ORIGINAL ARTICLES

Pulse Oximetry and Capnography in Lung Function Laboratories

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OBJECTIVE: To compare values reflecting oxyhemoglobin saturation obtained by pulse oximetry (SpO_2) and values for end-tidal carbon dioxide pressure ($PETCO_2$) obtained by capnography with direct measures of gas saturation values and pressures (PaO_2 and $PaCO_2$) in arterial blood gas samples.

PATIENTS AND METHODS: : We studied 57 consecutive patients ranging in age from 34 to 83 years—16 of whom were smokers—who presented for lung function testing.

RESULTS: The mean (SD) SpO_2 was 95% (2.4%), and oxygen saturation measured directly in arterial blood samples was 95.1% (2.3%) (*P*=NS). The mean $PETCO_2$ was 37.9 (5.3) mm Hg and $PaCO_2$ by arterial blood gas analysis was 40.6 (5.4) mm Hg (*P*<.0001). The correlation between the 2 measurements of oxygen saturation (SpO_2 and direct assessment) was 0.806 (*P*<.0001), and the correlation between $PETCO_2$ and $PaCO_2$ was 0.845 (*P*<.0001). The mean difference between the 2 expressions of oxygen saturation was 0.08% (1.46%) and between $PETCO_2$ and $PaCO_2$ was 2.7 (2.9) mm Hg.

CONCLUSION: Both measurement devices (pulse oximeter and capnograph) are appropriate for use in a lung function laboratory. The difference between $PETCO_2$ and the $PaCO_2$ should be kept in mind.

Key words: *Pulse oximetry. Capnography. Oxyhemoglobin. $PaCO_2$*

Determinación de la pulsioximetría y de la capnografía en el laboratorio de función pulmonar

OBJETIVO: Comparar los valores de oxihemoglobina, obtenidos mediante un pulsioxímetro, y de presión arterial de anhídrido carbónico ($PaCO_2$) al final de la espiración, medida con un capnógrafo, con los obtenidos a partir de una muestra de sangre arterial (oxihemoglobina y $PaCO_2$).

PACIENTES Y MÉTODOS: El estudio se realizó en 57 pacientes consecutivos —16 de ellos fumadores— que acudieron para un estudio de la función pulmonar, de entre 34 y 83 años años de edad.

RESULTADOS: El valor medio (± desviación estándar) de la oxihemoglobina por pulsioximetría fue del 95 ± 2,4% y en sangre arterial del 95,1 ± 2,3% (p = NS). El valor medio de la $PaCO_2$ al final de la espiración, medida por el capnógrafo, fue de 37,9 ± 5,3 mmHg y el de la $PaCO_2$ en sangre arterial de 40,6 ± 5,4 mmHg (p < 0,0001). El coeficiente de correlación entre las 2 determinaciones de oxihemoglobina fue de 0,806 (p < 0,0001) y entre la $PaCO_2$ al final de la espiración y la $PaCO_2$ en sangre arterial fue de 0,845 (p < 0,0001). La media de las diferencias entre ambos valores de oxihemoglobina fue del 0,08 ± 1,46%, y entre la $PaCO_2$ al final de la espiración y la $PaCO_2$ fue de 2,7 ± 2,9 mmHg.

CONCLUSIÓN: Ambos equipos de lectura (pulsioxímetro y capnógrafo) han demostrado ser correctos para su uso en el laboratorio de función pulmonar. Deben tenerse en cuenta las diferencias apreciadas entre la $PaCO_2$ al final de la espiración y la $PaCO_2$ arterial.

