

Validity of transcutaneous oxygen/carbon dioxide pressure measurement in the monitoring of mechanical ventilation in stable chronic respiratory failure

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Validity of transcutaneous oxygen/carbon dioxide pressure measurement in the monitoring of mechanical ventilation in stable chronic respiratory failure. V. Rosner, B. Hannhart, F. Chabot, J.M. Polu. ©ERS Journals Ltd 1999.

ABSTRACT: The accuracy and precision of transcutaneous pressure measurements of oxygen (P_{tc,O_2}) and carbon dioxide (P_{tc,CO_2}) in the monitoring of nocturnal assisted ventilation in adult patients were evaluated.

Transcutaneous measurements obtained with two analysers, Radiometer TINA-TCM3 (R) and Kontron MicroGas-7650 (K), were compared with arterial blood gases analysed in blood samples withdrawn simultaneously in 10 patients. Sensors were heated to 43°C. Measurements of transcutaneous blood gases and arterial blood gases were collected six times at 1-h intervals.

The data obtained with both instruments were similar and did not significantly change over the 5 h test period. Measurement of P_{tc,O_2} underestimated arterial oxygen tension (P_{a,O_2}) and this underestimation increased with the level of P_{a,O_2} ($p<0.01$). Measurements of P_{tc,CO_2} overestimated arterial carbon dioxide tension (P_{a,CO_2}) and this overestimation increased with the level of P_{a,CO_2} ($p<0.05$). These errors suggested an instrumental bias. Mathematical correction of this bias neutralized the error in accuracy and improved the precision (sd of the differences transcutaneous blood gases - arterial blood gases). An additional correction, suppressing the between-subject scattering, improved the actual precision: precision was reduced from 1.9 to 0.8 kPa (14.4 to 5.7 mmHg) (R) and from 1.7 to 0.5 kPa (13.1 to 3.7 mmHg) (K) for oxygen, and from 1.0 kPa (7.8 mmHg) (R) and 0.7 kPa (5.6 mmHg) (K) to 0.4 kPa (3.2 mmHg) for carbon dioxide (R and K).

In conclusion, with these two successive corrections, transcutaneous oxygen and carbon dioxide provide a reliable estimation of blood gases to monitor nocturnal ventilation in adults with chronic respiratory failure.

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Nocturnal assisted positive pressure ventilation is effective in the treatment of severe hypercapnic chronic respiratory disease. Its primary objective is to reduce hypercapnia and its efficacy is usually judged by arterial blood gas determination (arterial oxygen tension (P_{a,O_2}) and arterial carbon dioxide tension (P_{a,CO_2})). Transcutaneous oxygen (P_{tc,O_2}) and carbon dioxide (P_{tc,CO_2}) tensions reflect partial pressures of gases in arterial blood. Usually, a combined oxygen (PO_2)/carbon dioxide (PCO_2) tension skin probe equipped with Clark and Stow-Severinghaus electrodes is used to measure P_{tc,O_2} and P_{tc,CO_2} after "arteriolization" of the skin by warming to a temperature between 41°C and 45°C. In the newborn, because of skin thinness, transcutaneous values of oxygen and carbon dioxide approach the pressures in arterial blood [1]. The main advantage is the real-time estimation over prolonged periods of time without necessity of blood sampling.

The purpose of this study was to determine the accuracy and precision of this method in the monitoring of nocturnal assisted ventilation in adult patients with stable severe chronic respiratory failure. Measurements of P_{tc,O_2} and P_{tc,CO_2} obtained hourly with two different devices were

compared with the values of P_{a,O_2} and P_{a,CO_2} measured simultaneously in arterial blood. The correction of instrumental and individual sources of dispersion should allow estimation of the actual precision of the measurements obtained by this method.

Materials and methods

Ten patients (seven males and three females), mean age of 64 yrs (range 53–73 yrs), were included in this study. None of the subjects were obese (body mass index between 22 and 30 kg·m⁻²). The patients suffered from severe chronic respiratory failure due to chronic obstructive pulmonary disease (n=5), kyphoscoliosis (n=4) and sequelae of tuberculosis (n=1). They all benefited from nocturnal assisted ventilation and, in six cases, long-term supplemental oxygen. None of the patients had a recent history of acute respiratory failure and all were haemodynamically stable. They were hospitalized either for initiation or routine yearly control of their mechanical nocturnal ventilation *via* a nasal mask (n=9) or tracheostomy cannula

(n=1). They were ventilated, as needed, with supplemental oxygen at a flow rate of 1–3 L·min⁻¹. Each subject gave their informed consent following a detailed presentation of study objectives and protocol. This study was approved by the local ethics committee. In each patient, an indwelling catheter was inserted in the radial artery. Blood gas determinations were performed using a Radiometer ABL 520 device (Copenhagen, Denmark). Measurements of P_{tc,O_2} and P_{tc,CO_2} were recorded simultaneously using two monitors equipped with heated dual PO_2/PCO_2 electrodes, the Radiometer TINA TCM3 with an E5280 probe (R), and the Kontron Instruments MicroGas 7650 (K; Basle, Switzerland). Both monitors were calibrated according to the manufacturer's instructions. *In vivo* calibration using a reference arterial blood sample was not performed.

