Transcutaneous Carbon Dioxide Pressure Monitoring in a Specialized Weaning Unit

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OBJECTIVE: To evaluate transcutaneously measured P\textsubscript{CO\textsubscript{2}} (P\textsubscript{tcCO\textsubscript{2}}) values during ventilator weaning and during bronchoscopies on ventilated patients, and to compare P\textsubscript{tcCO\textsubscript{2}} values to P\textsubscript{aCO\textsubscript{2}} values from arterial blood analysis and end-tidal P\textsubscript{CO\textsubscript{2}} (P\textsubscript{ETCO\textsubscript{2}}) values from capnography. METHODS: In our specialized weaning unit we measured P\textsubscript{tcCO\textsubscript{2}} in tracheostomized patients with prolonged weaning failure during daytime spontaneous breathing trials (SBTs) (23 measurement sessions in 15 patients), during their first nights off the ventilator (12 measurement sessions in 12 patients), during bronchoscopy while ventilated (80 measurement sessions in 21 patients), simultaneous with arterial blood draw for blood gas analysis (48 measurements in 38 patients), and simultaneous with P\textsubscript{ETCO\textsubscript{2}} measurements (39 measurements in 31 patients). RESULTS: There were often large changes (> 10 mm Hg) in P\textsubscript{tcCO\textsubscript{2}} during daytime SBTs (23%) and the initial overnight off-the-ventilator periods (42%), which influenced the decisions of whether to continue the SBT. P\textsubscript{tcCO\textsubscript{2}} often rose during bronchoscopy (mean ± SD increase of 10.7 ± 5.8 mm Hg), which influenced the physician to change the ventilator settings 44% of the time. P\textsubscript{aCO\textsubscript{2}}, closely matched P\textsubscript{tcCO\textsubscript{2}} (mean ± SD difference of 0.5 ± 4.1 mm Hg). There was a greater difference between P\textsubscript{aCO\textsubscript{2}} and P\textsubscript{ETCO\textsubscript{2}} (3.7 ± 7.7 mm Hg during prolonged exhalation, and 6.8 ± 7.2 mm Hg during tidal breathing). CONCLUSIONS: Monitoring P\textsubscript{tcCO\textsubscript{2}} is very helpful in assessing and managing patients undergoing SBTs, during the first night off the ventilator, and during bronchoscopy on ventilated patients. P\textsubscript{tcCO\textsubscript{2}} more closely matches P\textsubscript{aCO\textsubscript{2}}, than does P\textsubscript{ETCO\textsubscript{2}}. Key words: capnometry, capnography, carbon dioxide, bronchoscopy, physiologic monitoring, weaning. [Respir Care 2008;53(8):1042–1047. © 2008 Daedalus Enterprises]

Introduction

Patients with respiratory failure are at risk for worse hypercapnia when off the ventilator, as well as during bronchoscopy. Assessment of hypercapnia and changes in arterial P\textsubscript{CO\textsubscript{2}} (P\textsubscript{aCO\textsubscript{2}}) are often used to determine whether a patient receiving a high level of ventilatory support can be considered for a spontaneous breathing trial (SBT) and whether the patient is tolerating the SBT. Typically, P\textsubscript{aCO\textsubscript{2}} is assessed by drawing an arterial blood gas sample. However, drawing arterial blood is time-consuming and often painful, there is a delay until results are known, and the results provide only a snapshot of the patient’s gas exchange, which may be misleading if the patient’s ventilation increased due to the painful arterial puncture.

Other methods to assess hypercapnia include end-tidal P\textsubscript{CO\textsubscript{2}} (P\textsubscript{ETCO\textsubscript{2}}) and transcutaneous P\textsubscript{CO\textsubscript{2}} (P\textsubscript{tcCO\textsubscript{2}}) monitoring. P\textsubscript{ETCO\textsubscript{2}} monitoring has been used during weaning from mechanical ventilation. P\textsubscript{tcCO\textsubscript{2}} monitoring has been used during noninvasive ventilation. Though P\textsubscript{ETCO\textsubscript{2}} closely matches P\textsubscript{aCO\textsubscript{2}} in patients with normal lungs and normal tidal volume (V\textsubscript{T}), it does not match P\textsubscript{aCO\textsubscript{2}} as well in patients with severe lung disease or in patients with normal lungs undergoing endoscopy, and is impractical during bronchoscopy.