Palabras clave: *Pulsioxímetro. Capnógrafo. Oxihemoglobina. $PaCO_2$.*

Introduction

The efficacy of lung function is evaluated primarily by arterial blood gas analysis. If PaO_2 and $PaCO_2$ are within normal limits, then lung function is normal.[1] Many medical decisions, such as whether or not to administer supplementary oxygen in the hospital, prescribe home oxygen therapy, initiate noninvasive ventilation, or initiate mechanical ventilation or wean the patient from it, etc, are based on the interpretation of arterial blood gas values. Some of these decisions, which must be taken more and more often in recent years, have important personal, social, and economic repercussions. Technical innovations have made the equipment used for analyzing gases simpler and easier to handle.[2] It is in this context that we describe our experience with oxyhemoglobin assessment through pulse oximetry (SpO_2) and with the continuous, indirect estimation of $PaCO_2$ by way of end-tidal carbon dioxide pressure ($PETCO_2$) using capnography.

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Our objective was to test the accuracy of pulmonary gas exchange monitoring by SpO_2 and capnography in a normal clinical setting since these 2 techniques simplify the decision-making process regarding oxygenation and ventilation and circumvent unnecessary arterial blood sampling procedures.

Patients and Methods

Patients

We studied a group of 57 consecutive patients who were referred to our laboratory, owing to a variety of reasons, for lung function testing and arterial blood gas analysis. In all cases we documented anthropometric data, the reason for the visit, and factors that could possibly affect results of analyses (smoking, for example). Readings were performed simultaneously (SpO_2 and arterial puncture) and consecutively (capnography). All equipment had previously been tested and calibrated.

Pulse Oximetry

Oxyhemoglobin saturation was assessed by the Nanox 2 pulse oximeter (Medlab GmbH, Karlsruhe, Germany; Spanish representative, Sibelmed, Barcelona). The Nanox 2 device obtains SpO_2 values by traditional spectrophotometry. First we recorded the most widely-known sources of error—both those that result in inaccurate readings, such as weak pulse signals, painted nails, tattoos, etc, and those owing to the binding of hemoglobin to other elements (carboxyhemoglobin and methemoglobin). The readings were obtained by putting the sensor on the index finger of the patient's favored hand and waiting until pulse reached a regular rhythm; then the value that was most stable for a minimum of 30 seconds was noted. Patients were comfortably seated and breathing naturally at rest.

Capnography

$PETCO_2$, to reflect $PaCO_2$, was determined by the Cap 10 capnograph (Medlab GmbH, Karlsruhe, Germany; Spanish representative, Sibelmed, Barcelona), which measures end-tidal pressure by means of an infrared-absorbing sensor. Again, patients were comfortably seated and breathing naturally at rest. The most stable value was recorded after a minimum of 30 seconds of observation.

Arterial Blood Gas Sampling

Analysis of arterial blood gases was performed at the same time as pulse oximetry with a blood sample from the radial artery of the contralateral arm. We followed the standard procedure for our laboratory,[3] which includes use of a local anesthetic prior to puncture. Values were obtained using an analyzer (ABL 500: Radiometer, Bronshoj, Denmark) connected to a carbon monoxide meter (OSM-3: Radiometer). At least 2 readings were taken from each sample. If PaO_2 and $PaCO_2$ values differed no more than 1 mm Hg, the optimal values were taken for each (the higher one for PaO_2 and the lower one for $PaCO_2$). If the values differed by more than 1 mm Hg, a third reading was taken.

Statistical Analysis

Values were expressed as means (SD) and ranges. Procedures were compared using the Student *t* test for parametric data. We used the Pearson correlation test and the Bland-Altman plot to detect bias in the readings. A value of $P<.05$ was considered significant.

Results

The mean age of the patients studied was 67 (11) years. The 16 (28%) active smokers had a mean carboxyhemoglobin saturation of 2.9% (1.1%). The mean oxyhemoglobin saturation value for all blood samples of the population studied was 95.1% (2.3%) (range: 86.4% to 98.5%); and the value obtained by SpO_2 was 95.0% (2.4%) (range: 85% to 98%) (P=NS). The mean oxyhemoglobin saturation value for the 16 smokers was 94.9% (2.7%) (range: 87.6% to 98.5%); and the value obtained by SpO_2 was 95.5% (2.2%) (range: 91% to 98%) (P=.007).

