ORIGINAL ARTICLES

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

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OBJECTIVE: To evaluate the usefulness of transcutaneous carbon dioxide pressure ($TcPCO_2$) monitoring in patients hospitalized for respiratory disease.

PATIENTS AND METHODS: We used a SenTec $TcPCO_2$ monitor that also determines transcutaneous oxygen saturation (SpO_2) by means of a sensor placed behind the ear lobe at a temperature of 42ºC. We compared arterial blood gas measurements—$PaCO_2$ and arterial oxygen saturation (SaO_2)—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 $TcPCO_2$ was 43.25 mm Hg and the median $PaCO_2$ was 42.6 mm Hg with no significant differences between the 2 measurements. The correlation was significant (ρ=0.979; *P*<.0001) and the corresponding regression equation was $TcPCO_2$=–2.475+1.058 $PaCO_2$. The mean difference was 0.16mm 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 SaO_2, the median was 94% and for SpO_2, 95%. The difference between the 2 medians was significant (*P*<.004). The correlation was also significant (ρ=0.822; *P*<.0001) with SpO_2=4.427+0.97 SaO_2. 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 SpO_2 does tend to overestimate SaO_2.

Key words: *Transcutaneous carbon dioxide pressure. Transcutaneous oxygen saturation. Partial pressure of carbon dioxide, arterial. Arterial oxygen saturation. Respiratory diseases.*

Utilidad de la presión transcutánea del anhídrido carbónico en la valoración gasométrica de adultos hospitalizados con enfermedad respiratoria

OBJETIVO: Estudiar la utilidad de la medida de la presión transcutánea de anhídrido carbónico ($PtcCO_2$) en pacientes con enfermedad respiratoria hospitalizados.

PACIENTES Y MÉTODOS: Utilizamos el analizador de $PtcCO_2$ SenTec®, que también determina la saturación transcutánea de oxígeno ($SatcO_2$), mediante un sensor colocado en el lóbulo de la oreja a una temperatura de 42 °C. Se compararon los valores gasométricos –presión arterial de anhídrido carbónico ($PaCO_2$) y saturación arterial de oxígeno (SaO_2)– con los transcutáneos, analizando la correlación, recta de regresión y la concordancia entre ambos métodos.

RESULTADOS: Se incluyó a 30 pacientes (20 varones y 10 mujeres) con diversas enfermedades respiratorias, con una media (± desviación estándar [DE]) de edad de 71 ± 13 años. La mediana de la $PtcCO_2$ era de 43,25 mmHg, y la de la $PaCO_2$ de 42,6 mmHg, sin existir diferencias entre ellas. La correlación era significativa (rho = 0,979; p < 0,0001), siendo la $PtcCO_2$ = –2,475 + 1,058 $PaCO_2$. La media de las diferencias fue de 0,16 mmHg (intervalo de confianza del 95%, de –0,74 a 1,06); la media de las diferencias menos 1,96 DE fue de –4,64 mmHg, y más 1,96 DE, de 4,96 mmHg.

En cuanto a la SaO_2, la mediana era del 94%, y la de la $SatcO_2$ del 95%, con diferencias entre ambas (p < 0,004). La correlación fue significativa (rho = 0,822; p < 0,0001), con $SatcO_2$ = 4,427 + 0,97 SaO_2. La media de la concordancia era del 1,14% (intervalo de confianza del 95%, 0,381-1,899%); la media menos 1,96 DE era del –2,93%, y más 1,96 DE, del 5,21%.

CONCLUSIONES: La determinación transcutánea de anhídrido carbónico y de la SaO_2 es de utilidad en pacientes con enfermedad respiratoria hospitalizados, dada su buena correlación y concordancia, aunque la $SatcO_2$ tiende a sobrevalorar la SaO_2.

Palabras clave: *Presión transcutánea de CO_2. Presión arterial de CO_2. Saturación transcutánea de oxígeno. Saturación arterial de oxígeno. Enfermedades respiratorias.*

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Manuscript received May 27, 2005. Accepted for publication October 25, 2005.

