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An observational study of simultaneous pulse oximetry and arterial oxygen saturation readings in intensive care unit/high dependency unit in COVID-19 patients

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ABSTRACT

Background: The coronavirus-2019 (COVID-19) pandemic has increased the use of pulse oximeters worldwide. It has become an inevitable tool in the monitoring of the disease. However, the accuracy of pulse oximeters in COVID-19 has not been established. **Aims and Objectives:** The aims of the study were to examine the relationship between oxygen saturation as measured by pulse oximeter (SpO_2) and oxygen saturation measured by arterial blood gas analysis (SaO_2) measurements in COVID-19 patients admitted to the intensive care unit (ICU)/high dependency unit (HDU) and to assess the ability of SpO_2 readings to detect low SaO_2 and low oxygen tension in COVID-19 patients. **Materials and Methods:** This prospective observational study was conducted in the COVID-19 ICU and high dependency unit of a tertiary care hospital in Bengaluru, India. All patients admitted with confirmed COVID-19, meeting the eligibility criteria, were included in the study. We assessed bias and limits of agreement between paired samples of oxygen saturation from pulse oximetry (SpO_2) and arterial oxygen saturation from blood gas analysis (SaO_2). **Results:** The sample mean difference SpO_2-SaO_2 is −0.86% (bias) and the 95% confidence interval for the mean difference was −1.67 and −0.04. The lower limit of agreement was −7.32 with a 95% confidence interval (−8.74, −5.91). The upper limit of agreement was 5.61 with a 95% confidence interval of 4.19 and 7.02. **Conclusion:** SpO_2 values are not completely dependable in estimating SaO_2 in COVID-19 patients in ICU/HDU; therefore, arterial blood gas analysis measurement of oxygen saturation has to be done depending on the clinical scenario CTRI (CTRI/2020/11/029035).

Key words: COVID-19; Oxygen saturation from ABG; SpO_2

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INTRODUCTION

The ongoing coronavirus pandemic has caused pain and suffering all across the globe. Although huge leaps have been made in the fields of medicine in the past century, the pandemic has proven to be a great challenge to humankind. The understanding of the virus and its mechanism is not complete and still eludes scientists. The world is struggling and to date, no drugs have been proven to be curative and no vaccine has been found to have 100% efficacy.

Pulse oximeters are used widely across the globe to monitor patients and to guide people when to seek medical help when they are in home isolation. They are widely used in various clinical settings for decision-making regarding the severity of the disease and titration of oxygen therapy as it is a simple and non-invasive method compared to arterial blood gas analysis which is invasive and requires trained staff and equipment and can be done only in a clinical setting. Pulse oximeter can be a standalone device or it can be part of multiparameter monitors. Oxyhemoglobin absorbs more light in infrared band and deoxyhemoglobin

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in red band. Pulse oximeter works by estimating oxygen saturation from pulse oximetry (SpO_2) from this differential absorption of red (660 nm) and infrared (940 nm) light.[1]

Some coronavirus-2019 (COVID-19)-positive patients have profound hypoxemia, but respiratory distress shown by them may not correspond to their oxygen levels, that is, they might not be exhibiting signs of distress as expected.[2] This peculiar feature of COVID-19 patients can make timely referral to the intensive care units (ICUs) difficult. Knowing the relationship between SpO_2, arterial oxygen saturation from blood gas analysis (SaO_2), and arterial oxygen tension (PaO_2) will greatly help in timely oxygen therapy for COVID-19 patients.

Hence, we conducted this observational study in COVID-19-positive patients admitted to intensive care and high dependency units (HDUs) due to COVID-related complications. Ebmeier et al.,[3] have shown that there could be clinically important difference in agreement between SpO_2 and SaO_2 readings in non-COVID patients in ICU. Some studies have shown that SpO_2 can be approximated to the blood oxygen saturation levels obtained from arterial blood gas analysis but few other studies have shown to have results that are contradictory.[4-6] Philip et al., in their study, noted that the agreement between SpO_2 and SaO_2 was limited to a small degree in COVID-19 patients.[7]

Aims and objectives

The aims of our study were to examine the relationship between oxygen saturation as measured by pulse oximeter (SpO_2) and oxygen saturation measured by arterial blood gas analysis (SaO_2) measurements in COVID-19 patients admitted to ICU/HDU and to assess the ability of SpO_2 readings to detect low SaO_2 and low oxygen tension (PaO_2) in COVID-19 patients.

