Usefulness of Transcutaneous Carbon Dioxide Pressure Monitoring to Measure Blood Gases in Adults Hospitalized for Respiratory Disease


Servicio de Neumología, Hospital Universitario Dr. Peset, Valencia, Spain.

OBJECTIVE: To evaluate the usefulness of transcutaneous carbon dioxide pressure (TcPCO₂) monitoring in patients hospitalized for respiratory disease.

PATIENTS AND METHODS: We used a SenTec TcPCO₂ monitor that also determines transcutaneous oxygen saturation (SpO₂) by means of a sensor placed behind the ear lobe at a temperature of 42°C. We compared arterial blood gas measurements—PaCO₂ and arterial oxygen saturation (SaO₂)—with transcutaneous measurements and analyzed the correlation, regression line, and agreement between the 2 methods.

RESULTS: Thirty patients (20 men and 10 women) with various respiratory diseases and a mean (SD) age of 71 (13) years were included in the study. The median TcPCO₂ was 43.25 mm Hg and the median PaCO₂ was 42.6 mm Hg with no significant differences between the 2 measurements. The correlation was significant (ρ = 0.979; P < 0.001) and the corresponding regression equation was TcPCO₂ = –2.475 + 1.058 PaCO₂. The mean difference was 0.16 mm Hg (95% confidence interval [CI], –0.74 to 1.06). The lower limit of agreement (mean –1.96 SD) was –4.64 mm Hg, and the upper limit (mean +1.96 SD) was 4.96 mm Hg. For SaO₂, the median was 94% and for SpO₂, 95%. The difference between the 2 medians was significant (P < 0.004). The correlation was also significant (ρ = 0.822; P < 0.001) with SpO₂ = 0.437 + 0.97 SaO₂. The mean difference was 1.14% (95% CI, 0.381% to 1.899%). The lower limit of agreement (mean –1.96 SD) was –2.93% and the upper limit (mean +1.96 SD) was 5.21%.

CONCLUSIONS: Transcutaneous determination of carbon dioxide pressure and oxygen saturation is useful for patients hospitalized for respiratory disease in view of its good correlation and agreement, although SpO₂ does tend to overestimate SaO₂.

Key words: Transcutaneous carbon dioxide pressure. Transcutaneous oxygen saturation. Partial pressure of carbon dioxide, arterial. Arterial oxygen saturation. Respiratory diseases.
progression. This involves repeated arterial punctures, which are annoying and sometimes difficult. In order to avoid this problem it has become routine practice to use pulse oximetry as a reflection of arterial oxygen saturation and to give some idea of oxygen pressure. Pulse oximetry, while subject to errors associated with hemodynamic factors, technical problems, or shifts in the oxyhemoglobin dissociation curve, is a technique that does allow continuous monitoring of oxygen saturation.\(^1\) However, as correlation and agreement between oxygen pressure measured transcutaneously and in arterial blood is poor, the former cannot substitute for the latter in following adults with respiratory diseases or for monitoring during tests such as bronchoscopy.\(^2,3\)

\(\text{PaCO}_2\) pressure can be estimated indirectly by measuring end-tidal pressure (PETCO\(_2\)), which is considered to be similar to that of pulmonary capillary pressure. This is useful in situations such as monitoring invasive mechanical ventilation or intubating for general anesthesia.\(^4\) Although PETCO\(_2\) monitoring may be useful in the lung function laboratory,\(^2\) the difference between this measurement and PaCO\(_2\) increases in situations where there are considerable ventilation-perfusion alterations.\(^5\) For this reason, PETCO\(_2\) monitoring is not reliable in exacerbations of patients with chronic obstructive pulmonary disease (COPD).

As the ability of CO\(_2\) to diffuse is good and can be increased by warming the skin, the use of transcutaneous CO\(_2\) pressure (TcPCO\(_2\)) measurements for monitoring blood gases has been suggested.\(^6\) While TcPCO\(_2\) measurement is routinely used in neonatal and pediatric patients,\(^8\) its usefulness in adults with respiratory diseases is not well established.

We studied patients with respiratory disease requiring blood gas evaluation hospitalized during November 2004. All patients gave informed consent to participate in the study. A sensor was placed behind the right ear lobe of the seated patient and a TcPCO\(_2\) value that remained constant for at least 30 seconds was recorded, as was transcutaneous oxygen saturation (SpO\(_2\)). Arterial blood gas samples were taken simultaneously and immediately sent for analysis. Two analyses were done, and a third was done if there was a difference greater than 1 mm Hg between the 2 values. The value closest to normal was recorded. The SaO\(_2\) determination included measurement of carboxyhemoglobin and methemoglobin. For each patient we also recorded the type of respiratory disease, age, sex, body mass index (BMI), and PaO\(_2\).