Introduction

The clinical evaluation of patients with respiratory disease exacerbations may require repeated arterial blood gas measurements in order to monitor disease

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]

$PaCO_2$ 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,[5] the difference between this measurement and $PaCO_2$ increases in situations where there are considerable ventilation-perfusion alterations.[6] 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.[7] 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 analyzed the accuracy, correlation, and agreement of $TcPCO_2$ with $PaCO_2$ in patients hospitalized for respiratory disease.

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.[9] 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 ρ 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.

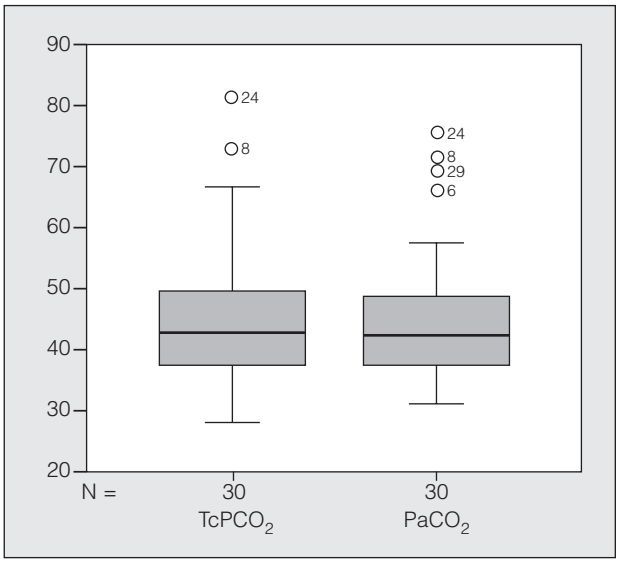

Figure 1. Box plot of transcutaneous carbon dioxide pressure ($TcPCO_2$) and $PaCO_2$ values. N indicates number of cases.

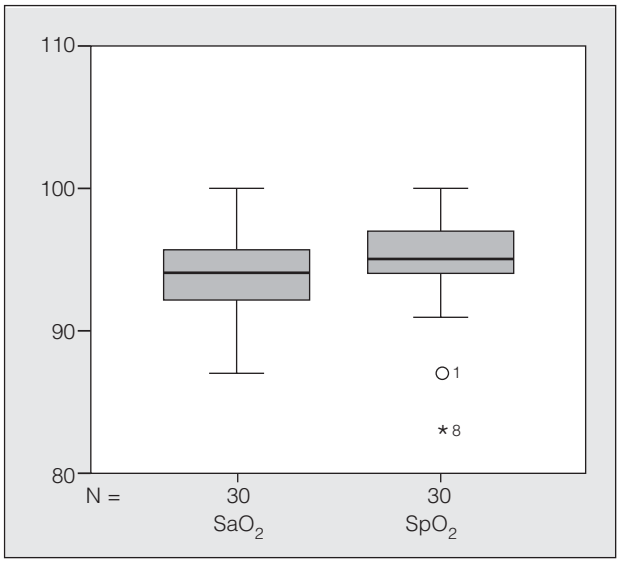

Figure 2. Box plot of transcutaneous oxygen saturation (SpO_2) and arterial oxygen saturation (SaO_2). N indicates number of cases.

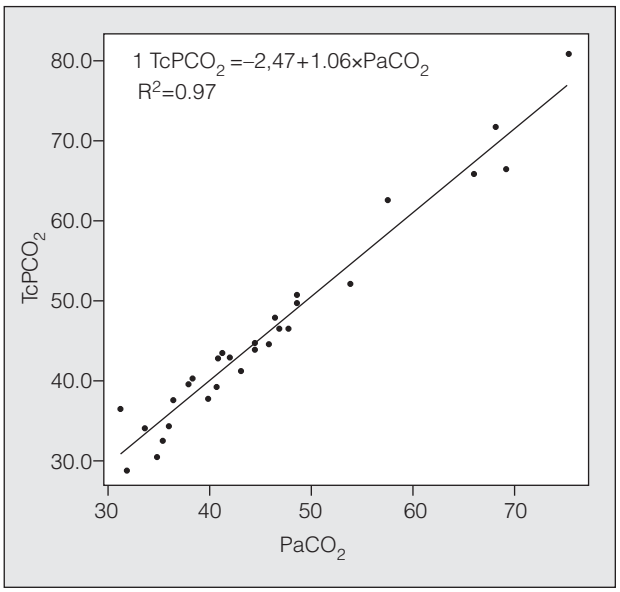

Figure 3. Linear regression equation of transcutaneous carbon dioxide pressure ($TcPCO_2$) vs $PaCO_2$. R^2 indicates coefficient of determination.