The mean $PaCO_2$ was 40.6 (5.4) mm Hg (range: 31.8 mm Hg to 57.2 mm Hg); and $PETCO_2$ obtained by capnography was 37.9 (5.3) mm Hg (range: 27 mm Hg to 53 mm Hg) (P<.0001).

The coefficient of linear correlation between the 2 measurements of oxyhemoglobin saturation (by arterial blood gas analysis and SpO_2) for all patients studied was r=0.806 (P<.0001). The correlation coefficient between $PaCO_2$ and $PETCO_2$ was r=0.845 (P<.0001). See Figure 1 for the distribution of these variables.

Figure 2 shows a Bland-Altman plot of the variables. The mean difference between the 2 techniques for measuring oxyhemoglobin saturation was 0.08 (1.46%) (95% CI, –2.1% to 2.2%). The mean difference between $PaCO_2$ and $PETCO_2$ was 2.7 (2.9) mm Hg (95% CI, –2.1 mm Hg to 6.5 mm Hg).

The Table shows a matrix of statistically significant correlations between the variables studied. The difference in oxyhemoglobin saturation values between the 2 techniques was significantly related to age: r=0.335 (P=.02); to carboxyhemoglobin, r=–0.432 (P=.001); to $PETCO_2$, r=–0.273 (P=.04); and to SpO_2, r=–0.392 (P=.03). The difference between $PaCO_2$ and $PETCO_2$ was also significantly related to age: r=0.381 (P=.005); to pH, r=–0.283 (P=.03); to PaO_2, r=–0.416 (P=.001); to $PaCO_2$, r=0.320 (P=.02); to real oxyhemoglobin saturation, r=-0.337 (P=.01); and to oxyhemoglobin saturation assessed by SpO_2, r=–0.281 (P=.03).

Discussion

The findings of the present study indicate that oxyhemoglobin saturation estimated as SpO_2 by pulse oximetry adequately reflects arterial blood oxyhemoglobin saturation. $PETCO_2$ obtained by capnography enabled estimation of alveolar ventilation, with a bias in the same direction—since it indirectly reflects $PaCO_2$. However, the 2 devices for automatic

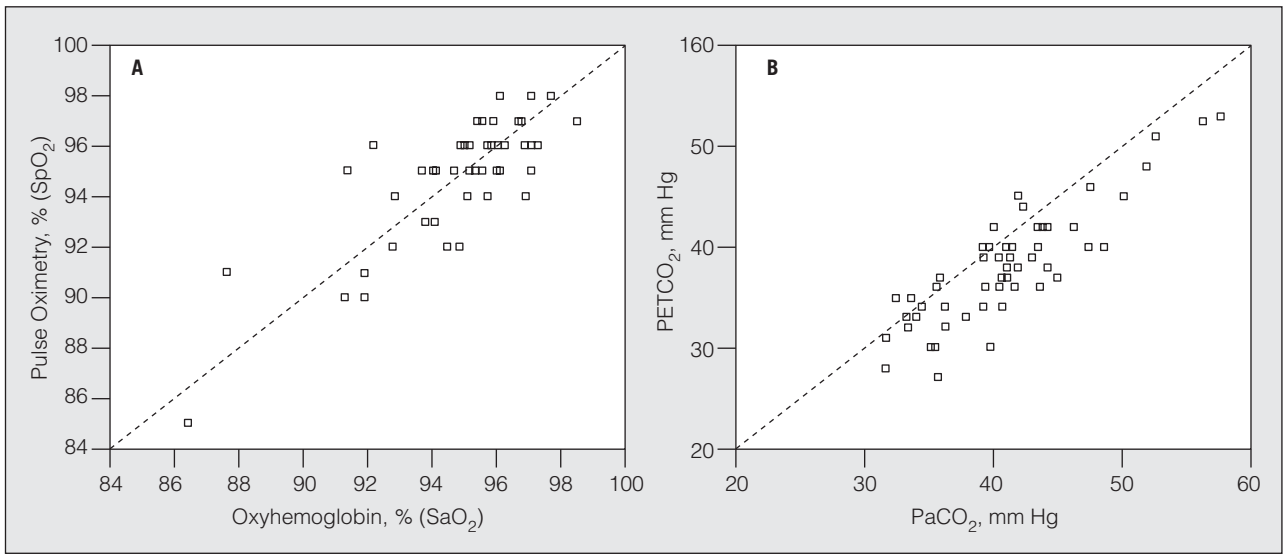

Figure 1. Linear correlation between oxyhemoglobin saturation (SaO_2) and pulse oximetry (SpO_2) (A), and between carbon dioxide pressure ($PaCO_2$) and end-tidal carbon dioxide pressure ($PETCO_2$) (B).

