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Transcutaneous Carbon Dioxide Monitoring in Subjects With Acute Respiratory Failure and Severe Hypercapnia

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BACKGROUND: Transcutaneous carbon dioxide (P_{tcCO_2}) monitoring is being used increasingly to assess acute respiratory failure. However, there are conflicting findings concerning its reliability when evaluating patients with high levels of P_{aCO_2}. Our study evaluates the accuracy of this method in subjects with respiratory failure according to the severity of hypercapnia. METHODS: We included subjects with respiratory failure, admitted to a respiratory intermediate care unit, who required arterial blood gas analysis. Simultaneously, P_{tcCO_2} was measured using a digital monitor. Relations between P_{aCO_2} and P_{tcCO_2} were assessed by the Pearson correlation coefficient. Bland-Altman analysis was used to test data dispersion, and an analysis of variance test was used to compare the differences between P_{aCO_2} and the corresponding P_{tcCO_2} at different levels (level 1, <50 mm Hg; level 2, 50–60 mm Hg; level 3, >60 mm Hg). RESULTS: Eighty-one subjects were analyzed. The main diagnosis was COPD exacerbation (45%). P_{tcCO_2} correlated well with P_{aCO_2} ($r2 = 0.93$, $P < .001$). Bland-Altman analysis showed a mean $P_{aCO_2} - P_{tcCO_2}$ difference of 4.9 ± 4.4 with 95% limits of agreement ranging from −3.6 to 13.4. The difference between variables increased in line with P_{aCO_2} severity: level 1, 1.7 ± 3.2 mm Hg; level 2, 3.7 ± 2.8; level 3, 6.8 ± 4.7 (analysis of variance, $P < .001$). CONCLUSIONS: Our study showed an acceptable agreement of P_{tcCO_2} monitoring with arterial blood gas analysis. However, we should consider that P_{tcCO_2} underestimates P_{aCO_2} levels, and its accuracy depends on the level of hypercapnia, so this method would not be suitable for acute patients with severe hypercapnia. *Key words: hypercapnia; noninvasive ventilation; respiratory care units; respiratory insufficiency; transcutaneous blood gas monitoring; transcutaneous carbon dioxide partial pressure determination; transcutaneous capnometry.* [Respir Care 0;0(0):1–•. © 0 Daedalus Enterprises]

Introduction

Transcutaneous carbon dioxide (P_{tcCO_2}) monitoring is an increasingly popular noninvasive method for assessing alveolar ventilation. This procedure has the advantage over arterial blood samples of avoiding pain and providing continuous monitoring.

Several studies have reported a good agreement between P_{tcCO_2} and P_{aCO_2} in different subject populations, such as: pediatric critical care,[1] sleep laboratories,[2] out-patients,[3] during major surgery,[4] in emergency departments,[5] and ICUs.[6]

The accuracy of P_{tcCO_2} has also been studied in acute respiratory failure settings with a variety of results, which range from a very good agreement to unacceptable results for clinical practice.[6-12] This controversy could be explained by the heterogeneity of diagnosis and by the fact that the number of subjects with severe ventilatory abnormalities is very different in these studies.

However, when we look at the studies that have evaluated subjects with high levels of P_{aCO_2}, conflicting find-

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The authors have disclosed no conflicts of interest.

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ings are continuously observed. Some authors suggest that at high P_{aCO_2} values, larger differences between P_{tcCO_2} and P_{aCO_2} are observed.[9,13] In contrast, other studies[6-8] consider that the agreement between the 2 methods is independent of the level of P_{aCO_2}. These differences are especially relevant in situations of acute respiratory failure, when the level of hypercapnia may condition therapeutic decisions, such as the need for mechanical ventilation. The aim of our study was to assess the accuracy of P_{tcCO_2} in subjects with acute respiratory failure according to the severity of hypercapnia.

QUICK LOOK

Current knowledge

Transcutaneous carbon dioxide (P_{tcCO_2}) monitoring is an increasingly popular noninvasive method for assessing acute respiratory failure. This procedure has the advantage over arterial blood samples of avoiding pain and providing continuous monitoring. However, there are conflicting findings concerning its reliability when evaluating patients with high levels of P_{aCO_2}.