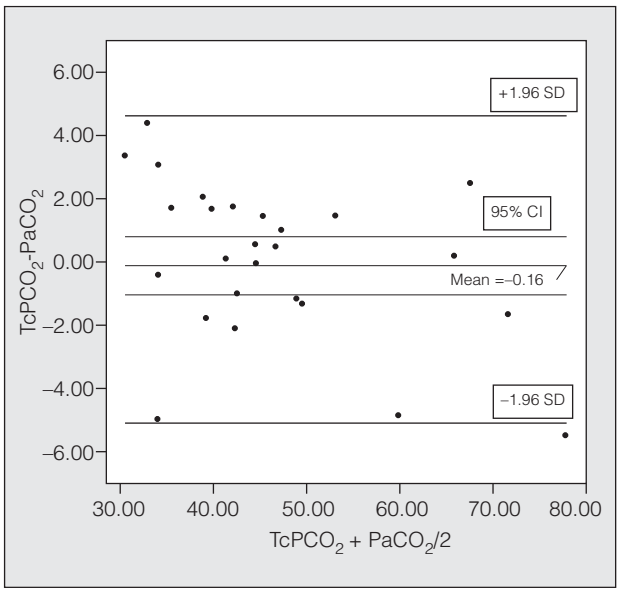

Figure 4. Analysis of agreement between transcutaneous carbon dioxide pressure ($TcPCO_2$) and $PaCO_2$. CI indicates confidence interval.

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 $TcPCO_2$ and $PaCO_2$ values were not normal due to the presence of high values (Figure 1) and (P<.004 and P<.002 in the Shapiro-Walk test, respectively). SpO_2 values, with the presence of low readings, were also distributed asymmetrically (P<.001), while SaO_2 values had a normal distribution (P<.991) (Figure 2).

The median $TcPCO_2$ was 43.2 mm Hg (range, 28.8 to 80.9), the bottom quartile was at 37.9 mm Hg, and the top quartile was at 49.9 mm Hg. Median $PaCO_2$ was 42.6 mm Hg (range, 31.5 to 75.4), the bottom quartile was at 37.6 mm Hg, and the top quartile was at 48.7 mm Hg. Differences between CO_2 measurements were not significant (P<.88), and the correlation was significant (ρ=0.979; P<.0001). The corresponding

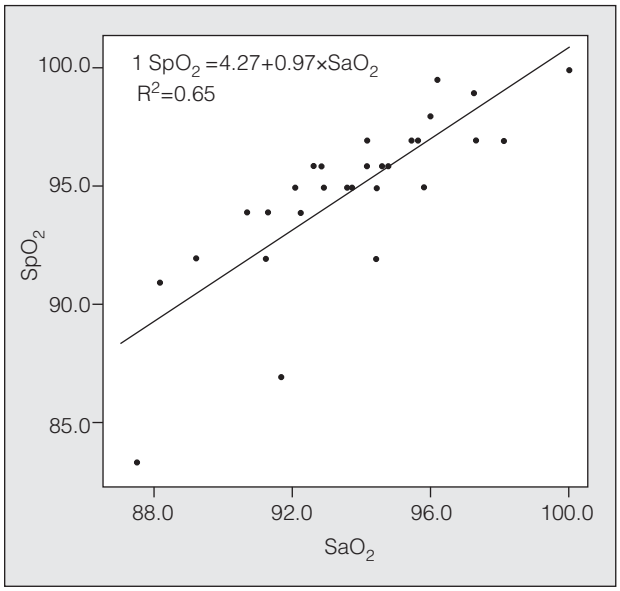

Figure 5. Regression line of transcutaneous oxygen saturation (SpO_2) vs arterial oxygen saturation (SaO_2). R^2 indicates coefficient of determination.