MATERIALS AND METHODS

This is a single-center prospective observational cross-sectional study in the ICU and HDU of a tertiary care hospital during the COVID-19 pandemic from November 2020 to February 2021. Our hospital was a major hospital dedicated to COVID patients during the first wave of the pandemic in India. The Institutional Ethics Committee approval was obtained and study registered in CTRI (CTRI/2020/11/029035).

Criteria for admission of reverse transcription-polymerase chain reaction confirmed COVID-19-positive patients to the ICU included: Saturation <90% in room air, adult respiratory distress syndrome, sepsis, or comorbid conditions with concern for clinical deterioration. Admission to HDU: Saturation <94% in room air (90–94%), respiratory rate more than 24/min, tachycardia more than 120/min, or any abnormal laboratory values.

Inclusion criteria

COVID-19-positive patients of age more than or equal to 18 years and ≤80 years admitted to ICU/HDU.

Exclusion criteria

Patients aged <18 years and >80 years, diagnosis of methemoglobinemia, smokers, and patients with nail polish were excluded from the study.

Informed consent was obtained for including patient's data in the study. Demographic data and comorbid conditions of all patients were noted. All patients admitted to the units were given routine monitoring of vitals and arterial blood gas sampling was done when clinically indicated as part of routine clinical management of COVID-19 and any associated disease. No investigations were done solely for the purpose of the study. Paired recording of SpO_2 and SaO_2 was done simultaneously.[3] The SpO_2 value on the monitor at the time when the blood was seen to enter the ABG collection syringe was noted for simultaneous reading and the sample was immediately analyzed using ABL80 FLEX blood gas analyzer, after removing air bubbles. The blood gas analyzer was properly calibrated. The SpO_2 recordings were done using Skanray Star 65 monitor with Nellcor Nell 1 SpO_2 monitor and Mindray Mec 2000 monitor with adult SpO_2 sensor probes. The monitors were calibrated by the biomedical department of our institution. All SpO_2 values were taken using finger probes. Finger probe was placed in the opposite hand as that of arterial blood gas sampling. The measurements were taken 3–4 h after admission to the unit. Local factors influencing pulse oximeter readings and use of vasoactive drugs were noted. Acute Physiology and Chronic Health Evaluation II score[8] was calculated within the first 24 h of admission to the unit. Type of oxygen therapy for COVID-19 respiratory failure was noted along with FiO_2 at the time of sampling.

Statistical analysis

All data collected were entered into Microsoft Office Excel worksheet. Quantitative data were expressed as mean and standard deviation. Qualitative data were expressed as proportions. Bland–Altman method[9] was used for assessing agreement between SaO_2 and SpO_2. Statistical program R was used for the statistical analysis.

RESULTS

Sixty-five paired measurements were taken from 65 patients admitted to the ICU and HDU. Thirty-nine patients were from ICU and rest from HDU. Table 1 shows the characteristics of patients. Comorbid conditions such as

cardiovascular disease and diabetes mellitus were noted but not used for further analysis. Modes of oxygen therapy used for COVID-19 pneumonia were included in the study. Table 1 shows patient characteristics.Table 2 shows the values obtained from arterial blood gas analysis and oxygen saturation from pulse oximeter.

Table 1: Characteristics of patients

Age (years), mean (SD)	57.72 (15.20)
Sex, *n* (%)	Female 19 (29.23%)
APACHE Ⅱ score, mean (SD)	12.35 (5.35)
Vasopressors/Inotropes, *n* (%)	7 (10.7%)
Comorbid conditions, *n* (%)	
Cardiovascular disease	14 (21.5%)
Diabetes mellitus	10 (15.4%)
Chronic kidney disease	3 (4.6%)
Modes of oxygen therapy, *n* (%)	
NIV*	21 (32.31%)
Intubated	3 (4.62%)
NRBM+	33 (50.77%)
HFNO++	2 (3.08%)
Face mask	6 (9.23%)