Study protocol

Assisted ventilation was initiated at 22:00 h. Probes were randomly placed on the skin of either the right or left subclavicular region of the bed-resting patient. The probes were heated to 43°C and maintained on the skin for <6 h to avoid burning [2]. After 20 min, P_{tc,O_2} and P_{tc,CO_2} values were recorded, and a 3 mL sample of arterial blood withdrawn simultaneously for blood gas determination. The latter was taken as a reference value. Transcutaneous pressure measurements as well as the simultaneous arterial blood gas sampling were then repeated five-times at hourly intervals.

Data analysis

Comparison between transcutaneous pressure and arterial blood gas measurements. The difference between transcutaneous blood gas tension ($P_{tc,O_2/CO_2}$) and arterial blood gas tensions ($P_{a,O_2/CO_2}$) was expressed as $\Delta(P_{tc,O_2/CO_2} - P_{a,O_2/CO_2})$. The mean of the 60 differences represents the accuracy of $P_{tc,O_2/CO_2}$, as stated in the literature. The standard deviation of the distribution of these differences represents the precision of the measurements. The relationship between the $\Delta(P_{tc,O_2/CO_2} - P_{a,O_2/CO_2})$ and the magnitude of the corresponding $P_{a,O_2/CO_2}$ taken as the reference value was analysed by linear regression using the least-square method.

Variability over time. To detect any systematic and progressive change in the relationship between $P_{tc,O_2/CO_2}$ and $P_{a,O_2/CO_2}$ over the 5 h study period, the six differences in each patient were tested as a function of time by analysis of variance for repeated measurements (AN-OVA and Scheffé's test) [3].

Results

The transcutaneous probes were well tolerated and no burns occurred over the 5 h study period. The handling of both devices was simple. With the exception of the ease of automatic calibration for the Kontron monitor, there was no notable difference in the use of the devices.

Comparison between transcutaneous pressure and arterial blood measures

Accuracy and precision of $P_{tc,O_2/CO_2}$ are listed in table 1. For oxygen, the mean difference was negative, reflecting an overall underestimation of P_{a,O_2} by transcutaneous measurement. On the contrary, it was positive for P_{tc,CO_2} , and corresponded to an overall overestimation of P_{a,CO_2} . The results obtained with the two monitors did not differ significantly.

The overall relationship between the $\Delta(P_{tc,O_2/CO_2} - P_{a,O_2/CO_2})$ and $P_{a,O_2/CO_2}$ are plotted in figure 1 for oxygen and in figure 2 for carbon dioxide. In the case of oxygen, underestimation increased with P_{a,O_2} levels ($p < 0.01$), with a large scattering from -6.9 to +1.9 kPa (-52 to +14 mmHg) for R, and from -6.9 to +0.9 kPa (-52 to +7 mmHg) for K. For carbon dioxide, overestimation was slight during normocapnia ($P_{a,CO_2} < 5.9$ kPa (<44 mmHg)) with extreme values ranging -0.7–+2.0 kPa (-5–+15 mmHg) for R and -1.2–+1.5 kPa (-9–+11 mmHg) for K, but increased significantly ($p < 0.05$) in hypercapnia, reaching 2.7 kPa (20 mmHg) with both monitors when P_{a,CO_2} exceeded 6.7 kPa (50 mmHg). There was no significant difference between the two monitors. For each of the instruments, and both gases, the slopes of the individual least-square lines between the $\Delta(P_{tc,O_2/CO_2} - P_{a,O_2/CO_2})$ and $P_{a,O_2/CO_2}$ were similar for all subjects (covariance analysis), showing a systematic bias presumably due to the instrument.

Variability as a function of time

As confirmed by the variance analysis, the mean differences $\Delta(P_{tc,O_2/CO_2} - P_{a,O_2/CO_2})$ remained constant over the 5 h study period. The two monitors did not differ significantly.