Though P\textsubscript{tcCO\textsubscript{2}} monitors have been used for years, especially in pediatrics, recent advances in technology have provided easy-to-use, self-calibrating devices that continu-
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ABSTRACT: We describe our experience with transcutaneous carbon dioxide pressure monitoring in a specialized weaning unit. A pulse oximeter ear clip, clipped to the ear lobe, simultaneously measures oxygen saturation and carbon dioxide pressure. The monitor is recalibrated each time it is placed back in the docking station. For patients using the sensor, the sensor automatically keeps the sensor calibrated. A breath hold reading, with changes in PtcCO2, starting within a minute of abrupt changes in ventilation. The sensor was kept in place throughout the bronchoscopy, SBT, or overnight period, and PtcCO2, oxygen saturation, and heart rate data were collected every 10 s with a data-logging device. The sensor was removed from the docking chamber, put in an ear clip, a drop of sensor gel is placed on the sensor, and the sensor is clipped to the ear lobe. It usually takes 2–4 min to reach a stable PtcCO2 reading, with changes in PtcCO2, starting within a minute of abrupt changes in ventilation. The sensor was kept in place throughout the bronchoscopy, SBT, or overnight period, and PtcCO2, oxygen saturation, and heart rate data were collected every 10 s with a data-logging device. The sensor membrane was routinely changed every 2 weeks. Occasionally the membrane needed to be changed sooner if the monitor displayed a message to change the membrane.

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The differences between PaCO2 and PtcCO2 was 2.9 mm Hg (H11006). An unpaired Student’s t test. Values from patients with and without chronic obstructive pulmonary disease (COPD) were compared with an unpaired Student’s t test. Correlation coefficients are reported for PtcCO2 and PETCO2 versus PaCO2. A Bland-Altman analysis was performed of PaCO2 minus PtcCO2 versus PaCO2.

Results

Forty-one patients were studied. PtcCO2 was measured during 48 simultaneous arterial blood draws in 38 patients, 39 simultaneous blood draws/PETCO2 measurements in 31 patients, 80 bronchoscopies in 21 patients, 23 SBTs in 15 patients, 14 SBTs with starting/ending respiratory mechanics in 11 patients, and 12 initial nights off the ventilator in 12 patients. Though the recommended maximum duration for sensor placement is 8 hours because of concern about heating the skin to 42°C, none of the patients had any complaints of discomfort or evidence of skin damage or irritation from the sensor being on the ear overnight, for up to 10 hours.

PtcCO2 closely matched PaCO2 in the Bland-Altman analysis (Fig. 1). The mean PaCO2 minus PtcCO2 difference was 0.5 ± 4.1 mm Hg (n = 48), and the mean of the absolute differences was 2.9 ± 2.9 mm Hg.

PtcCO2 matched PaCO2 (the PaCO2 minus PtcCO2 difference was 0.4 ± 4.4 mm Hg, n = 39) more closely than did prolonged-exhalation PETCO2 (P = .006) or tidal-breathing PETCO2 (P < .001) (Fig. 2). The PaCO2 minus PETCO2 difference was lower (P < .001) during prolonged exhalation (3.7 ± 7.7 mm Hg, n = 39) than during tidal breathing (6.8 ± 7.2 mm Hg, n = 39).

The 31 patients with matched PaCO2, PtcCO2, and PETCO2 measurements had a mean age of 61 ± 15 y, and included 21 complex medical patients, of whom 9 had a history of COPD, 6 had spinal cord injury (of whom 1 had COPD), and 4 had respiratory muscle weakness from other neurologic diseases. Table 1 shows the results of the PaCO2, PtcCO2, and PETCO2 differences in patients with and without COPD.

