Original Article

Evaluation of a transcutaneous carbon dioxide monitor in patients with acute respiratory failure

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Abstract:

BACKGROUND: Non-invasive measurement of oxygenation is a routine procedure in clinical practice, but transcutaneous monitoring of PCO_2 ($PtCO_2$) is used much less than expected.

METHODS: The aim of our study was to analyze the value of a commercially available combined SpO_2/$PtCO_2$ monitor (TOSCA-Linde Medical System, Basel, Switzerland) in adult non-invasive ventilated patients with acute respiratory failure. Eighty critically ill adult patients, requiring arterial blood sample gas analyses, underwent SpO_2 and $PtCO_2$ measurements (10 min after the probe was attached to an earlobe) simultaneously with arterial blood sampling. The level of agreement between $PaCO_2$ - $PtCO_2$ and SaO_2 - SpO_2 was assessed by Bland-Altman analyses.

RESULTS: Both, SaO_2 from blood gas analysis and SpO_2 from the transcutaneous monitor, and $PaCO_2$ and $PtCO_2$ were equally useful. No measurements were outside of the acceptable clinical range of agreement of ± 7.5 mmHg.

CONCLUSIONS: The accuracy of estimation of the TOSCA transcutaneous electrode (compared with the "gold standard" blood sample gas analysis) was generally good. Moreover, TOSCA presents the advantage of the possibility of continuous non-invasive measurement. The level of agreement of the two methods of measurement allows us to state that the TOSCA sensor is useful in routine monitoring of adults admitted to an intermediate respiratory unit and undergoing non-invasive ventilation.

Key words:

Non-invasive measurement, $PaCO_2$, $PtCO_2$, respiratory failure, SaO_2, SpO_2, transcutaneous electrode

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Transcutaneous technology for the non- invasive monitoring of oxygen and carbon dioxide has been used for 40 years. It was initially believed that $PtCO_2$ measurements would not be satisfactory in adults because of their thicker epidermidis. The first transcutaneous electrode consisting of a stow-severinghaus glass electrochemical sensor was modified for transcutaneous use by the incorporation of a thermostatically controlled heater unit. A close correlation between the transcutaneous carbon dioxide tension ($PtCO_2$) and arterial carbon dioxide tension ($PaCO_2$)was demonstrated.[1] Transcutaneous measurements of oxygen and carbon dioxide depend on an increased capillary blood flow due to a heating element in the electrode increasing the temperature of underlying tissue: the electrode then measures the gas tension of the underlying tissue. In stable hemodynamic conditions, the two measurements correlate well.[2] In adults there is a greater variation than in pediatric patients from site to site and the suggested locations for optimal results are the forearm, chest, abdomen or earlobe. Recently, a combined sensor has been developed for the measurements of both transcutaneous CO_2 and pulse oximetric saturation: this electrode contains an electrochemical electrode (for $PtCO_2$), a light emitter-sensor (for SpO_2), and a heating element to increase local perfusion. The small size of the sensor allows convenient placement on the earlobe.[3] The sensor's measurement directly reflects $PaCO_2$ and oxygen saturation (SaO_2).[3,4] Arterial blood gas analysis is the gold standard for $PaCO_2$ measurement, but this method presents major disadvantages because each determination of $PaCO_2$ requires withdrawal of arterial blood and laboratory analysis. Other disadvantages are that assessment of $PaCO_2$ is intermittent; relatively expensive; and there is a time delay in obtaining results. In addition, the need for invasive monitoring is not without complications such as infection, hemorrhage, and vessel occlusion.[5] Previous studies of correlation between $PaCO_2$ and $PtCO_2$ have had conflicting findings and have not targeted to subgroups with severe ventilatory disturbance such as those requiring non invasive ventilation.[5] Our study was aimed to determine the feasibility of estimating arterial PCO_2 using a combined $SatO_2$/$PtCO_2$ monitor (TOSCA, Linde Medical System, Linde Basel, Switzerland) in patients with acute respiratory failure undergoing non invasive ventilation.

Methods

The study was approved by the Local Research Ethics Committee. Eighty patients were enrolled

after giving their informed consent: they were hemodynamically stable and admitted to the Intermediate respiratory care unit of the Respiratory Diseases Division of the Hospital of Sestri Levante. Each subject had acute respiratory failure needing non-invasive ventilation. The principal disease causing respiratory failure was chronic obstructive pulmonary disease (COPD) (sixty four patients), cardiogenic pulmonary edema (five patients), neuromuscular diseases (eleven patients: three with Steinert myotonic, one with spinal muscular atrophy type 2, three with cyphoscoliosis, and four with amiotrophic lateral sclerosis).