What this paper contributes to our knowledge

In subjects with acute respiratory failure, a portable P_{tcCO_2} device provided an acceptable assessment of P_{aCO_2} when compared with the accepted standard measurement of P_{aCO_2}. However, P_{tcCO_2} underestimated P_{aCO_2} levels, and its accuracy depended on the level of hypercapnia. P_{tcCO_2} was less reliable in subjects with severe hypercapnia.

Methods

Study Design

This was a prospective observational study. Written informed consent was not considered necessary for the study, given its non-interventional nature. The data of the subjects were anonymized for the purposes of analysis. Confidential information regarding subjects was protected according to Spanish regulations. The study was approved by the Clinical Research Ethics Committee of Bellvitge University Hospital.

Study Setting and Population

The study was conducted in a respiratory intermediate care unit at the Bellvitge University Hospital, a teaching hospital with 600 beds, between June 2012 and December 2013. The annual new patient attendance at this respiratory intermediate care unit is approximately 250. Patients with respiratory failure (acute or acute-on-chronic) who required arterial blood gas analysis as a part of their care were eligible for inclusion.

Study Protocol, Measurements, and Data Collection

Eligible subjects were identified and enrolled by one of the senior respiratory intermediate care unit physicians trained in the use of the P_{tcCO_2} monitor. P_{tcCO_2} was measured using a digital monitor (SenTec, Therwill, Switzerland). After automatic calibration, carried out according to the manufacturer's recommendations, a probe was placed on the subject's upper chest using a drop of conductive solution. The sensor was heated to 42°C over 5 min, inducing local vasodilatation to increase skin permeability to CO_2. A minimum of 20 min was allowed for stabilization, and an arterial blood gas sample was obtained from the radial artery. The P_{tcCO_2} reading on the monitor at the moment of the withdrawal of the needle was recorded. Arterial blood gases were analyzed immediately using an ABL800 FLEX gas analyzer (Radiometer, Copenhagen, Denmark) and expressed in mm Hg.

The data collected included subject demographics, body mass index, cause of respiratory failure, vital signs, use of vasoactive drugs, oxygen (F_{IO_2}) or use of noninvasive ventilation, arterial blood gas analysis, and P_{tcCO_2} measurements.

Data Analysis

Descriptive data are presented as mean ± SD and as *n* (%). The Pearson correlation coefficient was used to evaluate the linear relationship between the paired arterial and transcutaneous carbon dioxide measurements. Agreement between these 2 variables was estimated using the Bland-Altman method. Bias (the mean difference between P_{aCO_2} and P_{tcCO_2}) and 95% limits of agreement were calculated. With the purpose of analyzing the behavior of the P_{tcCO_2} in relation to hypercapnia, an analysis of variance test was performed to compare the bias between paired P_{aCO_2}-P_{tcCO_2} measurements at different levels of P_{aCO_2} (level 1, <50 mm Hg; level 2, 50–60 mm Hg; level 3, >60 mm Hg). Values of $P < .05$ were considered statistically significant. Statistical tests were run using SPSS 16 for Windows (SPSS, Chicago, Illinois).

Results

Ninety-five subjects were enrolled in the study. Eleven measurements were excluded because venous blood gases were drawn, and technical problems with the monitor led to the exclusion of 3 subjects. A total of 81 subjects were

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Table 1. Characteristics of Study Subjects (N = 81)

Characteristics	Values
Age, mean ± SD y	66 ± 11
Male sex, *n* (%)	49 (60.5%)
BMI, mean ± SD kg/m^2	34 ± 9
Systolic arterial blood pressure, mean ± SD mm Hg	127 ± 16
Diastolic arterial blood pressure, mean ± SD mm Hg	69 ± 12
Diagnosis at admission, *n* (%)	
COPD exacerbation	34 (45)
Chest wall diseases	12 (16)
Neuromuscular disease	5 (7)
Obesity hypoventilation syndrome	22 (29)
Asthma	1 (1)
Pneumonia	2 (3)
Noninvasive ventilation, *n* (%)	31 (38)
Vasoactive drugs, *n* (%)	2 (2.5)
Oxygen supplementation, *n* (%)	58 (72)
Blood gases, mean ± SD	
pH	7.30 ± 0.8
P_{aO_2}, mm Hg	70.1 ± 17.3
P_{aCO_2}, mm Hg	59.8 ± 11.9
P_{tcCO_2}, mm Hg	54.9 ± 10.4

BMI = body mass index

Table 2. Agreement Between P_{aCO_2} and P_{tcCO_2} at Different Levels of P_{aCO_2}

