A Comparison of Arterial Oxygen Saturation Measured Both by Pulse Oximeter and Arterial Blood Gas Analyzer in Hypoxemic and Non-hypoxemic Pulmonary Diseases

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Abstract

Background: The purpose of this study was to determine the correlation between SpO_2 and arterial O_2 saturation measured with blood gas analyzer (SaO_2) in hypoxemic and non-hypoxemic patients. Hypoxemia was considered as $SPO_2 < 90\%$. **Methods:** In this study, SpO_2 and SaO_2 were measured simultaneously. Mean±SD of SpO_2 and SaO_2 with coefficient of correlation, accuracy, sensitivity and specificity were measured and calculated. **Results:** This study included 152 patients. The accuracy of pulse oximetry was 90.8%, sensitivity was 93.3% and specificity was 89.1%. The hypoxemic and non-hypoxemic patients had good correlation between SpO_2 and SaO_2 (in hypoxemic group: r = 0.865, p<0.001; in non-hypoxemic group: r = 0.95, p<0.001). In 22 patients with $SpO_2 < 80\%$, the mean±SD of SpO_2 and SaO_2 were 70.63±9.13% and 74.40±10.24%, respectively (p=0.003); in 44 patients with $90\% > SpO_2 \geq 80\%$, the mean ±SD of SpO_2 and SaO_2 were 86.31±2.83% and 87.30±4.22% (p=0.105), respectively; and in 86 patients with $SpO_2 \geq 90\%$, the mean±SD of SpO_2 and SaO_2 were 94.37±2.18% and 94.17±3.71% (p=0.590), respectively. **Conclusions:** In pulmonary diseases with $SpO_2 \geq 80\%$, pulse oximetry has high accuracy in estimating SaO_2 and may be used instead of arterial blood gases (ABG). In patients with $SpO_2 < 80\%$, however, the exact estimation of SaO_2 and the evaluation of oxygenation by pulse oximeter is not a good substitution for ABG analyzer.

Keywords: pulse oximetry, arterial blood oxygen saturation, arterial blood gases, lung disease, hypoxemia

INTRODUCTION

Pulse oximetry is a useful tool for clinical and investigational purposes for indirect measurements of oxygen saturation [1-3]. Measurement of oxygen saturation with pulse oximetry (SpO_2) can be used for evaluation and control of hypoxemia in chronic obstructive pulmonary disease (COPD). As pulse oximetry is a non–invasive device, it can be used instead of arterial blood gases (ABG). Pulse oximetry is based on two physical principles. Firstly, the absorption of light at two different wave lengths (red = 660 mm and infra–red = 940 nm) is different in oxygenated and in deoxygenated hemoglobin. Secondly, the absorption of light at two different wave lengths has a pulsatile component, resulting from the changing volume of arterial blood with each pulse beat, and this can be distinguished from the non-pulsatile component due to venous, capillary, and tissue light absorption [4]. Some studies suggest that this method does not exactly reflect the values of ABGs [2,5,6].

The majority of patients with COPD during hospitalization are hypoxemic and have decreased arterial oxygen saturation. Many studies suggest that pulse oximeters are inaccurate at low saturations[7-11], because as SaO_2 decreases, bias will be increased, while precision (the standard deviation of the differences) will be decreased, with SpO_2 increasingly overestimating SaO_2.

In a recent meta–analysis of the measurement of SaO_2 by pulse oximetry, Jensen et al. concluded that, from the 74 studies, pulse oximeters were accurate within 2% in the range of 70-100% SaO_2 [12]. The performance of the Ohmeda pulse oximeter deteriorated below an SpO_2 of 75% [13]. In the study of Chiappini et al., a lack of accuracy of the pulse oximeter was found, but only for SaO_2 values <82% [14].

The aim of the current study was to evaluate the efficacy of pulse oximetry in hypoxemic patients with COPD. To achieve this goal, SpO_2 values measured by non–invasive technique such as pulse oximetry were compared with SaO_2 values measured by an invasive technique such as ABG. ABG analyzer was used as the reference method.