All patients were monitored for $PtCO_2$ and SpO_2 and all patients underwent non-invasive ventilation. The sensor probe, cleaned with alcohol and dried before each application, was applied to the skin of the earlobe using one drop of contact gel. After 5 minutes calibration period before placement of the monitor, and an additional 10 minutes equilibration period (as indicated by manufacturers),[6,7] $PtCO_2/SaO_2$ was recorded simultaneously with arterial blood sampling gas analysis in the usual way (Bayer Rapid Point 405).[8] The primary outcome of this study was to investigate the agreement between $PaCO_2$ and $PtCO_2$, and between SaO_2 and SpO_2; and the second outcome was to evaluate the skin irritations caused by heating-up the sensor. A measurement was considered acceptable if it was in a clinical range of agreement of ±7.5 mmHg or 1 KPa.[8]

Statistical analyses

The level of agreement between the two measurements was assessed by Bland-Altman analysis.[9] The statistical analysis of the results was performed using R-project program (R 2.12.02 version, 2010).

Results

Eighty comparisons were analyzed. Median age was 70.88 ± 7.56 (Interquartile range IQR 44-82); 48 (60%) patients were male, while 32 (40%) were female. Median $PaCO_2$ was 56.97 ± 9.98 (IQR 42-89), median O_2 saturation was 90.89 ± 4.82(IQR 79-98). Median pH was 7.308 ± 0.02 (IQR 7.25-7.35) and median systolic blood pressure was 132.58 ± 17.22 mmHg (IQR 104-169) [Table 1].

Standard blood gas SaO_2 analysis and TOSCA SpO_2 were studied over a range of 79% to 98%. Standard blood gas analysis $PaCO_2$ and TOSCA $PtCO_2$ were studied over a range of 42 to 89 mmHg. There was a close correlation between the oxygen saturation from blood gas analysis and transcutaneous SpO_2, $PaCO_2$ and transcutaneous $PtCO_2$ and limits of correlation lower than ±7 mmHg.[4,6-8] No measurement was outside the acceptable clinical range of agreement of ±7.5 mmHg.[7,10] A scatter plot of the relationship between $SatO_2/PtSatO_2$ and $PaCO_2/PtCO_2$ was shown in Figure 1a and b and average difference and 95% limits of agreement was shown in Figure 2. None of the patients experienced adverse effects due to skin irritation caused by heating-up the sensor clipped to the earlobe.

Discussion

It is widely known that the value of pulse-oximetry to detect only hypoventilation is limited in the presence of supplemental

Table 1: Characteristics of the patients

Variable	Data
Sex	Males 48 (60%); females 32 (40%)
Age	70.88 ± 7.56 range 44-82
Diagnosis	COPD 64 AHF 5 NMD 11
Systolic blood pressure (mmHg)	A 132.58 ± 17.22 R 169-104
O_2 saturation (%)	A 90.89 ± 4.82 R 79-98
$PaCO_2$ (mmHg)	A 56.97 ± 9.98 R 42-89
pH	A 7.308 ± 0.02 R 7.25-7.35

A = Average; R = Range; COPD = Chronic obstructive pulmonary diease; AHF = Acute heart failure; NMD = Neuro-muscular disease