	Bias ± SD	95% CI	Limits of Agreement
Level 1 (*n* = 13)*	1.77 ± 3.29	−0.22 to 3.76	−4.6 to 8.22
Level 2 (*n* = 29)†	3.69 ± 2.84	2.61–4.77	−1.8 to 9.23
Level 3 (*n* = 39)‡	6.77 ± 4.75	5.22–8.31	−2.5 to 16.11

* P_{aCO_2} < 50 mm Hg.
† P_{aCO_2} = 50–60 mm Hg.
‡ P_{aCO_2} > 60 mm Hg.

analyzed with paired measurements for arterial and transcutaneous carbon dioxide tension recorded for each one.

The clinical characteristics of the subjects included are presented in Table 1. The mean age was 66 ±11 y. COPD exacerbation (34 subjects or 45%) was the main final diagnosis, followed by obesity hypoventilation syndrome (22 subjects or 22%). At the time of arterial blood sampling, 72% of the subjects were receiving oxygen, and 38% were receiving noninvasive ventilation. None of the subjects studied were in shock or hypothermic, and only 2 required inotropic support. Mean P_{aCO_2} was 59.8 ± 11.9 mm Hg (range 30–99 mm Hg), and mean P_{tcCO_2} was 54.9 ± 10.4 mm Hg (range 29–80 mm Hg). In relation to P_{aCO_2} level, subjects were distributed as follows: level 1 (<50 mm Hg), 13 (16%); level 2 (50–60 mm Hg), 29 (36%); level 3 (>60 mm Hg), 39 (48%). The differences between paired P_{aCO_2}-P_{tcCO_2} measurements at different levels of P_{CO_2} are provided in Table 2.

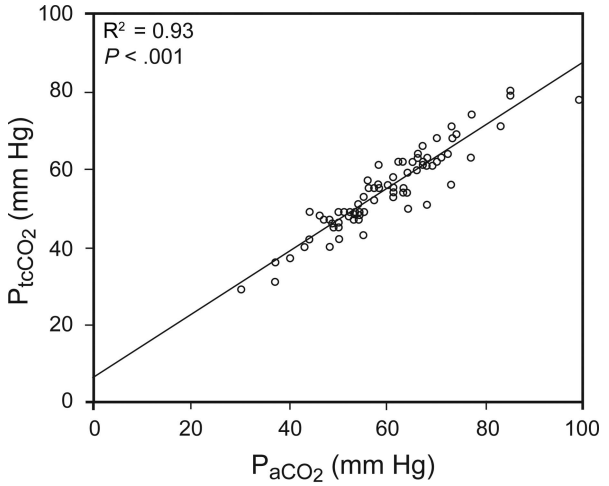

Fig. 1. Linear correlation between transcutaneous CO_2 (P_{tcCO_2}) and arterial CO_2 (P_{aCO_2}).

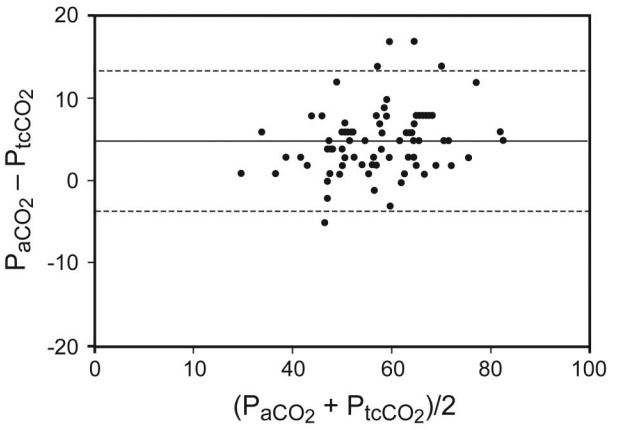

Fig. 2. Bland-Altman analysis between paired measurements of arterial P_{CO_2} (P_{aCO_2}) and transcutaneous CO_2 (P_{tcCO_2}). The solid line represents the mean difference between the 2 methods, and the dotted lines denote the limits of agreement (±1.96 SD).

There was a high correlation between P_{aCO_2} and P_{tcCO_2}, as shown in Figure 1; R^2 was 0.93 ($P < .001$). The Bland-Altman plot of all the subjects included in the study is presented in Figure 2. The mean bias between the 2 methods of measurement was 4.9, and limits of agreement (bias ± 1.96 SD) ranged from −3.6 to 13.4. We also calculated the bias and the limits of agreement between the parameters for each group separately (Fig. 3). In the group of more severe hypercapnic subjects with P_{aCO_2} > 60 mm Hg, the Bland-Altman test showed a mean bias of 6.7 and limits of agreement from −2.5 to 16.1.