**Patients and Methods**

**Study Population**

We studied patients with respiratory disease requiring blood gas evaluation hospitalized during November 2004. All patients gave informed consent to participate in the study. A sensor was placed behind the right ear lobe of the seated patient and a TcPCO\(_2\) value that remained constant for at least 30 seconds was recorded, as was transcutaneous oxygen saturation (SpO\(_2\)). Arterial blood gas samples were taken simultaneously and immediately sent for analysis. Two analyses were done, and a third was done if there was a difference greater than 1 mm Hg between the 2 values. The value closest to normal was recorded. The SaO\(_2\) determination included measurement of carboxyhemoglobin and methemoglobin. For each patient we also recorded the type of respiratory disease, age, sex, body mass index (BMI), and PaO\(_2\).

**Measurements**

We used a TcPCO\(_2\) monitor that utilizes a digital V-Sign sensor (SenTec AG, Therwil, Switzerland). The sensor consists of a clip that is placed on the ear lobe. It is equipped with a heating unit that maintains a temperature of 42°C and determines TcPCO\(_2\) with a resolution of 0.1 mm Hg (measurement range, 0 mm Hg to 200 mm Hg), SpO\(_2\) (resolution, 1%), and pulse rate (resolution, 1 beat/min), according to the information provided by the manufacturer. The SenTec digital monitor uses the algorithm proposed by Severinghaus.\(^8\) Response time has also been shown to be less than 80 seconds.

**System Description**

The digital monitoring system is calibrated automatically against a known CO\(_2\) concentration. For the sake of reliability, it is recommended that this calibration be performed for 24 hours the first time the system is used, although in subsequent uses only a few minutes are required.

TcPCO\(_2\) can be monitored for 8 hours. After this period, the system should be recalibrated as indicated by the manufacturer. The system continuously displays the values analyzed or their plethysmographic curve on a color liquid crystal display and, with appropriate software, can also upload the complete study to a computer for subsequent analysis. It is recommended that a drop of gel be placed on the membrane, and that the membrane be changed after 2 weeks of use. The calibration cartridge lasts approximately 1 month. Once the sensor has been positioned, the TcPCO\(_2\) signal stabilizes in no more than 10 minutes, with no need for the sensor to be repositioned or for the skin to be prepared again.

**Statistical Analysis**

Values are expressed as means (SD) or as medians, ranges, or top and bottom quartiles depending on the type of distribution of the sample analyzed. Box plots were constructed. We used the Shapiro-Wilk test for normality, the paired Student \(t\) test to compare normally distributed samples, and the nonparametric Wilcoxon test to compare non-normally distributed samples.\(^10\) For normally distributed samples, the Pearson correlation coefficient was used to assess the correlation between transcutaneous and arterial measurements; otherwise, Spearman’s \(\rho\) was used. When the correlation was significant, the corresponding regression equation was computed, along with the coefficient of determination (\(R^2\)) and the standard error of the estimate (SEE).\(^11\) As 2 methods of analyzing the same measurement are likely to have good correlation, we used the Bland and Altman\(^12\) method to analyze the agreement between the 2 methods of assessing arterial blood oxygen saturation (SpO\(_2\) with the SenTec device and SaO\(_2\)) and CO\(_2\) pressures (TcPCO\(_2\) and PaCO\(_2\)) in arterial blood and to determine whether the differences were of clinical importance. This analysis considered the mean difference and its 95% confidence interval (CI). We also calculated the lower limit of agreement (mean –1.96 SD), the upper limit (mean +1.96 SD), and their 95% CI. The level of statistical significance was set at .05. Statistical analysis was performed with the SPSS 11.5 statistical software package.

**Results**

We studied 30 patients (20 men and 10 women) with a mean (SD) age of 71 (13.45) years, BMI of 28.7 (9.2) kg/m\(^2\), pH of 7.43 (0.05), and PaO\(_2\) of 71 (3.1) mm Hg.
Patients with COPD exacerbations (15 cases) predominated. There were 12 cases of pneumonia, 4 cases of asthma, 3 cases of pulmonary embolism, 3 cases of sleep apnea, 2 cases of pachypleuritis, 2 cases of bronchiectasis, 2 cases of hemoptysis, and 1 case of pulmonary neoplasia. Five patients (17%) were active smokers.

The distributions of TcPCO₂ and PaCO₂ values were not normal due to the presence of high values (Figure 1) and (P<.004 and P<.002 in the Shapiro-Wilk test, respectively). SpO₂ values, with the presence of low readings, were also distributed asymmetrically (P<.001), while SaO₂ values had a normal distribution (P<.991) (Figure 2).

The median TcPCO₂ was 43.2 mm Hg (range, 28.8 to 80.9), the bottom quartile was at 37.6 mm Hg, and the top quartile was at 48.7 mm Hg. Differences between CO₂ measurements were not significant (P<.88), and the correlation was significant (ρ=0.979; P<.0001). The corresponding
regression equation was TcPCO2 = –2.475 + 1.058 PaCO2 (F = 775.150; P < .0001) (Figure 3). R² was 0.965 (SEE, 2.3616 mm Hg). In the agreement analysis the mean difference between TcPCO2 and PaCO2 was 0.16 mm Hg (95% CI, –0.74 to 1.06). The lower limit, 1.96 SD below the mean difference, was –4.64 mm Hg (95% CI, 3.4 to 6.52) (Figure 4). The SE of the mean difference was 0.441 mm Hg; the SE of the upper and lower limits was 0.763 mm Hg.

