Transcutaneous Carbon Dioxide Pressure Monitoring in a Specialized Weaning Unit

Douglas C Johnson MD, Salma Batool MD, Ronald Dalbec RRT

OBJECTIVE: To evaluate transcutaneously measured P_{CO_2} (P_{tcCO_2}) values during ventilator weaning and during bronchoscopies on ventilated patients, and to compare P_{tcCO_2} values to P_{aCO_2} values from arterial blood analysis and end-tidal P_{CO_2} (P_{ETCO_2}) values from capnography. METHODS: In our specialized weaning unit we measured P_{tcCO_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_{ETCO_2} measurements (39 measurements in 31 patients). RESULTS: There were often large changes (> 10 mm Hg) in P_{tcCO_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_{tcCO_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_{aCO_2} closely matched P_{tcCO_2} (mean ± SD difference of 0.5 ± 4.1 mm Hg). There was a greater difference between P_{aCO_2} and P_{ETCO_2} (3.7 ± 7.7 mm Hg during prolonged exhalation, and 6.8 ± 7.2 mm Hg during tidal breathing). CONCLUSIONS: Monitoring P_{tcCO_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_{tcCO_2} more closely matches P_{aCO_2} than does P_{ETCO_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_{CO_2} (P_{aCO_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.[1] Typically, P_{aCO_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_{CO_2} (P_{ETCO_2})[2] and transcutaneous P_{CO_2} (P_{tcCO_2}) monitoring. P_{ETCO_2} monitoring has been used during weaning from mechanical ventilation.[3] P_{tcCO_2} monitoring has been used during noninvasive ventilation.[4] Though P_{ETCO_2} closely matches P_{aCO_2} in patients with normal lungs and normal tidal volume (V_T), it does not match P_{aCO_2} as well in patients with severe lung disease[4] or in patients with normal lungs undergoing endoscopy,[5] and is impractical during bronchoscopy.

Though P_{tcCO_2} monitors have been used for years, especially in pediatrics,[6] recent advances in technology have provided easy-to-use, self-calibrating devices that contin-

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Sentec and Aspen Medical Products provided the transcutaneous carbon dioxide/oximetry monitoring system used in this research. The authors report no conflicts of interest in the content of this paper.

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uously measure P_{tcCO_2} with a small electrochemical sensor covered by a membrane, clipped to the ear lobe, and simultaneously measure blood oxygen saturation with the same monitor. P_{tcCO_2} should be as accurate in patients with lung disease as those without lung disease, since the measurement depends on tissue P_{CO_2}, as opposed to exhaled P_{CO_2}, and recent studies[7,8] found that P_{tcCO_2} closely matches P_{aCO_2}.

We wanted to evaluate the role of P_{tcCO_2} monitoring in our 8-bed specialized weaning unit in a rehabilitation/long-term-acute-care hospital, which receives patients from acute-care hospitals for ventilator weaning. Our hypotheses were:

- P_{tcCO_2} would detect important changes in alveolar ventilation during SBTs in the day and overnight, and alter ventilator management
- P_{tcCO_2} would detect important changes in alveolar ventilation during bronchoscopy in ventilator-dependent patients, and lead to changes in ventilator settings
- P_{tcCO_2} would better reflect P_{aCO_2} in ventilator-dependent patients than does P_{ETCO_2}

Methods

We have routinely used P_{tcCO_2} monitoring since November 2004. All patients in our ventilator weaning program from December 2004 to December 2005 were eligible for the study. Patients were studied prospectively, with results included from patients who consented to our institutional-review-board-approved protocol to allow use of their data. All the subjects had tracheostomy tubes, were ventilator-dependent for at least 2 weeks, and met the criteria for prolonged weaning failure.[9]

P_{tcCO_2} was measured (Digital Monitoring System, Sentec, Therwil, Switzerland) during blood draws for arterial blood gas (ABG) analysis, during bronchoscopies on ventilated patients, during SBTs, and during the patient's first night off the ventilator. P_{tcCO_2}, P_{ETCO_2}, respiratory mechanics, and Borg dyspnea scale were measured at the start and the end of the SBTs in most patients. The respiratory mechanics measurements included respiratory rate, V_T, rapid shallow breathing index, maximum inspiratory pressure, maximum expiratory pressure, and vital capacity.