We performed an analysis of variance (Fig. 4) to analyze the effect of the different levels of P_{aCO_2} on the bias from the blood samples and the corresponding P_{tcCO_2}. The difference between both variables increases in line with

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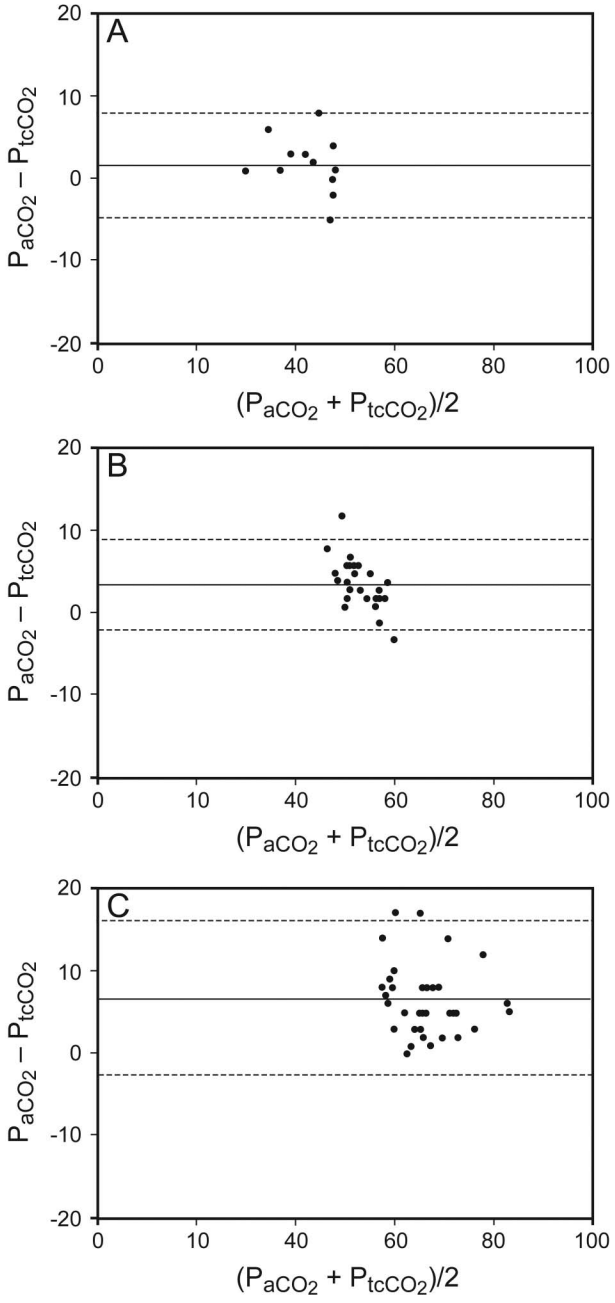

Fig. 3. Bland-Altman analysis between paired measurements of arterial P_{CO_2} (P_{aCO_2}) and transcutaneous CO_2 (P_{tcCO_2}) for each group of subjects: level 1 P_{aCO_2} <50 mm Hg (A); level 2 P_{aCO_2} 50–60 mm Hg (B); level 3 P_{aCO_2} >60 mm Hg (C). Solid lines represent the mean difference between the 2 methods, and the dashed lines denote the limits of agreement (±1.96 SD).

P_{aCO_2} severity: level 1, 1.77 ± 3.29 mm Hg; level 2, 3.69 ± 2.84; level 3, 6.77 ± 4.75 (analysis of variance, $P < .001$). During this study, we did not observe any adverse effects from or subject discomfort with the heating electrode, and no skin lesions were found after probe removal.