MATERIALS AND METHODS

The study was performed in the form of a cross–sectional survey on hospitalized patients with COPD in the Internal Medicine Department of Shahid Beheshti Hospital in Kashan during the winter of 2003. Diagnosis was confirmed by history, clinical examination, chest X–ray

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Table 1. Prevalence distribution of oxygen saturation measured by pulse oximetry (SpO_2) and ABG (SaO_2) in 152 COPD patients

SpO_2 \ SaO_2	Hypoxemic (%)	Non-hypoxemic (%)	Total
Hypoxemic	56 (36.8%)	10 (6.6%)	66 (43.4%)
Non-hypoxemic	4 (2.6%)	82 (54%)	86 (56.6%)
Total	60 (39.4%)	92 (60.6%)	152 (100%)

Table 2. Statistical indexes of oxygen saturation values measured by both SpO_2 and SaO_2 and statistical test results based on SpO_2 in COPD patients

Statistical indexes Groups	Method	Oxygen saturation (mean± SD)	p value
$SpO_2 < 80\%$ (n=22)	ABG	74.40±10.24	0.003
	Pulse oximetry	70.63±9.13	
$90\% > SpO_2 \geq 80\%$ (n=44)	ABG	87.30±4.22	0.105
	Pulse oximetry	86.31±2.83	
$SpO_2 \geq 90\%$ (n=86)	ABG	94.17±3.71	0.590
	Pulse oximetry	94.37±2.18	

ABG: Arterial blood gases.

findings and pulmonary function test according to the American Thoracic Society (ATS) criteria [15]. Arterial blood sample was obtained from the radial artery following confirmation of collateral vessel flow by Allen's test. Before taking the sample, the syringe lumen was heparinized (0.1 cc). Air bubbles, if present, were immediately expelled from the sample; the sample was sealed in an iced container and sent to laboratory for analysis using blood gases analyzer (AVL 995 Automatic Blood Gases, Graz, Austria). SpO_2 was obtained using a pulse oximeter (Nellcor – NBP 195). The finger probe for the unit was placed on the index finger of the opposite arm from which the arterial sample had been taken. In this study, ABG values were taken as reference values. According to SpO_2, the studied patients were divided into three groups: $SpO_2 < 80\%$, $90\% > SpO_2 \geq 80\%$ and $SpO_2 \geq 90\%$. Hypoxemia was considered as SpO_2 or $SaO_2 < 90\%$ in patients with COPD.

After collecting data, the mean±SD of SpO_2 and SaO_2 values were calculated. Arterial oxygen saturation values were compared using t – paired and Wilcoxon signed rank tests, and p values <0.05 were considered to be statistically significant. This comparison was made individually in hypoxemic and non–hypoxemic patients. Correlation coefficient, specificity and sensitivity of pulse oximetry (SpO_2) and ABG (SaO_2) were also calculated and compared, as well as the agreement rate between them.

RESULTS

One hundred and fifty-two patients with COPD were included in the study (97 male, 55 female). According to SpO_2 values, 66 (43%) were hypoxemic and 86 (57%) were non–hypoxemic. Based on ABG results, SaO_2 values were less than 90% in 60 (39%) patients, and the values were equal or more than 90% in 92 (61%). The mean±SD oxygen saturation values (SaO_2) measured by ABG analyzer system were greater than those measured by pulse oximetry (SpO_2): (SaO_2=89.14±8.60%, SpO_2=88.39±9.13%; correlation coefficient = 0.935, p<0.05).

In 66 patients who were hypoxemic ($SpO_2 < 90\%$), the mean±SD SaO_2 and SpO_2 were: 82.82±9.04% and 80.86±9.22%, respectively; r=0.865, p<0.05 (Figure 1). In 22 of the hypoxemic patients, the mean±SD of SaO_2 and SpO_2 were: 74.40±10.24% and 70.63±9.13%, respectively; r=0.856, p<0.05 (Figure 2).

As patients were defined non–hypoxemic based on SpO_2 values, the mean±SD of SpO_2 and SaO_2 were 94.37±2.18%, 94.17±3.71%, respectively; there was high correlation coefficient between these groups, r=0.95, p<0.001 (Figure 3).

Table 1 shows the prevalence distribution of oxygen saturation values measured by pulse oximetry (SpO_2) and ABG (SaO_2) in COPD patients. The agreement rate of SpO_2 and SaO_2 was 90.8%, and sensitivity and specificity of pulse oximetry were 93.3% and 89.1%, respectively.

Table 2 shows statistical indexes of oxygen saturation values measured by either SpO_2 or SaO_2, and statistical test results individually based on SpO_2.

There were significant differences between pulse oximetry results (SpO_2) and ABG values (SaO_2) in the limit of $SpO_2 < 80\%$ (p=0.003), while there was no significant difference between the two methods in the limit of $SpO_2 \geq 80\%$ (p=0.105) and $SpO_2 \geq 90\%$ (p=0.590).