The sensor combines a pulse oximeter and a membrane-covered electrochemical sensor to measure P_{tcCO_2}, and warms the skin to 42°C. The monitor provides a digital display of P_{tcCO_2}, oxygen saturation, heart rate, and graphic trend data. The display is updated once per second, with no software averaging of P_{tcCO_2}, and about 4-second averaging of oxygen saturation. There is a docking station for the sensor, which automatically keeps the sensor calibrated, using a calibration gas cylinder. The sensor is also recalibrated each time it is placed back in the docking station. The calibration usually takes 2–5 min. For patient use, the sensor (which is 15 mm in diameter, 8 mm in height) is 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 P_{tcCO_2} reading, with changes in P_{tcCO_2} starting within a minute of abrupt changes in ventilation. The sensor was kept in place throughout the bronchoscopy, SBT, or overnight period, and P_{tcCO_2}, oxygen saturation, and heart rate data were collected every 10 s with a data-logging device (Pocket-Logger, Pace Scientific, Moorsville, North Carolina) attached to the P_{tcCO_2} monitor. The data-logging device collects up to 4 days of data and allows computer download, display, and analysis of results. 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.

For P_{tcCO_2}, ABG, and P_{ETCO_2} measurements the first step was placing the P_{tcCO_2} monitor on the patient and waiting for a stable P_{tcCO_2} reading. P_{ETCO_2} was then also monitored (NICO, Novametrix Medical Systems, Wallingford, Connecticut). The P_{ETCO_2} during tidal breathing (the highest P_{ETCO_2} of at least 4 regular breaths) and P_{tcCO_2} were then recorded at the time the arterial blood sample was drawn. Then P_{ETCO_2} was measured with a prolonged exhalation (the highest P_{ETCO_2} of at least 2 efforts), with the patient asked to take a breath in, and then blow all the way out (for at least 5 s). The P_{tcCO_2}, ABG, and P_{ETCO_2} measurements were done when ABG analysis was ordered for clinical purposes. Most patients had an initial ABG analysis with simultaneous P_{tcCO_2} and P_{ETCO_2} measurements. Thereafter, P_{CO_2} was followed with P_{ETCO_2} and/or P_{tcCO_2}; additional arterial blood samples were rarely drawn.

SBTs were performed as tolerated by the patient, up to the duration specified by the physician, with baseline P_{tcCO_2} taken once the P_{tcCO_2} reading was stable. Overnight off-the-ventilator periods were begun once the patient had stable P_{tcCO_2} (or P_{ETCO_2}) and stable respiratory mechanics during prolonged (usually 16-h) SBTs in the day. Baseline P_{tcCO_2} was taken at the start of the evening measurements (usually near 9:00 PM). The peak P_{tcCO_2} was compared to baseline.

Bronchoscopy was performed via the tracheostomy tube, under conscious sedation with fentanyl and midazolam, while the patient was being ventilated with a pressure control mode and a set inspiratory pressure, positive end-expiratory pressure, inspiratory time, and backup respiratory rate. The ventilator was usually initially set to match the patient's baseline respiratory rate and pre-sedation V_T. Most bronchoscopies lasted more than 30 min in patients with mucus plugging and lobar or segmental atelectasis. Most bronchoscopies involved repeated insertions and re-

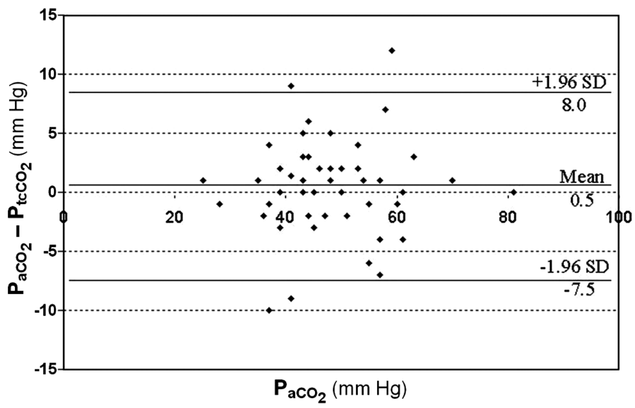

Fig. 1. Bland Altman analysis of P_{aCO_2} (measured from arterial blood) and transcutaneously measured P_{CO_2} (P_{tcCO_2}). The mean ± SD P_{aCO_2} minus P_{tcCO_2} difference is 0.5 ± 4.1 mm Hg (n = 48 measurements in 38 patients).