During the SBTs (Fig. 3), PtcCO2 rose 7.4 ± 7.3 mm Hg (from 46.9 ± 6.3 mm Hg to 54.3 ± 10.3 mm Hg), and it rose > 10 mm Hg in 6 (23%) of 23 SBTs. The 15 patients in the SBT group had a mean age of 73 ± 12 y, and included 14 complex medical patients, of whom 6 had COPD, and 1 had amyotrophic lateral sclerosis and pneumonia. Table 2 shows the respiratory mechanics results from the 14 SBTs. Some patients had large PtcCO2 despite worse respiratory mechanics.

During the initial night off the ventilator (Fig. 4), PtcCO2 rose 12.8 ± 10.9 mm Hg (from 47.2 ± 4.1 mm Hg to 59.9 ± 13.2 mm Hg), and it rose > 10 mm Hg in 5 (42%) of 12 patients. Those 12 patients’ mean age was 64 ± 17 y, and they included 10 complex medical patients, of whom 3 had COPD, and 2 had C4 spinal cord injury with quad-
riplegia and pneumonia. With 9 of the patients we then attempted to keep them off the ventilator thereafter (2 whose PtcCO$_2$ rose /H11022 10 mm Hg, and 7 whose PtcCO$_2$ rose /H11022 10 mm Hg). Five of those 9 patients were able to stay off the ventilator permanently, and 4 had to go back on the ventilator (after 3, 3, 6, and 15 d). Those 4 patients (ages 56, 72, 85, and 86 y) all had complex medical problems and increased pulmonary secretions at the time of needing renewed ventilator support.

PtcCO$_2$ often rose during bronchoscopy (Fig. 5) (a rise of 10.7 ± 5.8 mm Hg, from 43.4 ± 7.3 mm Hg to 54 ± 9.8 mm Hg (n = 80). The PtcCO$_2$ findings influenced the physician to change ventilator settings by increasing minute volume (by raising the pressure-control level and/or the respiratory rate) during 44% of the bronchoscopies, and many patients were managed by removing the bronchoscope until PCO$_2$ improved. It is likely the PCO$_2$ would have risen even more if PtcCO$_2$ had not been monitored. During half the bronchoscopies, PtcCO$_2$ rose at least 10 mm Hg and peak PtcCO$_2$ was at least 50 mm Hg. The bronchoscopist increased minute volume in 27 of those 40 bronchoscopies, but in only 8 of the 40 bronchoscopies that had PtcCO$_2$ rises of /H11021 10 mm Hg or peak PtcCO$_2$ /H11021 50 mm Hg. Without ventilator adjustments, it is likely that 48 (60%) of the 80 bronchoscopies would have had a PtcCO$_2$ rise of at least 10 mm Hg and peak PtcCO$_2$ of at least 50 mm Hg.

Discussion

We found continuous and noninvasive PtcCO$_2$ measurement very helpful in assessing and managing patients dur-
Fig. 5. Change in transcutaneously measured PCO2 (PtcCO2) (increase from baseline to peak PtcCO2) versus baseline PtcCO2 during bronchoscopies on ventilated patients (n = 80 measurements in 21 patients).

ing SBTs, and during bronchoscopies on ventilated patients. PtcCO2 monitoring is comfortable and well tolerated by adult patients. Our study confirms the findings of others,4-7,8 that PtcCO2 values from the Sentec monitor closely match PaCO2 values from arterial blood analysis.

We found PtcCO2 a better measure of PaCO2 than PETCO2. Though PETCO2 during prolonged exhalation was close to PaCO2 in patients without COPD, it significantly underestimated PaCO2 in patients with COPD, who probably had increased dead space. PETCO2 during tidal breathing underestimated PaCO2 in patients with and without COPD. Thus, PETCO2 seems a good measure only in patients without COPD during a prolonged exhalation maneuver, whereas PtcCO2 is a good measure for continuous monitoring in all patients.

PtcCO2 significantly increased in some patients during SBTs and their initial nights off the ventilator. Though most of our patients with stable respiratory mechanics had stable PtcCO2 during SBTs, some patients had stable respiratory mechanics with substantial elevations in PaCO2, and others had worsening respiratory mechanics but stable PtcCO2. We suspect that differences in respiratory drive accounted for the discrepancies between PtcCO2 and respiratory mechanics. Patients with a high respiratory drive would preserve PaCO2 despite worse mechanics, whereas those with a low respiratory drive would increase PaCO2 despite fairly stable respiratory mechanics.