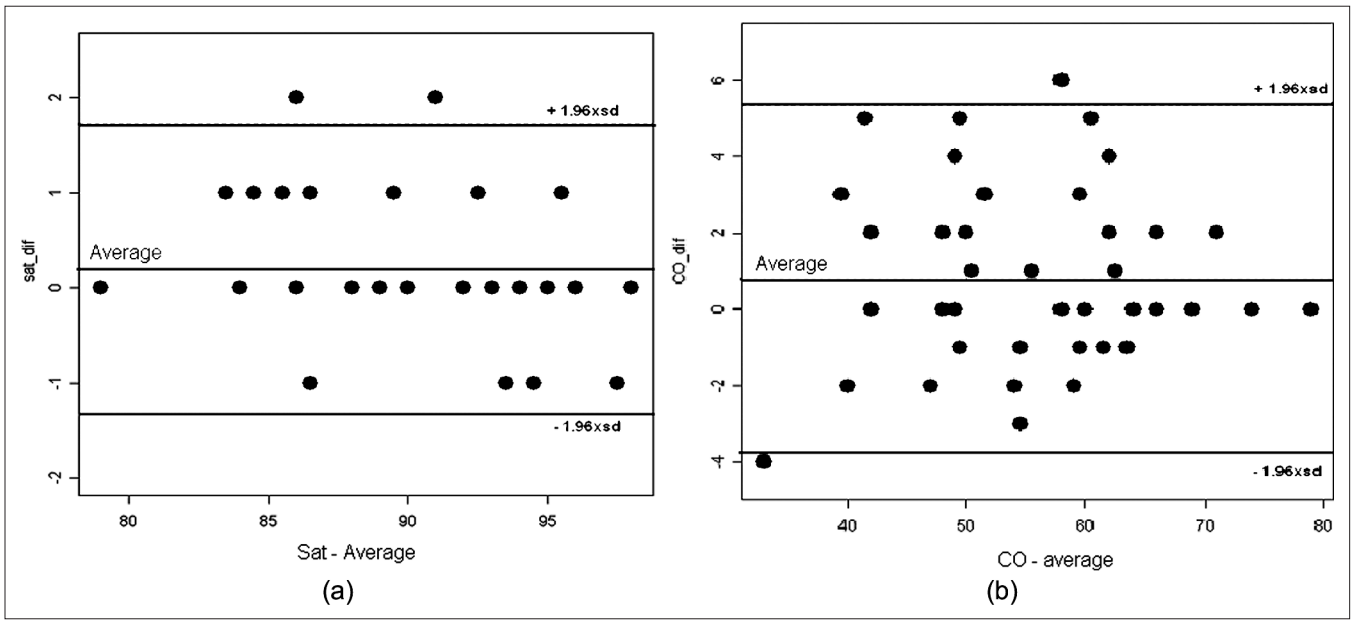

Figure 1: Bland-Altman plot of difference between two estimation of (a) PO_2 and their average (b) PCO_2 and their average

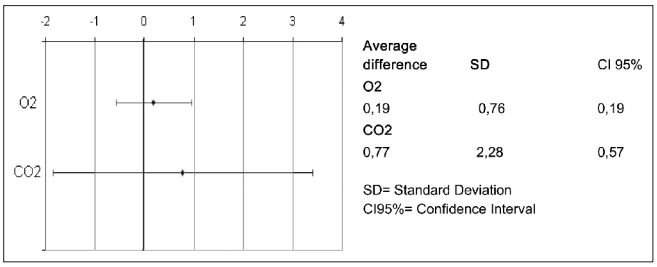

Figure 2: $SatO_2$ and PCO_2: Averages and 95% confidence limits

oxygen. Carbon dioxide monitoring, which is a more accurate measure of the respiratory function, appears to be used much less than expected, outside the operation theater or intensive care unit.[8]

Transcutaneous measurement of CO_2 is based on the observation that this gas has a high tissue solubility and diffusion through the skin and that application of the local heat dilates blood vessels, and to enhance skin permeability. This permits the non-invasive measurement of the arterial PCO_2.[10-14] We have evaluated the accuracy of a transcutaneous sensor for non-invasive evaluation of arterial carbon dioxide in adult patients with acute respiratory failure, compared with the "gold standard" arterial blood sample analysis. The results showed an acceptable level of correlation between SaO_2 and SpO_2, as well as between $PaCO_2$ and $PtCO_2$, as reported in previous studies.[3,4,7,15-22] The agreement between the two methods is independent of the level of $PaCO_2$.[7] The monitor is simple to use and offers the advantage of the possibility of continuous non- invasive measurement. Therefore, it can allow to reduce the number of invasive sampling of arterial blood sampling,[3] saving money and decreasing discomfort. Our study was made only in hemodynamically stable patients, like subjects undergoing non-invasive ventilation, having a pH from 7.25 to 7.35 and monitored with TOSCA. Another study demonstrated that the use of both vasopressors and vasodilators had no significant effects on $PtCO_2$ measurements.[2,11,14] The TOSCA sensor is able to detect the desaturation events significantly earlier than the finger sensors of other devices.[4] It is well tolerated: no adverse events such as skin lesions have been observed following the removal of the sensor after an application time of up to eight hours.[7] Other complimentary studies have been published in recent years. These have looked at critically ill children,[15] emergency room patients with acute respiratory failure,[16] patients during cardiopulmonary exercise testing,[17] or healthy individuals.[18] Two previous studies have evaluated critically illness patients:[4,7] the first one[4] looked at eighteen patients, among whom, nine had hemodynamic instability treated with inotropic or vasoactive drugs; the second study[7] evaluated 69 critically ill patients admitted to the surgical intensive care unit for major surgery, multiple trauma, or septic shock. Of this group, 39 were placed on mechanical ventilation. Only three further studies have evaluated transcutaneous monitoring in patients undergoing non-invasive ventilation: the first two[16,17] (with a small number of patients) had a good agreement between $PaCO_2$ and $PtCO_2$, the third,[5] instead, reported a sub-optimal result.

Our study selected 80 patients affected by respiratory failure that were hemodynamically stable (no inotropic or vasoactive agents used). We found a good correlation between $PaCO_2$/$PtCO_2$. Our study presents some limitations: it is a single center study and the acceptable limits of agreement of 7.5 mmHg were chosen based on previous studies.[7,10,16] In conclusion, the placement of the probe is technically easy and rapid. The device can used continuously even for eight hours.[20,21] We found that the TOSCA sensor is useful in adult routine monitoring practice in an intermediate respiratory unit, where patients have no hemodynamic instability and are completely awake. The device measurements allow real time estimation of CO_2 level over a prolonged period and facilitates proactive (rather than reactive) ventilator manipulation.[22] Moreover, the device may help in deciding the timing of arterial sampling and may therefore considerably reduce, as reported by a previous study,[20,22] the frequency of painful invasive arterial sampling.

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