DISCUSSION

Our results show that there is a significant difference in oxygen saturation measurement when using pulse oximetry and ABG in patients with SpO_2 less than 80%. In these conditions, pulse oximetry is not a reliable device for monitoring oxygenation status in COPD patients (p=0.003). However, no significant differences were found between the two methods in those with $90\% > SpO_2 \geq 80\%$ (p=0.105), and also for groups with $SpO_2 \geq 90\%$ (p=0.590).
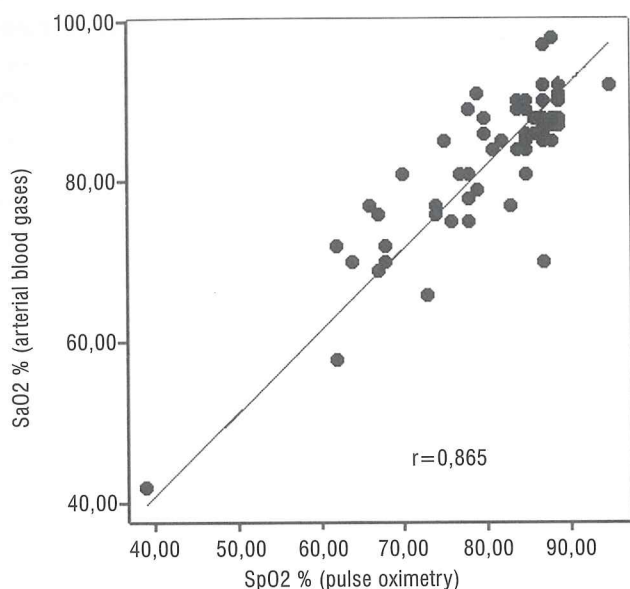
Figure 1. Oxygen saturation measured with ABG analyzer (SaO$_2$) against that measured with pulse oximeter (SpO$_2$) in hypoxemic patients. r: Correlation coefficient.

Figure 2. Oxygen saturation measured with ABG analyzer (SaO$_2$) against that measured with pulse oximeter (SpO$_2$) in hypoxemic patients with SpO$_2$ <80%. r: Correlation coefficient.

When considered in all 152 patients, pulse oximetry showed oxygen saturation value as 0.75% less than ABG (88.39±9.13 vs. 89.14±8.60%). It has practical use in patients for improving the oxygenation status.

In the present study, inaccurate readings of pulse oximetry in SpO$_2$<80%, 90%>SpO$_2$≥80% and SpO$_2$≥90% were 3.76, 0.98 and 0.2%, respectively, indicating that the greater the hypoxemic status, the higher the rate of disturbances which may occur in accuracy between SpO$_2$ and SaO$_2$ measurements. In study of Carter et al., the performance of pulse oximetry deteriorated below an SpO$_2$ of 75% [13]. Webb et al. reported that pulse oximetry is poorly calibrated at low saturations and generally less accurate and less precise than at normal saturations [16]. In study of Webb et al., nearly 30% of values reviewed were erroneous by more than 5% at saturation of less than 80% [16].

Regarding the comparison between oxygen saturation measured by pulse oximetry and ABG, many studies have been conducted related to accuracy. In the study of Chiappini et al., a significant difference was found between SpO$_2$ and SaO$_2$ values [14]. SpO$_2$ values were lower than SaO$_2$ (90.58±5.45% vs. 92.14±5.79%). Similar to our study, a lack of accuracy of the pulse oximeter was found, but only for SpO$_2$ values below 82%.

Many studies have been conducted regarding the accuracy of oxygen saturation values measured by the different pulse oximeters now available [17-19]. There was no agreement between the two methods using statistical t – test and simple regression analysis.
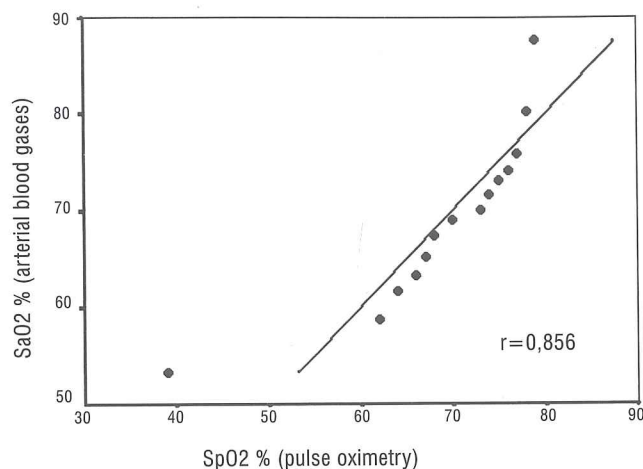
In a study of Hannhart et al., the accuracy of six types of pulse oximeters was compared with SaO$_2$ in hypoxemic patients with COPD. The bias (mean SpO$_2$ – SaO$_2$ difference) and the error in precision (SD of the differences) were both below 4% for two kinds of instruments and remained below 1.2 and 3 for the others [20].

In patients with abnormal cardiac index, the pulse oximeter measurements exceeded the actual oxygen saturation (SaO$_2$) by up to 7% [21]. In a study performed by Carone et al. during exercise in COPD patients, SpO$_2$ was significantly lower than SaO$_2$ by 0.7% on average (90.1±5% vs 90.7±4.7%) [22].