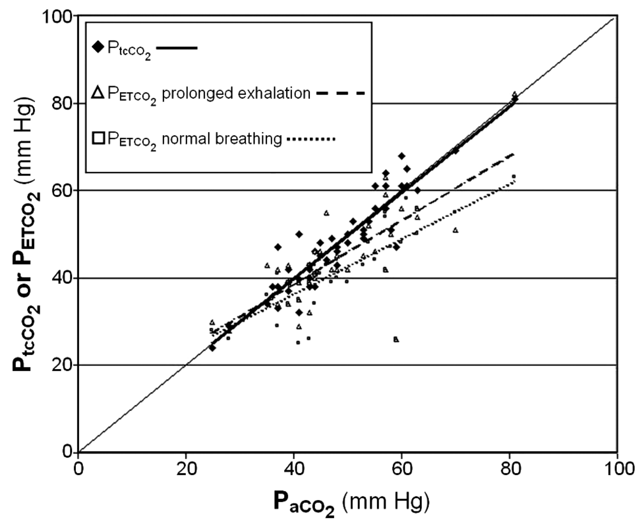

Fig. 2. Transcutaneously measured P_{CO_2} (P_{tcCO_2}) and end-tidal P_{CO_2} (P_{ETCO_2}) during prolonged exhalation, and P_{ETCO_2} during normal breathing versus simultaneously measured P_{aCO_2}. The lines represent linear regression analyses. P_{tcCO_2} = 0.971 P_{aCO_2} + 0.90, correlation coefficient 0.93 (n = 48 measurements in 38 patients). P_{ETCO_2} with prolonged exhalation = 0.735 P_{aCO_2} + 9.10, correlation coefficient 0.76 (n = 39 measurements in 31 patients). P_{ETCO_2} with normal breathing = 0.635 P_{aCO_2} + 10.76, correlation coefficient 0.78 (n = 39 measurements in 31 patients).

movals of the bronchoscope, acetylcysteine/saline installations, and air insufflation to segmental bronchi in the atelectatic areas. As a rule, the bronchoscopist adjusted the ventilator's minute volume by increasing the inspiratory pressure and/or respiratory rate if P_{tcCO_2} rose to > 50 mm Hg and > 10 mm Hg above baseline.

The results are expressed as mean ± standard deviation. The differences between P_{aCO_2} and P_{tcCO_2} and between P_{aCO_2} and P_{ETCO_2} were compared with a paired 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 P_{tcCO_2} and P_{ETCO_2} versus P_{aCO_2}. A Bland-Altman analysis was performed of P_{aCO_2} minus P_{tcCO_2} versus P_{aCO_2}.

Results

Forty-one patients were studied. P_{tcCO_2} was measured during 48 simultaneous arterial blood draws in 38 patients, 39 simultaneous blood draws/P_{ETCO_2} 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.

P_{aCO_2} closely matched P_{tcCO_2} in the Bland-Altman analysis (Fig. 1). The mean P_{aCO_2} minus P_{tcCO_2} difference was 0.5 ± 4.1 mm Hg (n = 48), and the mean of the absolute differences was 2.9 ± 2.9 mm Hg.

P_{tcCO_2} matched P_{aCO_2} (the P_{aCO_2} minus P_{tcCO_2} difference was 0.4 ± 4.4 mm Hg, n = 39) more closely than did prolonged-exhalation P_{ETCO_2} (P = .006) or tidal-breathing P_{ETCO_2} (P < .001) (Fig. 2). The P_{aCO_2} minus P_{ETCO_2} 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 P_{aCO_2}, and P_{tcCO_2}, and P_{ETCO_2} 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 P_{aCO_2}, P_{tcCO_2}, and P_{ETCO_2} differences in patients with and without COPD.