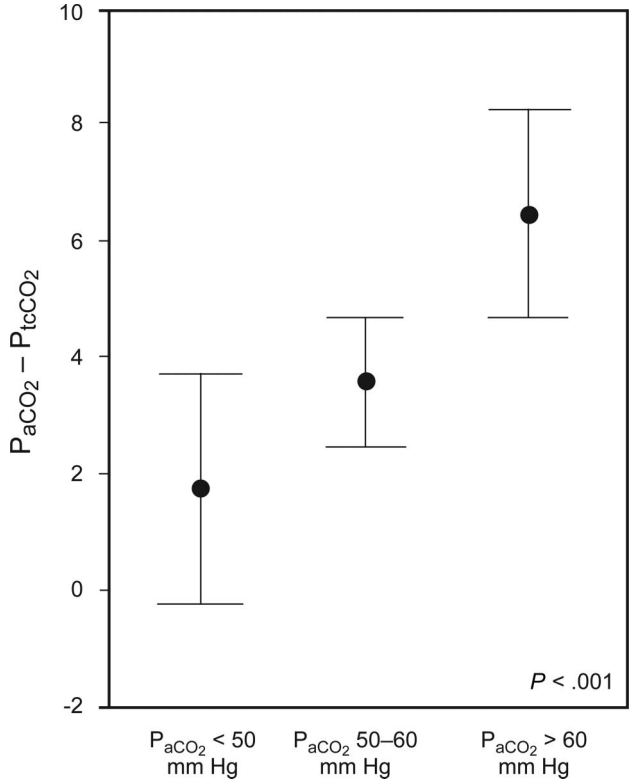

Fig. 4. Analysis of variance test to analyze the bias related to P_{aCO_2}-P_{tcCO_2} couple at different levels of P_{aCO_2}.

Discussion

The present study evaluated the accuracy of the SenTec digital monitor for P_{tcCO_2} measurements in subjects with acute respiratory failure according to the severity of hypercapnia. Although we generally found good agreement between transcutaneous carbon dioxide and P_{aCO_2}, the measurements of P_{tcCO_2} were less reliable in subjects with severe hypercapnia. In fact, in the group of subjects with higher P_{aCO_2} values, the bias between P_{tcCO_2} and P_{aCO_2} was clinically relevant and could interfere with the interpretation of the results and the management of the respiratory failure.

Although several studies that have investigated the accuracy of P_{tcCO_2} monitoring in subjects with acute respiratory failure have found a good agreement between the 2 methods, most of them did not evaluate patients with high hypercapnia levels. For instance, in subjects admitted to an emergency department, Delerme et al[5] found that the mean difference between P_{aCO_2} and P_{tcCO_2} was 1 mm Hg with limits of agreement of −3.4 to 5.6 and that all P_{tcCO_2} values were within 5 mm Hg of P_{aCO_2} values. In subjects with severe asthma or pneumonia, Perrin et al[11] obtained a bias of −0.13 mm Hg with limits of agreement of −3.9 and 3.7 mm Hg. McVicar and Eager[12] found a mean difference of 0.15 mm Hg, and the limits of agreement were −6

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to 6.2 mm Hg. It should be noted that mean P_{aCO_2} in these 3 studies was <50 mm Hg (39, 36, and 41 mm Hg respectively). Conversely, ours was 59 mm Hg, and 48% of the cases were in the group of P_{aCO_2} > 60 mm Hg. This could explain why, in a similar setting of acute respiratory failure, our bias and limits of agreement are worse than those reported previously.

To our knowledge, this is the first study that has purposely assessed the validity of transcutaneous measurements in subjects with different levels of hypercapnia, including a high number of severe hypercapnic patients. According to our results, the difference between the 2 variables increases as the level of P_{aCO_2} rises. The group with P_{aCO_2} > 60 mm Hg showed a bias of 6.7, with limits of agreement of −2.5 and 16. Our findings are consistent with those of other authors,[13,14] who have argued that the reliability and accuracy of this method decreases when evaluating severe ventilatory disturbance with high levels of P_{aCO_2}. Storre et al,[13] who used a SenTec digital monitor, reported a bias of 4.6 mm Hg and limits of agreement of −3.9 and 13.2 mm Hg in 10 subjects with a mean P_{aCO_2} of 67 mm Hg. Kelly and Klim,[9] using a Radiometer TCM4 device in subjects undergoing noninvasive ventilation, found a poor agreement between P_{aCO_2} and P_{tcCO_2}. In this study, mean P_{aCO_2} was 60 mm Hg, and the bias was 6.1, with limits of agreement of −10 and 22 mm Hg.

