAB patients.**

KEY WORDS: oxygen, carbon dioxide, transcutaneous, weaning, mechanical ventilation, cardiac surgery, arterial, blood gas

THE DECISION TO successfully wean postoperative cardiac surgical patients from mechanical ventilation and extubate them traditionally requires guidance from measured values of partial pressures of arterial oxygen (PaO_2) and carbon dioxide ($PaCO_2$). The measurement of partial pressure of arterial gases requires the prolonged placement of an indwelling arterial cannula and repeated arterial blood gas (ABG) estimations. The drawbacks of this technique are blood loss (it is a considerable problem in cardiac patients and neonates and when the care involves groups with religious beliefs against blood or blood products), costs to the health care delivery system, and a low but measurable morbidity.[1] ABG analysis may expose the health care workers to the hazard of sharp injuries and blood exposure.

Partial pressure of transcutaneous carbon dioxide ($ptcCO_2$) analysis was introduced in the early 1980s using locally heated electrochemical sensors that were applied to the skin surface. This methodology provides a continuous noninvasive real-time estimation of the arterial CO_2 value and can be used for assessing the adequacy of ventilation.[2] Transcutaneous gas measurement provides an assessment of the physiologic consequences of both macrovascular and microvascular flow disruption. The fact that CO_2 has high tissue solubility and diffuses through the skin easily makes $ptcCO_2$ a suitable technique for monitoring CO_2. The usefulness of this monitor has been validated in neonates and premature infants,[3] but its utility has not been validated during the weaning of mechanical ventilation in the postoperative period after adult cardiac surgery. The data obtained by this equipment are not complete in the clinical sense because most clinicians are used to seeing the values of arterial blood gases along with those of acid base chemistry, blood sugar, and other biochemical values such as serum lactate and calcium levels.

This study was conducted with the assumption that patients with normal hemodynamic parameters in the immediate postoperative period (and normal ABG values at that time) are likely to sustain normal ABG values in the later postoperative periods, unless other parameters such as blood pressure and cardiac index decreased greatly. Arguably, the transcutaneous technique might malfunction in the presence of conditions that would reduce the skin blood flow such as hypothermia, hypotension, hypocapnia, and vasoconstriction.

The present study was designed to evaluate the TINA TCM4 (Radiometer, Copenhagen, Denmark) for the measurement of $ptcO_2$ and $ptcCO_2$ as an alternate measure of partial pressures to wean patients from mechanical ventilation after OPCAB. The authors analyzed the interchangeability of the transcutaneous values with those of the partial pressure of arterial oxygen (PaO_2) and the partial pressure of arterial carbon dioxide ($PaCO_2$) obtained with ABG analysis to wean mechanical ventilation in patients who had undergone OPCAB. In addition, the relation between $ptcO_2$ and $ptcCO_2$ and ABG values was noted. By the design of the work, the authors not only planned to assess the feasibility of weaning the patients from mechanical ventilation after cardiac surgery, but also the accuracy of the technique because every measurement used in decision-making was compared against the standard of measurement, the ABGs.

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MATERIALS AND METHODS

Institutional ethical committee approval and written informed consent from all the patients were obtained. A prospective observational analysis of 32 consecutive patients older than 18 years who underwent elective OPCAB was performed at the authors' cardiosurgical unit during 2008. Patients with normothermia at the end of surgery were included. The $ptcO_2$ and $ptcCO_2$ were obtained to facilitate the weaning of patients in the postoperative period. Patients with inotropic or ventilatory therapy before surgery, hemodynamically significant arrhythmias, intra-aortic balloon counterpulsation, and/or unsatisfactory revascularization (assessed by an electrocardiogram [ECG]) were excluded. Evidence of low cardiac output, low mean arterial pressure $<$50 mmHg, central venous pressure $>$15 mmHg, pulmonary capillary wedge pressure $>$25 mmHg, urine output $<$0.5 mL/kg, and a high gradient ($>$6°-7°C) between the core and peripheral temperature also were criteria for exclusion from the study.

All the patients included in the study were premedicated with oral alprazolam, 7 μg/kg, 1 hour before being transferred to the operating room. In the operating room, an ECG, central venous pressure, rectal and nasal temperatures, blood sugar, and urine output were monitored. An arterial catheter was inserted in the right femoral artery to measure continuous invasive arterial pressure and to obtain blood samples for ABG studies. A pulmonary artery catheter capable of measuring continuous cardiac output (Swan Ganz CCI/VIP; Edward Lifesciences, LLC, Irvine, CA) was inserted. Normothermia was maintained by the administration of warm intravenous (IV) fluids, a blanket circulating warm water under the patient, and maintaining the temperature of the operating room above 20°C. The anesthetic technique was standardized in all patients with IV fentanyl, 250 to 500 μg, rocuronium bromide, and 1.5% to 2.5% end-tidal sevoflurane titrated to 1 minimal alveolar concentration in 100% O_2. Total body heparinization was achieved with 300 U/kg of IV heparin. The activated coagulation time of more than 250 seconds was taken as acceptable. After completion of the surgery, the residual effect of heparin was reversed with IV protamine sulphate to an activated coagulation time of $<$140 seconds. After the completion of surgery and closure, an ECG was recorded to rule out inadequate revascularization or perioperative myocardial infarction.