Discussion

Several studies have compared transcutaneous tensions and arterial blood gas determinations for carbon dioxide alone [4–7], or associated with oxygen [8, 9] in children and in adults. The underestimation of P_{a,O_2} by the transcutaneous determination is attributed to oxygen consumption by superficial tissues and the overestimation of

Table 1. – Accuracy and precision of transcutaneous versus arterial blood gas determinations, for oxygen and carbon dioxide in 60 measurements: effects of the successive corrections of instrumental bias and between-subject variability

	$\Delta P_{tc,O_2} - P_{a,O_2}$		$\Delta P_{tc,CO_2} - P_{a,CO_2}$	
	R	K	R	K
Accuracy	-10.9	-15.1	8.1	7.1
Initial precision	14.4	13.1	7.8	5.6
Precision after correction of instrumental bias	8.8	8.0	5.8	4.6
Precision after suppression of between-subject variability	5.7	3.7	3.2	3.2

Results are expressed in mmHg. P_{tc,O_2} : transcutaneous oxygen tension; P_{a,O_2} : arterial oxygen tension; P_{tc,CO_2} : transcutaneous carbon dioxide tension; P_{a,CO_2} : arterial carbon dioxide tension; R: radiometer; K: kontron. 1 mmHg=0.133 kPa.

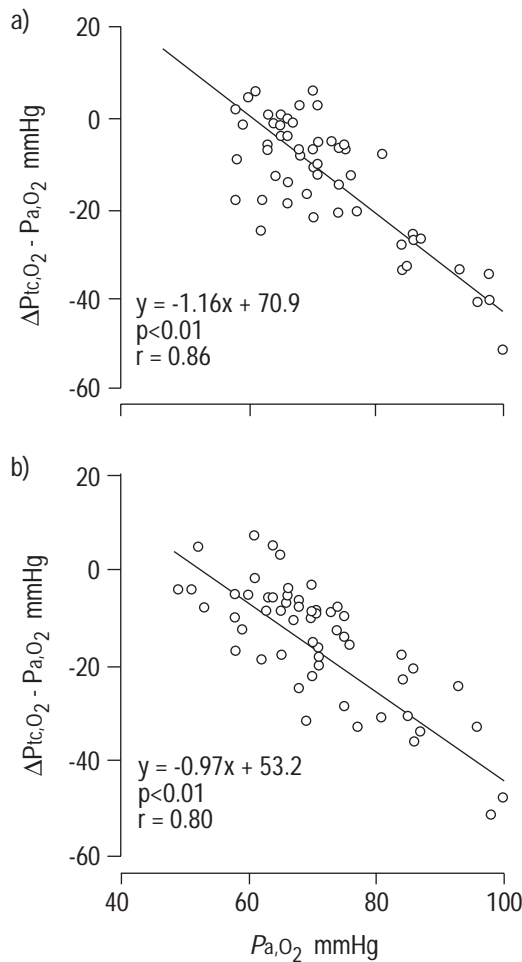


Fig. 1. – Differences between transcutaneous oxygen tension (P_{tc,O_2}) and arterial oxygen tension (P_{a,O_2}), ($\Delta P_{tc,O_2} - P_{a,O_2}$), related to P_{a,O_2} in 10 subjects (six measurements for each subject, *i.e.* a total of 60 measurements) for: a) Radiometer TINA TCM3; and b) Kontron Instruments MicroGas analyser. 1 mmHg=0.133 kPa.

P_{a,CO_2} to tissue metabolic production. Estimation of $P_{a,O_2}/CO_2$ by $P_{tc,O_2}/CO_2$ is better for carbon dioxide than for oxygen because of the better diffusion of the former [2]. In other studies, transcutaneous and arterial measurements were better correlated than those reported here [4–9]. These results could probably, at least partially, be explained by the younger age of their studied population (neonates and children [8]) and by the higher probe temperature (44 *versus* 43°C [4, 8, 9]). More recently, JANSSENS *et al.* [7], with a probe heated to 43.5°C, found, in adults, an accuracy of P_{tc,CO_2} of 0.1 kPa (0.75 mmHg) with a precision of 0.3 kPa (2.6 mmHg). The delay in which P_{tc,O_2} and P_{tc,CO_2} respond to actual arterial changes must also be taken into account [9]. However, in the current patients in steady conditions, the variations in blood gas levels were small and slow, and the delay probably only played a small role.

In the present study, the more P_{a,O_2} increased, the greater the magnitude of underestimation by P_{tc,O_2} . Consequently, an improvement in blood gases could potentially be overlooked. As previously reported [8], the mean value of $\Delta(P_{tc,O_2} - P_{a,O_2})$ clearly increased for P_{a,O_2} values >10.6 kPa (>80 mmHg). The increase in the over-