During the SBTs (Fig. 3), P_{tcCO_2} 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 P_{tcCO_2} rises with stable respiratory mechanics, and others had stable P_{tcCO_2} despite worse respiratory mechanics.

During the initial night off the ventilator (Fig. 4), P_{tcCO_2} 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-

Table 1. P_{aCO_2}, P_{tcCO_2}, and P_{ETCO_2} Differences Between Patients With Matched Values

	Without COPD (28 measurements in 21 patients) (mean ± SD) (mm Hg)	With COPD (11 measurements in 10 patients) (mean ± SD) (mm Hg)	P
P_{aCO_2} minus P_{tcCO_2}	0.0 ± 4.1	1.4 ± 5.3	.38
P_{aCO_2} minus P_{ETCO_2} during prolonged exhalation	1.7 ± 5.4	8.7 ± 10.4*	.009
P_{aCO_2} minus P_{ETCO_2} during tidal breathing	4.9 ± 5.1*†	11.7 ± 9.3*	.005

* P_{aCO_2} minus transcutaneously measured P_{CO_2} (P_{tcCO_2}) was smaller than P_{aCO_2} minus end-tidal P_{CO_2} (P_{ETCO_2}) during prolonged exhalation in patients with chronic obstructive pulmonary disease (COPD) (P = .02) and during tidal breathing in patients without COPD (P < .001) and with COPD (P = .001).
† P_{aCO_2} minus P_{ETCO_2} during prolonged exhalation was smaller than during tidal breathing in patients without COPD (P < .001).

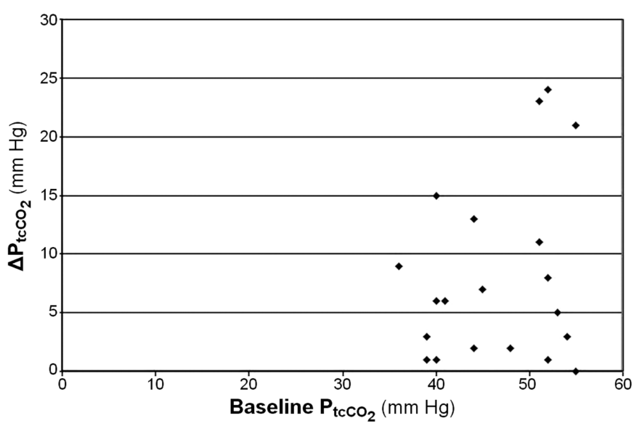

Fig. 3. Change in transcutaneously measured P_{CO_2} (P_{tcCO_2}) (increase from baseline to peak P_{tcCO_2}) versus baseline P_{tcCO_2} during spontaneous breathing trials (n = 23 measurements in 15 patients).

Table 2. Respiratory Mechanics at the Start and End of Spontaneous Breathing Trials*

	Start	End
Respiratory rate (mean ± SD breaths/min)	27.6 ± 8.0	31.3 ± 12.5
RSBI (mean ± SD)	101 ± 52	121 ± 67
MIP (mean ± SD cm H_2O)	30.5 ± 6.1	34.2 ± 8.6
MEP (mean ± SD cm H_2O)	33.2 ± 13.2	36.6 ± 8.6
Borg dyspnea scale score (mean ± SD)	1.8 ± 1.4	2.9 ± 1.5
Patients whose P_{tcCO_2} rose > 10 mm Hg (n)	4 of 14 (RSBI changes +79, +144, +11, –22)	
Patients whose RSBI rose > 20 (n)	4 of 14 (P_{tcCO_2} changes 0, 1, 11, 24; Borg scale changes 0, 1, 1, 2.5)	

* n = 14
RSBI = rapid shallow breathing index (ratio of respiratory frequency to tidal volume)
MIP = maximum inspiratory pressure
MEP = maximum expiratory pressure
P_{tcCO_2} = transcutaneously measured carbon dioxide tension