TABLE
Matrix of Correlations for the Variables Studied*

	PaO_2	$PaCO_2$	$PETCO_2$	SaO_2	SpO_2	Diff O_2	Diff CO_2
PaO_2		–0.605 0.000	–0.385 0.003	0.773 0	0.776 0		–0.416 0.001
$PaCO_2$			0.845 0	–0.431 0.001	–0.547 0		0.32 0.02
$PETCO_2$					–0.402 0.002	–0.273 0.04	
SaO_2					0.806 0		–0.337 0.01
SpO_2						–0.392 0.03	–0.281 0.03
Diff O_2							
Diff CO_2							

*$PETCO_2$ indicates end-tidal carbon dioxide pressure; SaO_2, oxyhemoglobin saturation obtained by arterial blood gas analysis; SpO_2, oxyhemoglobin saturation obtained by pulse oximetry; Diff O_2, the difference between the 2 oxyhemoglobin saturation values; Diff CO_2, the difference between $PaCO_2$ and $PETCO_2$.

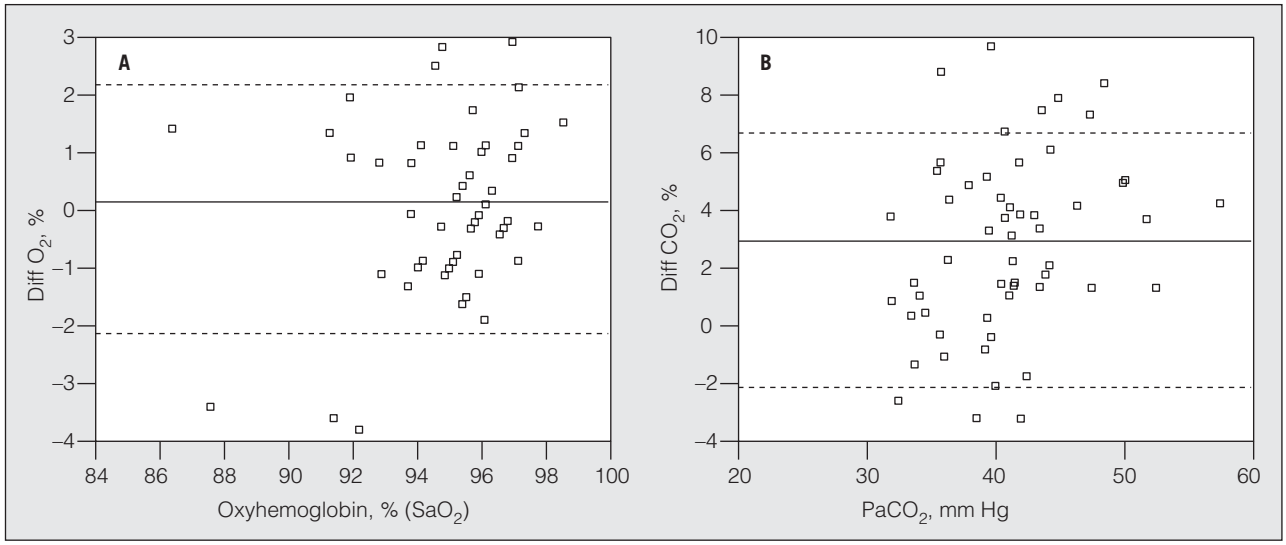

Figure 2. Agreement between oxyhemoglobin saturation measured by blood gas analysis and pulse oximetry (A) and between carbon dioxide pressure measured directly and end-tidal carbon dioxide pressure ($PETCO_2$) (B). Diff O_2 indicates the difference between oxyhemoglobin saturation values obtained by arterial blood gas sampling and those obtained by SpO_2; Diff CO_2, $PaCO_2$ – $PETCO_2$.

measurement have certain limitations and appropriate applications, which interpreters should be aware of and take into proper consideration.