The patients were transferred to the intensive care unit (ICU) for further postoperative care. The transcutaneous measurement used in this study consisted of the TINA TCM4 O_2 and a CO_2 monitor. The TINA TCM4 lead was connected to the patient on arrival in the ICU as per the recommendations of the manufacturer ($ptcCO_2$–pH solid-state glass Stow-Severinghaus type CO_2 electrode; $ptcO_2$–25-μm platinum Clark-type O_2 electrode). The electrode consisted of a single microcathode and a heated anode. The TINA TCM4 electrode was attached to the skin of the right or left upper chest of the patients through self-adhesive rings, with its temperature set to 43°C. The electrode attachment site was changed every 4 hours. The electrodes were calibrated with a standard gas chamber provided with the instrument.

After transfer of the patients to the surgical ICU, a baseline ABG estimation was performed. Normal values of pH (no metabolic or respiratory acidosis), standard bicarbonate, and base excess were prerequisites for the continuation of the study. In the postoperative period, the patients were mechanically ventilated. The postoperative monitoring parameters were the same as those used intraoperatively. The patients were mechanically ventilated with an inspired O_2 concentration (F_IO_2) of 0.8, a ventilatory frequency of 12/min, and a tidal volume of 10 mL/kg. ABG was performed 20 minutes after commencing mechanical ventilation. F_IO_2 was decreased from 0.8 to 0.6 and then to 0.4 if the PaO_2/F_IO_2 ratio was $>$300. The decrease in the F_IO_2 was directed by the investigator (investigator #1) who was blinded to ABG values, and to the values of pulse oximetry and end-tidal carbon dioxide. He made a decision based on the values of transcutaneous measurements only. The other investigator (investigator #2) had knowledge of both the ABG and transcutaneous values. Although he did not perform any interventions, he stopped the interventions of the other investigator if those were unsafe in terms of $ptcO_2$ and $ptcCO_2$. These events were called "holdups," and the frequency of such a holdup/patient was noted. After decreasing the F_IO_2 to 0.4 and if other criteria for weaning from the ventilator were fulfilled, the ventilatory mode was changed to synchronized intermittent mandatory ventilation.

Table 1. Anthropometric Measurements of the Study Population (n = 32)

Age (y)		59.5 (46-70)
Sex (male/female)		26/6
Weight (kg)		69 (58-81)
	On Arrival	During Measurements
Mean HR	95.5 (17.5)	99.9 (14.9)
Mean MAP	89.4 (17)	86.4 (16.2)
Mean PAP	12.1 (2.9)	13.9 (4.4)

NOTE. Variables were statistically comparable between groups ($p > 0.05$).

Abbreviations: HR, heart rate; MAP, mean arterial pressure; PAP, pulmonary artery pressure.

The values of $ptcO_2$ and $ptcCO_2$ were measured at 20 minutes after the following events: (1) transfer to the surgical ICU with F_IO_2 of 0.8, (2) decreasing the F_IO_2 to 0.6, (3) decreasing the F_IO_2 to 0.4, (4) changing the ventilatory mode to synchronized intermittent ventilation, and (5) connecting to a "T" piece. Patients were extubated when the $ptcO_2$ was $>$90 mmHg with an F_IO_2 of 0.4 and $ptcCO_2$ was $<$35 to 40 mmHg. In addition, other usual criteria including an awake patient responding to simple oral commands, adequate analgesia, mean arterial pressure $>$80 mmHg, urine output $>$1 mL/kg/h, spontaneous breathing (respiratory rate in the range of 10-15 breaths/min), absence of arrhythmias, blood loss $<$1 mL/kg/h, and normothermia (core temperature 36°C-38°C) were fulfilled before extubation.

PaO_2 with $ptcO_2$ and $PaCO_2$ with $ptcCO_2$ were correlated by linear regression, with calculation of the Pearson coefficient of correlation (r). A post hoc power analysis with a correlation coefficient revealed a sample size of 15 for O_2 and 17 for CO_2 with $\alpha = 0.05$ and $\beta = 0.01$. The bias and the limits of agreement between the parameters as described by Bland and Altman[4] and the folded empiric cumulative distribution plot described by Krouwer and Monti[5] were calculated. A mountain plot measures the difference of the value obtained by the standard method (ABG) and the method under investigation (the TINA TCM 4) on the x-axis and the percentile of differences on the y-axis. The resultant plot is inevitably a "mountain." As described by Krouwer and Monti,[5] if the apex of the "mountain" overlies "0," there is a high degree of interchangeability, and the "tails" of the mountain should be symmetric and should not be wide and "dragging." For the folded empiric cumulative distribution plot (mountain plot), $PaCO_2$ and PaO_2 values were used as the reference standard, and the percentiles for the differences were ranked and plotted against the percent difference. The analysis of variance for repeated measurements and the Student t test were used for other comparisons. A p value of 0.05 was considered significant.

RESULTS

The study included 32 patients mechanically ventilated in the postoperative period after OPCAB surgery. None of the subjects was excluded from participation, and the study was adequately powered. At 95% confidence interval, with a p value of $<$0.05, the hemodynamic variables did not change from 20% of baseline during all the measurement intervals (Table 1).