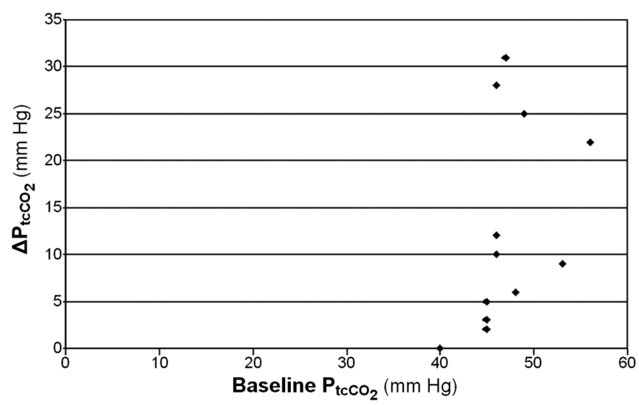

Fig. 4. Change in transcutaneously measured P_{CO_2} (P_{tcCO_2}) (increase from baseline to peak P_{tcCO_2}) versus baseline P_{tcCO_2} during the first night off the ventilator (n = 12 measurements in 12 patients).

riplegia and pneumonia. With 9 of the patients we then attempted to keep them off the ventilator thereafter (2 whose P_{tcCO_2} rose > 10 mm Hg, and 7 whose P_{tcCO_2} rose ≤ 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.

P_{tcCO_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 P_{tcCO_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 P_{CO_2} improved. It is likely the P_{CO_2} would have risen even more if P_{tcCO_2} had not been monitored. During half the bronchoscopies, P_{tcCO_2} rose at least 10 mm Hg and peak P_{tcCO_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 P_{tcCO_2} rises of < 10 mm Hg or peak P_{tcCO_2} < 50 mm Hg. Without ventilator adjustments, it is likely that 48 (60%) of the 80 bronchoscopies would have had a P_{tcCO_2} rise of at least 10 mm Hg and peak P_{tcCO_2} of at least 50 mm Hg.

Discussion

We found continuous and noninvasive P_{tcCO_2} measurement very helpful in assessing and managing patients dur-

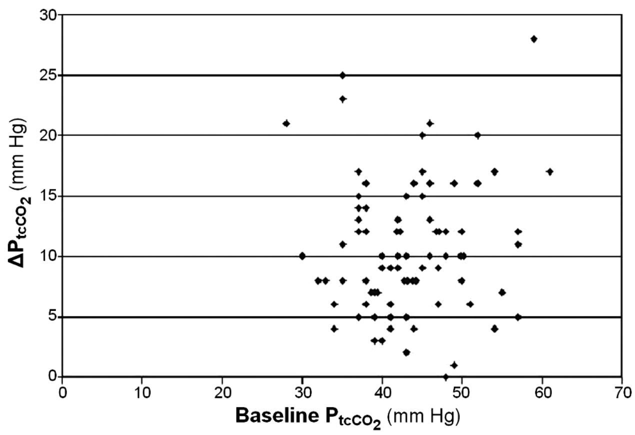

Fig. 5. Change in transcutaneously measured P_{CO_2} (P_{tcCO_2}) (increase from baseline to peak P_{tcCO_2}) versus baseline P_{tcCO_2} during bronchoscopies on ventilated patients (n = 80 measurements in 21 patients).

ing SBTs, and during bronchoscopies on ventilated patients. P_{tcCO_2} monitoring is comfortable and well tolerated by adult patients. Our study confirms the findings of others,[4,7,8] that P_{tcCO_2} values from the Sentec monitor closely match P_{aCO_2} values from arterial blood analysis.

We found P_{tcCO_2} a better measure of P_{aCO_2} than P_{ETCO_2}. Though P_{ETCO_2} during prolonged exhalation was close to P_{aCO_2} in patients without COPD, it significantly underestimated P_{aCO_2} in patients with COPD, who probably had increased dead space. P_{ETCO_2} during tidal breathing underestimated P_{aCO_2} in patients with and without COPD. Thus, P_{ETCO_2} seems a good measure only in patients without COPD during a prolonged exhalation maneuver, whereas P_{tcCO_2} is a good measure for continuous monitoring in all patients.