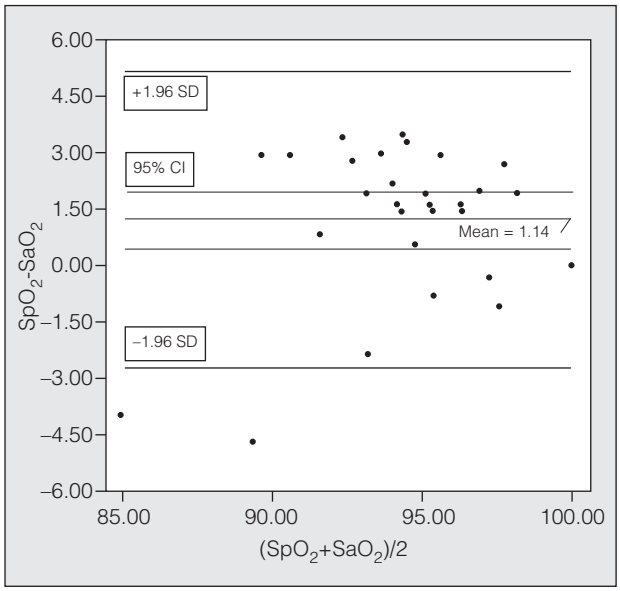

Figure 6. Analysis of agreement between transcutaneous oxygen saturation (SpO_2) and arterial oxygen saturation (SaO_2). IC indicates confidence interval.

regression equation was $TcPCO_2$=–2.475+1.058 $PaCO_2$ (F=775.150; *P*<.0001) (Figure 3). R^2 was 0.965 (SEE, 2.3616 mm Hg). In the agreement analysis the mean difference between $TcPCO_2$ and $PaCO_2$ 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, –3.08 to –6.2), and the upper limit, 1.96 SD above the mean difference, was 4.96 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 SaO_2, the median was 94% (range, 87% to 100%), the bottom quartile was at 92%, and the upper quartile was at 95.6%. Median SpO_2 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 SpO_2 values were higher than those of SaO_2. The correlation was significant (ρ=0.822; *P*<.0001). R^2 was 0.651 and SEE, 2.0702%. The regression equation was SpO_2=4.427+0.97 SaO_2 (F=52.304; *P*<.0001) (Figure 5). In the agreement analysis the mean difference between SaO_2 and SpO_2 was 1.14% (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%.

$TcPCO_2$ and SpO_2 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

$TcPCO_2$ monitoring has demonstrated its efficacy especially in neonates and infants, in whom accuracy in assessing CO_2 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 CO_2 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 CO_2 raises skin metabolism and leads to an increase in CO_2 production that must be corrected for when assessing transcutaneous values.[7]

$TcPCO_2$ and SpO_2 can be measured simultaneously with the same device in situations such as general anesthesia. Measurement is faster when the electrode is placed behind the ear lobe rather than on the finger or the arm.[14]

$TcCO_2$ monitoring has been shown to be more reliable than transcutaneous measurement of oxygen pressure, probably due to the greater diffusion capacity of CO_2 through the skin or to the skin's own oxygen consumption.[15] $TcPCO_2$ has been used successfully to assess $PaCO_2$ in adult intensive care patients. $TcPCO_2$ measurements are influenced by cardiac output as well as by $PaCO_2$ 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] $TcPCO_2$ 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, $TcPCO_2$ overestimates $PaCO_2$, an

error that increases with higher $PaCO_2$ values and needs to be corrected for.[19] Together with pulse oximetry, $TcPCO_2$ monitoring can be useful in detecting possible alveolar hypoventilation during bronchoscopy, especially if the patient is under sedation.[20]

In our patients $TcPCO_2$ monitoring proved to be extremely useful given its good correlation and agreement with $PaCO_2$ 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 SpO_2 value obtained while monitoring $TcPCO_2$ also showed good correlation and agreement with SaO_2. Transcutaneous assessment does, however, tend to overestimate, as has been noted in other studies,[21] 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.[4]

In view of the accuracy of $TcPCO_2$ and $SpO_2$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 $TcPCO_2$ values and a slight variation in SpO_2. 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.

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