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

Ebrahim Razi, Hossein Akbari

Department of Internal Medicine, Kashan University of Medical Sciences, Kashan, Iran

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 (SpO₂) 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 SaO₂ decreases, bias will be increased, while precision (the standard deviation of the differences) will be decreased, with SpO₂ increasingly overestimating SaO₂.

In a recent meta-analysis of the measurement of SaO₂ by pulse oximetry, Jensen et al. concluded that, from the 74 studies, pulse oximeters were accurate within 2% in the range of 70-100% SaO₂ [12]. The performance of the Ohmeda pulse oximeter deteriorated below an SpO₂ of 75% [13]. In the study of Chiappini et al., a lack of accuracy of the pulse oximeter was found, but only for SaO₂ 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, SpO₂ values measured by non-invasive technique such as pulse oximetry were compared with SaO₂ 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.
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). SpO2 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 SpO2, the studied patients were divided into three groups: SpO2 <80%, 90%>SpO2≥80% and SpO2 ≥ 90%. Hypoxemia was considered as SpO2 or SaO2 <90% in patients with COPD.

After collecting data, the mean±SD of SpO2 and SaO2 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 hypoxic and non–hypoxic patients. Correlation coefficient, specificity and sensitivity of pulse oximetry (SpO2) and ABG (SaO2) 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 SpO2 values, 66 (43%) were hypoxic and 86 (57%) were non–hypoxic. Based on ABG results, SaO2 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 (SaO2) measured by ABG analyzer system were greater than those measured by pulse oximetry (SpO2): (SaO2=89.14±8.60%, SpO2=88.39±9.13%; correlation coefficient = 0.935, p<0.05).

In 66 patients who were hypoxic (SpO2<90%), the mean±SD SaO2 and SpO2 were: 82.82±9.04% and 80.86±9.22%, respectively; r=0.865, p<0.05 (Figure 1). In 22 of the hypoxic patients, the mean±SD of SaO2 and SpO2 were: 74.40±10.24% and 70.63±9.13%, respectively; r=0.856, p<0.05 (Figure 2).

As patients were defined non–hypoxic based on SpO2 values, the mean±SD of SpO2 and SaO2 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. Prevalence distribution of oxygen saturation measured by pulse oximetry (SpO2) and ABG (SaO2) in 152 COPD patients

<table>
<thead>
<tr>
<th>SpO2</th>
<th>Hypoxemic (%)</th>
<th>Non-hypoxemic (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypoxemic</td>
<td>56 (36.8%)</td>
<td>10 (6.6%)</td>
<td>66 (43.4%)</td>
</tr>
<tr>
<td>Non-hypoxemic</td>
<td>4 (2.6%)</td>
<td>82 (54%)</td>
<td>86 (56.6%)</td>
</tr>
<tr>
<td>Total</td>
<td>60 (39.4%)</td>
<td>92 (60.6%)</td>
<td>152 (100%)</td>
</tr>
</tbody>
</table>

Table 2. Statistical indexes of oxygen saturation values measured by both SpO2 and SaO2 and statistical test results based on SpO2 in COPD patients

<table>
<thead>
<tr>
<th>Groups</th>
<th>Method</th>
<th>Oxygen saturation (mean± SD)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SpO2&lt;80% (n=22)</td>
<td>ABG</td>
<td>74.40±10.24</td>
<td>0.003</td>
</tr>
<tr>
<td>SpO2≥80% (n=44)</td>
<td>Pulse oximetry</td>
<td>70.63±9.13</td>
<td>0.105</td>
</tr>
<tr>
<td>SpO2≥90% (n=86)</td>
<td>ABG</td>
<td>94.37±2.18</td>
<td>0.590</td>
</tr>
</tbody>
</table>

DISCUSSION

Our results show that there is a significant difference in oxygen saturation measurement when using pulse oximetry and ABG in patients with SpO2 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 the limit of SpO2≥80% (p=0.105) and SpO2≥90% (p=0.590).
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 SpO₂ <80%, 90% >SpO₂ ≥80% and SpO₂ ≥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 SpO₂ and SaO₂ measurements. In study of Carter et al., the performance of pulse oximeter deteriorated below an SpO₂ 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 Chiapipini et al., a significant difference was found between SpO₂ and SaO₂ values [14]. SpO₂ values were lower than SaO₂ (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 SpO₂ 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 SaO₂ in hypoxemic patients with COPD. The bias (mean SpO₂ – SaO₂ 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 (SaO₂) by up to 7% [21]. In a study performed by Carone et al. during exercise in COPD patients, SpO₂ was significantly lower than SaO₂ 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% SpO₂ 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 (SpO₂ - SaO₂) was 1.7±6.9% (mean±SD) [23]. In that study, SpO₂ values were significantly higher than SaO₂, whereas in the present study SpO₂ values were less than SaO₂.

A number of factors affect the accuracy of pulse oximetry in the emergency department. Lee et al. reported in patients with carboxyhemoglobin (COHb) ≥2%, SpO₂ overestimated SaO₂ by more than 4% in 35% of cases, but in patients with COHb <2%, SpO₂ overestimated SaO₂ by
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 cutoff 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 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 SpO2>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 r – 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 SpO2≥80%. In conditions with low oxygen saturation (SpO2<80%) and in critical status, SpO2 is not sufficiently accurate to replace PaO2 and SaO2 measured by arterial blood gases analyzer.

REFERENCES