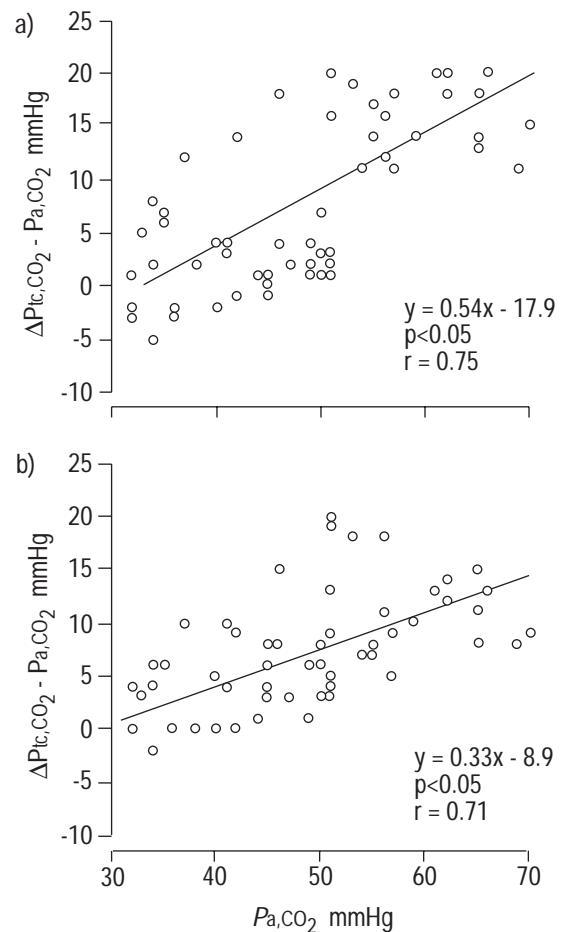


Fig. 2. – Differences between transcutaneous carbon dioxide tension (P_{tc,CO_2}) and arterial carbon dioxide tension (P_{a,CO_2}), ($\Delta P_{tc,CO_2} - P_{a,CO_2}$), related to P_{a,CO_2} in 10 subjects (six measurements for each subject, *i.e.* a total of 60 measurements) for: a) Radiometer TINA TCM3; and b) Kontron Instruments MicroGas analyser. (1 mmHg=0.133 kPa.)

estimation in P_{a,CO_2} by transcutaneous measurement when P_{a,CO_2} surpassed 6.7 kPa (50 mmHg) as found in this study was not observed by SANDERS *et al.* [6], but noticed by JANSSENS *et al.* [7]. This discrepancy can be explained by the difference in the range of observed PCO_2 .

In this study, arterial blood gas and transcutaneous blood gas measurements were repeated over 5 h. In accordance with JANSSENS *et al.* [7], this study found no evidence of an influence of time on the magnitude of the differences, in spite of the slight risk of electrode signal drift estimated at 0.13 kPa·h⁻¹ (1 mmHg·h⁻¹) by the manufacturer.

From these results, P_{a,O_2} and P_{a,CO_2} do not seem to be adequately reflected by transcutaneous tensions. However, the observed differences could presumably result from uncertainty owing to either instrumental or individual source linked to between-subject and within-subject variability. These two sources of error have to be eliminated in order to approach the real precision of blood gas estimation.

Instrumental source of uncertainty

The individual correlations between $\Delta(P_{tc,O_2}/CO_2 - P_{a,O_2}/CO_2)$ and $P_{a,O_2}/CO_2$ present a parallelism in their slope,

showing a systematic bias. Accuracy and precision of both monitors, for both gases, could be improved as shown in table 1, if the instrumental bias was rectified for the data by applying a corrective factor corresponding to the linear regression (figs. 1 and 2). Such a correction also improves the precision of P_{tc,O_2} and P_{tc,CO_2} by ~39 and 22%, respectively. Consequently, these results became closer to those reported elsewhere [4, 5, 7–9].

Individual scoring of uncertainty

Once instrumental bias calculated from all 60 measurements has been corrected for, the residual scattering of the data which affects precision is the result of both between-subject and within-subject variability. Assuming that the source of this between-subject dispersion remains stable in one given subject over the six measurements, it can be eliminated by expressing individual data as a change in $P_{tc,O_2/CO_2}$ from an individual baseline value instead of absolute values. So, each individual $P_{tc,O_2/CO_2}$ can be subtracted from the mean of the six measures. Such a correction of the between-subject variability results in an additional improvement in the precision of P_{tc,O_2} and P_{tc,CO_2} (table 1). This type of variability can be reduced by an individual *in vivo* calibration, but this needs an initial arterial blood gas sampling.

Finally, after correction, the residual within-subject dispersion represents the true precision of transcutaneous blood gas measurements which could be expected in a given patient (table 1). Its source remains uncertain. However, the residual lack of precision could be further optimized by repeated measurements, preferably under the same conditions, with calculation of a mean value.

In summary, the results obtained by both the Radiometer and Kontron monitors of comparable technology were similar and did not vary with time. The lack of accuracy appeared to be largely owing to instrumental bias which underestimated high oxygen tensions and overestimated high carbon dioxide tensions. This bias could benefit from an improvement in the software. Accuracy and precision could, therefore, be largely improved. Moreover, taking the between-subject variability into account allows a better estimation of the actual precision. The final precision is

compatible with the use of these monitors in the non-invasive monitoring of nocturnal assisted ventilation in severe chronic respiratory failure in adults.

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