P_{tcCO_2} 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 P_{tcCO_2} during SBTs, some patients had stable respiratory mechanics with substantial elevations in P_{tcCO_2}, and others had worsening respiratory mechanics but stable P_{tcCO_2}. We suspect that differences in respiratory drive accounted for the discrepancies between P_{tcCO_2} and respiratory mechanics. Patients with a high respiratory drive would preserve P_{CO_2} despite worse mechanics, whereas those with a low respiratory drive would increase P_{CO_2} 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. P_{tcCO_2} monitoring allows a noninvasive assessment of P_{CO_2} that accurately reflects P_{aCO_2}, even in patients with substantial lung disease, whereas P_{ETCO_2} often underestimates P_{aCO_2}. Therefore, P_{tcCO_2} 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, P_{aCO_2} increase < 10 mm Hg).[1] Though continuous oximetry and intermittent subjective clinical assessment during SBT are routine, P_{aCO_2} is not typically measured. P_{ETCO_2} and P_{tcCO_2} allow noninvasive assessment of the other component of gas exchange: P_{CO_2}.

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, V_T, 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] P_{ETCO_2} 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] P_{tcCO_2} matches P_{aCO_2} better than does P_{ETCO_2}, so P_{tcCO_2} monitoring has an advantage over P_{ETCO_2} 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]

Our approach to managing prolonged weaning failure includes: optimizing lung function by treating infections; bronchodilators if indicated; secretion-clearance, including mechanical in-exsufflation; changing the tracheostomy tube if needed, to allow use of a speaking valve when off the ventilator; and bronchoscopy with acetylcysteine lavage, then air insufflation in patients with atelectasis. On admission we obtained simultaneous P_{ETCO_2}, P_{tcCO_2}, and P_{aCO_2} measurements. The subjects had continuous oximetry monitoring and morning assessment of respiratory mechanics and P_{ETCO_2}, followed by an SBT if they passed the morning assessment, then another assessment of respiratory mechanics and P_{ETCO_2} at the end of the SBT. We monitored continuous P_{tcCO_2} during the initial SBT and during the first night off the ventilator. We also did spot checks of P_{tcCO_2} in patients whose P_{ETCO_2} did not closely match their P_{aCO_2}.

We had only one P_{tcCO_2} monitor, so we had to set an order of priority for its use. We prioritized bronchoscopy over SBT. In general, we extended the time off the ventilator in patients who had both stable respiratory mechanics and stable P_{tcCO_2}, but not in patients who had worse respiratory mechanics or worse P_{tcCO_2}. If a patient maintained stable mechanics and stable P_{tcCO_2} during SBT and overnight off the ventilator, we then tried discontinuing ventilator support. P_{tcCO_2} monitoring influenced our decisions on the duration of SBT and whether to end ventilatory support.

P_{CO_2} rise has been reported in moderate-sedation procedures, including thoracoscopy, colonoscopy, and bronchoscopy in non-ventilated patients.[5,7,14] In non-ventilated sedated patients undergoing bronchoscopy, Chhajed et al[14] found a P_{tcCO_2} rise of 9.5 ± 5.3 mm Hg. We found that P_{tcCO_2} also often increases during bronchoscopy on ventilated patients; P_{tcCO_2} rose ≥ 10 mm Hg above baseline to at least 50 mm Hg in 50% of the bronchoscopies. Prior to P_{tcCO_2} monitoring we relied on changes in oxygen saturation, respiratory rate, and V_T (in ventilated patients) as the indicator that P_{aCO_2} might be rising. With P_{tcCO_2} 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 P_{tcCO_2}), or could continue with the procedure without changes (if oxygen saturation and P_{tcCO_2} 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 P_{tcCO_2} 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 P_{tcCO_2} monitoring improves patient outcomes.

Conclusions

P_{tcCO_2} provides continuous and noninvasive measurement of P_{CO_2} that closely matches P_{aCO_2}, and P_{tcCO_2} is a better measure of P_{aCO_2} than is P_{ETCO_2}. P_{tcCO_2} rises substantially in some patients during SBTs and during the first night off the ventilator, and often rises during bronchoscopy on ventilated patients, so P_{tcCO_2} can help guide the duration of SBTs, discontinuation of ventilator support, and ventilator settings during bronchoscopy.

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