They concluded that noninvasive measurement of oxygen saturation is not adequate for estimating arterial saturation in COPD [22]. They suggested that a new cut–off limit of 93% SpO$_2$ should be used as the value above which it should be possible to consider the exercise–induced desaturation to be corrected and, consequently, to properly prescribe oxygen during daily life activities. The observed differences between our results with those of Carone et al. are perhaps due to the type of instrument and methods used in their study; they used ear probe instead of finger probe, as in our study [22]. In a study carried out in a group of patients with cyanotic congenital heart disease, the bias (SpO$_2$-SaO$_2$) was 1.7±6.9% (mean±SD) [23]. In that study, SpO$_2$ values were significantly higher than SaO$_2$, whereas in the present study SpO$_2$ values were less than SaO$_2$.

A number of factors affect the accuracy of pulse oximetry in the emergency department. Lee et al. reported in patients with carboxyhemoglobin (COHb) ≥2%, SpO$_2$ overestimated SaO$_2$ by more than 4% in 35% of cases, but in patients with COHb <2%, SpO$_2$ overestimated SaO$_2$ by
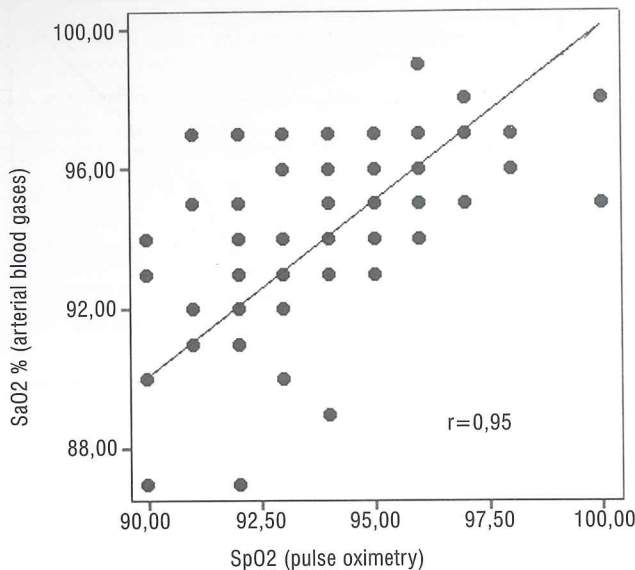
Figure 3. Oxygen saturation measured with ABG analyzer (SaO_2) against that measured with pulse oximeter (SpO_2) in non-hypoxemic patients. r: Correlation coefficient.

more than 4% in 8.4% of cases [24]. In another study, Kelly et al. reported that there is not sufficient agreement for oxygen saturation measured by pulse oximetry to replace analysis of an ABG sample in the clinical evaluation of oxygenation in emergency patients with COPD. However, oxygen saturation by pulse oximetry may be an effective screening test for systemic hypoxia, with the screening cut-off of 92% having sensitivity for the detection of systemic hypoxia of 100% with specificity of 86% [25].

A number of explanations have been proposed for the limited performance of pulse oximeters at low saturations. One is the slight variations in the output wavelength of the light emitting diodes which generate proportionally larger errors at low saturations [26,27]. Another is the generation of proportionally larger errors in the measurement of transmitted red light versus of infra-red light at low saturations because of the large extinction coefficient of reduced hemoglobin [28].

In the current study where oxygenation status was more than 90%, there was high correlation coefficient between the two methods of measurements (in non–hypoxemic groups, correlation coefficient was 0.95).

The study revealed that only four patients (2.6%) out of all who were considered non-hypoxemic according to pulse oximetry were considered hypoxemic in terms of ABG values. The obtained agreement rate was 90.8%. Given the critical point of $SpO_2 \geq 90\%$, about 90.8% of cases had correlation in this regard. Thus, although patients were considered as hypoxemic or non–hypoxemic according to pulse oximetry or ABG results, because of slight changes among the results

of the two methods, and also a wide variety of cases, there were significance differences observed in $t - test$, while correlation coefficient tests showed correlation between the two methods. This indicates a close relationship between them.

We conclude that considering the agreement rate between pulse oximetry and ABG of 90.8% and the errors of pulse oximetry versus ABG of 0.74, and given the correlation coefficient between the two methods (0.935), pulse oximetry is an available and non-invasive method that can be considered an appropriate substitute for ABG, especially in $SpO_2 \geq 80\%$. In conditions with low oxygen saturation ($SpO_2 < 80\%$) and in critical status, SpO_2 is not sufficiently accurate to replace PaO_2 and SaO_2 measured by arterial blood gases analyzer.

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