The main limitation on the use of SpO_2 is erroneous interpretation owing to the hidden presence of high carboxyhemoglobin or methemoglobin values. Interpretation requires remembering that for smokers the carboxyhemoglobin concentration exceeds 1.6% and will be hidden in the SpO_2 reading given by the pulse oximeter. Methemoglobin concentration, which is less than 0.5% in healthy individuals, is also indistinguishable in pulse oximetric estimates of hemoglobin saturation. Observe that in our study there were no significant differences between the 2 oxyhemoglobin saturation values among the 57 patients overall. The differences were significant, on the other hand, for the subgroup of 16 smokers, although they were of little clinical relevance in our study given that smoking intensity was low and had little influence on carboxyhemoglobin. For all 57 patients, the mean methemoglobin value was 0.4% (0.2%) and in no case introduced a relevant artifact. Factors leading to faulty readings, mentioned above in the Patients and Methods section, were controlled for during the study and did not bias the results.

The pulse oximeter is now widely used in clinical practice, whether it be in lung function laboratories, operating rooms, emergency departments, hospital rooms, or, more recently, to study disordered breathing during sleep. The limitations of SpO_2 are widely known but deserve mention—especially the ones we have noted above relative to smoking and carboxyhemoglobin—since such limitations can lead to overestimations.[5]

The use of capnography in this study offers a novel way to estimate $PaCO_2$ noninvasively. Although a $PETCO_2$ value cannot replace a real $PaCO_2$ reading for making decisions that depend directly on this variable, capnography does give a good indication of the real state of alveolar ventilation. Bias in the reading is highly predictable, usually in the same direction, toward an underestimation of the real $PaCO_2$.

Recent innovations that enable physicians to use noninvasive ventilation and perform nighttime monitoring of patients with sleep apnea syndrome in conventional hospital rooms have led to the need for a way to assess alveolar ventilation periodically. The capnograph enables continuous monitoring of $PETCO_2$. Moreover, the device used in the present study was equipped with a memory that saved information for 24 hours. However, our study involved outpatients, the majority of whom differed clinically from patients admitted to hospital units and sleep laboratories, or those undergoing therapeutic ventilation. The usefulness of capnographs should also be evaluated in such settings.

The correlations found between the variables, although statistically significant, were of little clinical significance. At the same time, the information provided by the analyses of agreement, which was not reflected by the linear correlations, must be emphasized. Although both oxyhemoglobin saturation assessments and both CO_2 pressure determinations were closely related, it cannot be inferred that the 2 techniques in each case are completely congruent. If what is required is exact information on the state of gas exchange, traditional arterial blood gas sampling is still the preferred technique. If, however, the objective is to monitor oxyhemoglobin saturation or ventilation, pulse oximetry and capnography meet the requirements. Both the latter techniques provide relevant answers to clinical questions that we will always have to deal with.

REFERENCES

1. Cotes JE. Lung function. Assessment and application in medicine. 5th ed. Oxford: Blackwell Scientific Publications, 1993; p. 263-98.
2. Martin L. All you really need to know to interpret arterial blood gases? Philadelphia: Lea & Febiger, 1992.
3. Agustí AGN, Burgos F, Casan P, Perpiñá M, Rodríguez-Roisin R, Sánchez L, et al. Normativa de la gasometría arterial. Arch Bronconeumol 1998;34:142-53.
4. Altman DG. Practical statistics for medical research. London: Chapman & Hall, 1991.
5. Gómez J, Mota S, Casan P, Sanchis J. Pulse oximetry in smokers. Respir Med 1998;92:454-60.