The criteria to determine if a patient receiving a high level of ventilatory support can be considered for an SBT include adequate oxygenation, stable cardiovascular status, and no substantial respiratory acidosis.1 This assessment typically includes ABG analysis. PtcCO2 monitoring allows a noninvasive assessment of PaCO2 that accurately reflects PaCO2 even in patients with substantial lung disease, whereas PETCO2 often underestimates PaCO2. Therefore, PtcCO2 monitoring should allow fewer arterial blood draws and reduce the need for arterial lines.

The criteria of SBT success include subjective variables (eg, worse mental status, patient discomfort, diaphoresis, and signs of increased work of breathing) and objective measurements, including hemodynamic stability and gas exchange acceptability (oximetry-measured oxygen saturation > 85-90%, pH > 7.32, PaCO2 increase < 10 mm Hg).1 Though continuous oximetry and intermittent subjective clinical assessment during SBT are routine, PaCO2 is not typically measured. PETCO2 and PtcCO2 allow noninvasive assessment of the other component of gas exchange: PaCO2.

Variables that have been studied as predictors of the outcome of ventilator discontinuation include minute volume, maximum negative inspiratory pressure, and the CROP (compliance, rate, oxygenation, and pressure) index while on the ventilator; and respiratory rate, VT, and rapid shallow breathing index during a brief SBT.1 Daily screening of respiratory function can shorten the duration of mechanical ventilation and improve the re-intubation rate.10 PETCO2 was one of the elements of a computer-driven weaning protocol that shortened weaning duration and total ventilation duration in intensive-care patients who did not have tracheostomy tubes.11 PtcCO2 matches PaCO2 better than does PETCO2, so PtcCO2 monitoring has an advantage over PETCO2 monitoring.

Though respiratory mechanics and tolerance of an SBT help predict whether the patient can stay off the ventilator, many patients still fail extubation; studies have reported re-intubation rates of 4%,10 7%,12 10%,10 and 18%.13 Prolonged-weaning-failure patients include those who need more than 3 SBTs or more than 7 days of weaning after the first SBT, and are estimated to be about 15% of ventilated patients.9
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PecO₂ rise has been reported in moderate-sedation procedures, including thoracoscopy, colonoscopy, and bronchoscopy in non-ventilated patients. In non-ventilated sedated patients undergoing bronchoscopy, Chhajed et al. found a PecO₂ rise of 9.5 ± 5.3 mm Hg. We found that PecO₂ also often increases during bronchoscopy on ventilated patients; PecO₂ rose ≥ 10 mm Hg above baseline to at least 50 mm Hg in 50% of the bronchoscopies. Prior to PecO₂ monitoring, we relied on changes in oxygen saturation, respiratory rate, and VT (in ventilated patients) as the indicator that PacO₂ might be rising. With PecO₂ monitoring, we know whether to adjust the fraction of inspired oxygen (if oxygen saturation decreased), remove the bronchoscope for a while, or increase the ventilator rate and/or pressure-control level (if increased PecO₂), or could continue with the procedure without changes (if oxygen saturation and PecO₂ were stable).

Continuous oximetry was a great advance for monitoring patients with respiratory problems, and is now routinely used to monitor patients with respiratory failure and during moderate-sedation procedures. Continuous combined monitoring of PacO₂ and oxygen saturation shows great promise to further improve the care of patients in respiratory failure and during moderate sedation. Further studies are needed to evaluate whether PecO₂ monitoring improves patient outcomes.

Conclusions

PecO₂ provides continuous and noninvasive measurement of PacO₂ that closely matches PacO₂, and PecO₂ is a better measure of PacO₂ than is PECO₂. PecO₂ rises substantially in some patients during SBTs and during the first night off the ventilator, and often rises during bronchoscopy on ventilated patients, so PecO₂ can help guide the duration of SBTs, discontinuation of ventilator support, and ventilator settings during bronchoscopy.

REFERENCES