In contrast, in a study designed to assess the accuracy of a TOSCA monitor in ICU subjects with varying P_{aCO_2}, Bendjelid et al[6] concluded that the agreement between the 2 methods was independent of the level of P_{aCO_2}. However, the study did not discriminate high P_{aCO_2} values because the hypercapnic group was defined by P_{aCO_2} > 42 mm Hg. In addition, the authors did not mention the average level of P_{aCO_2}, but when their graphs are analyzed, it seems that most samples had a value of <60 mm Hg. Cox et al,[7] using the same monitor as Bendjelid et al[6] in subjects with exacerbation of COPD, also obtained a good correlation between P_{aCO_2} and P_{tcCO_2}. However, despite finding a small bias (mean P_{tcCO_2} − P_{aCO_2} difference of −1.1 mm Hg), the limits of agreement were relevant (+4.5 to −6.8 mm Hg).

In accordance with other authors,[9,14,15] another important fact that we found was that P_{tcCO_2} values underestimate P_{aCO_2} values. We observed that not only does P_{tcCO_2} underestimate P_{aCO_2}, but also, this underestimation becomes more pronounced as hypercapnia increases. These results are very important in clinical practice because they can give a false impression of normality, especially in patients who may require ventilatory support. Our study was carried out in a respiratory intermediate care unit, where patients with severe ventilatory failure/disturbance and severe hypercapnia predominate (COPD exacerbation, neuromuscular diseases, obesity hypoventilation syndrome). In this context, although P_{tcCO_2} is useful to avoid repeated arterial blood samplings, P_{tcCO_2} values need to be interpreted with caution, especially in cases with high levels of hypercapnia, and arterial blood gas analysis therefore remains the accepted standard in the management of these patients. In critically ill subjects as Rodriguez et al[16] suggest, transcutaneous arterial carbon dioxide is probably more useful as a trend-monitoring tool to predict changes in P_{aCO_2} than as a single measurement. In the same way, van Oppen et al[17] in a pilot study demonstrate that P_{tcCO_2} provides a continuous and reliable tool and also allows pH prediction.

Some monitor and patient factors have been described that may affect transcutaneous carbon dioxide measurements and therefore could alter the results of our study. In order to avoid technical problems like trapped air bubbles, improper placement, or inappropriate calibration, the monitor was only used by trained personnel. Body mass index, tissue hypoperfusion, and the use of vasoconstricting drugs may affect accuracy.[18,19,20] In line with the results of Maniscalco et al,[21] which found a good agreement between P_{aCO_2} and P_{tcCO_2} (bias 1.3 mm Hg and limits of agreement −4 to 1.1) in a study of severe obese subjects (body mass index 43.7 kg/m^2), we considered that the body mass index of our subjects (mean 34 kg/m^2) did not affect the accuracy of P_{tcCO_2}. On the other hand, only 2 hypotensive subjects were included.

This study has some limitations that should be considered. P_{tcCO_2} measurements were recorded in real time, and the values were not retrospectively analyzed with the software provided by the SenTec digital monitor to correct hypothetical drift. In any case, the drift of the transcutaneous electrode would be relevant if monitoring is performed over a period of several hours[22,23] and not during short-term studies like ours, so we considered that this would not alter our results. The classification of P_{aCO_2} values in 3 different groups was done arbitrarily. Therefore, we are unable to establish a cut-off point corresponding to a P_{aCO_2} level at which the difference is clinically unacceptable. Our study was not designed to assess the accuracy of the monitor when used to follow trends in P_{aCO_2} over time because only one comparison was made. However, other authors[16,17] consider P_{tcCO_2} monitoring a useful tool in the treatment of acutely ill subjects. In these cases, measurements of P_{tcCO_2} would complement the arterial samples for following and monitoring trends.

Although we have evaluated a single-monitor device and consider that the level of agreement is related to the severity of hypercapnia and not to the accuracy of the SenTec digital monitor itself, further studies with different monitors and different levels of hypercapnia are probably needed to confirm our results.

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Conclusions

Our study suggests that in subjects with acute respiratory failure, a portable P_{tcCO_2} device provides an acceptable assessment of P_{aCO_2} when compared with the accepted standard measurement of P_{aCO_2}. However, these findings show that we have to take into account 2 clinically important aspects: P_{tcCO_2} undervalues P_{aCO_2} levels, and P_{tcCO_2} is less reliable in patients with severe hypercapnia. Bearing in mind these limitations, we cannot recommend the use of P_{tcCO_2} monitoring as a substitute for arterial blood gas analysis, especially in severely hypercapnic patients who could potentially require ventilatory support.

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