For SaO2, the median was 94% (range, 87% to 100%), the bottom quartile was at 92%, and the upper quartile was at 95.6%. Median SpO2 was 95% (range, 83% to 100%), the bottom quartile was at 94%, and the upper quartile was at 97%. There were significant differences between the 2 oxygen saturation measurements (P < .004), and SpO2 values were higher than those of SaO2. The correlation was significant (ρ = 0.822; P < .0001). R² was 0.651 and SEE, 2.0702%. The regression equation was SpO2 = 4.427 + 0.97 × SaO2 (F = 52.304; P < .0001) (Figure 5). In the agreement analysis the mean difference between SaO2 and SpO2 was 1.4% (95% CI, 0.381% to 1.899%). The lower limit, 1.96 SD below the mean difference, was –2.93% (95% CI, –1.613% to –2.93%) and the upper limit, 1.96 SD above the mean difference, was 5.21% (95% CI, 3.893% to 6.527%) (Figure 6). The SE of the mean difference was 0.372% and the SE of the mean ±1.96 SD, 0.644%.

TcPCO2 and SpO2 values remained stable in relation to each other and in each patient. The signal became irregular when the membrane needed to be changed. In no case were there adverse effects or did the test need to be repeated.

**Discussion**

TcPCO2 monitoring has demonstrated its efficacy especially in neonates and infants, in whom accuracy in assessing CO2 pressure in arterial blood is greater than in older patients. This depends on the value itself, however, as the discrepancy is greater with values more than 40 mm Hg.13 High CO2 values are precisely those that hold clinical interest for the management of respiratory diseases.

The warming of the skin that is needed to increase its permeability to CO2 raises skin metabolism and leads to an increase in CO2 production that must be corrected for when assessing transcutaneous values.7 TcPCO2 and SpO2 can be measured simultaneously with the same device in situations such as general anesthesia.14 TcPCO2 monitoring has been shown to be more reliable than transcutaneous measurement of oxygen pressure, probably due to the greater diffusion capacity of CO2 through the skin or to the skin's own oxygen consumption.15 TcPCO2 has been used successfully to assess PaCO2 in adult intensive care patients. TcPCO2 measurements are influenced by cardiac output as well as by PaCO2 itself.16

As the electrode is well tolerated when in place for more than 8 hours, with no adverse local reactions or drift of the signal,17 TcPCO2 monitoring can be carried out in sleep studies in patients with suspected hypercapnia (due either to alveolar hypoventilation, chronic airflow obstruction, or morbid obesity) and/or sleep apnea.18 In monitoring mechanical ventilation in chronic respiratory failure, TcPCO2 overestimates PaCO2, an
error that increases with higher PaCO₂ values and needs to be corrected for. Together with pulse oximetry, TcPCO₂ monitoring can be useful in detecting possible alveolar hypoventilation during bronchoscopy, especially if the patient is under sedation.

In our patients TcPCO₂ monitoring proved to be extremely useful given its good correlation and agreement with PaCO₂ values. We therefore believe that this technique could become routine practice on the hospital ward so that repeated arterial blood gas sampling can be avoided. The system was reliable, as the values remained stable in each patient and over repeated measurements. The membrane should be changed when the device so indicates; otherwise, measurements become erratic.

The SpO₂ value obtained while monitoring TcPCO₂ also showed good correlation and agreement with SaO₂. Transcutaneous assessment does, however, tend to overestimate, as has been noted in other studies, and this should be taken into account so that the degree of oxygenation is interpreted correctly. Nevertheless, the difference is small and of little clinical importance. Warming the zone would produce a shift to the right in the oxyhemoglobin dissociation curve, with a decrease in the affinity of hemoglobin for oxygen. The carboxyhemoglobin level was taken into account in the pulse oximetry reading, as oxygen saturation is overestimated by 1% for every 1% of carboxyhemoglobin. Methemoglobinemia, meanwhile, will also affect the reading because methemoglobin will not be detected and this will result in low readings.

In view of the accuracy of TcPCO₂ and SpO₂ with respect to arterial blood gas measurements, we may conclude that transcutaneous measurements are useful in monitoring the progress of patients with respiratory diseases, with no need for repeated arterial punctures, although there is greater dispersion in extreme TcPCO₂ values and a slight variation in SpO₂. It is advisable, however, to perform initial arterial blood gas analysis in order to determine pH and evaluate the oxygenation of venous blood in the lungs to provide a point of reference for subsequent measurements.

REFERENCES