*NIV: Non-invasive ventilation, +NRBM: Non-rebreather mask, ++HFNO: High-flow nasal oxygen, APACHE: Acute Physiology and Chronic Health Evaluation, SD: Standard deviation

Table 2: Arterial blood gas analysis and pulse oximeter values

SaO_2, mean (SD)	96.38 (3.39)
PaO_2, mean (SD)	106.8 (38.94)
pH, mean (SD)	7.43 (0.07)
SpO_2, mean (SD)	95.52 (3.56)

SD: Standard deviation, SaO_2: Arterial oxygen saturation, PaO_2: Arterial oxygen tension

Relation between SpO_2 and SaO_2

The purple segment gives the 95% confidence interval for the bias with the middle dashed line being the mean bias, the pink segment gives 95% confidence interval for the lower limit of agreement, and green segment gives the 95% confidence interval for the upper limit of agreement.

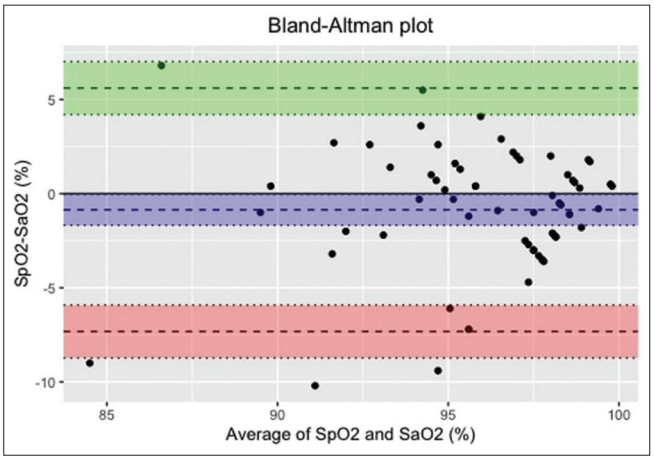

Figure 1: Bland–Altman plot

Figure 1 shows the Bland–Altman plot for graphical representation of the relationship between SpO_2 and SaO_2. Bias and limits of agreement were calculated. The sample mean difference SpO_2-SaO_2 was 0.86% (bias) and the 95% confidence interval for the mean difference is −1.67 and −0.04. This indicates that the mean of SpO_2 is less than the mean of SaO_2 for all COVID-19 patients in the world. The lower limit of agreement was −7.32 with a 95% confidence interval (−8.74, −5.91). The upper limit of agreement was 5.61 with a 95% confidence interval of 4.19 and 7.02.

We built a linear model to measure the relationship between SpO_2-SaO_2 and mean arterial pressure (MAP) at the time of sampling. The estimated coefficient of MAP was 0.044 with a P=0.246. The R^2 coefficient was only 0.021 which indicated that MAP has no significant association between the differences SpO_2 and SaO_2. We next tested the relationship with hematocrit values which also showed no significant association, estimate was 0.02, and P=0.808 and R^2 was 0.00095.

Ability of pulse oximeter to detect hypoxemia-SpO_2 ≤92% had a specificity 87% and sensitivity 100% to detect SaO_2 of 90% or less. The specificity was 84% and sensitivity was 50% for SpO_2 ≤92% to detect PaO_2 ≤60 mmHg. SpO_2 ≤90% showed specificity 95% and sensitivity 75% to detect a SaO_2 of 90% or less. SpO_2 ≤90% had a specificity 93% and sensitivity 50% to detect PaO_2 ≤60 mmHg.

DISCUSSION

Pulse oximeters are being widely used during the pandemic but evidence regarding the precision of pulse oximeter in COVID-19 patients is limited. There are not many studies addressing the same. Our findings from these 65 COVID-19-positive patients admitted to ICU and HDU show that the limits of agreement are suboptimal than other studies although the bias is −0.86%. The negative bias shows that SpO_2 underestimates SaO_2. Thirty-six out of 65 patients had their SpO_2 values <SaO_2 and six patients showed more than 5% difference between SpO_2 and SaO_2 in our study. Some studies have shown that SpO_2 overestimates SaO_2 while some have shown opposite results. Philip et al.,[7] in their study on 30 patients recovering from severe COVID-19 infection, noted suboptimal levels of agreement between SpO_2 and SaO_2 and a bias of 0.4%. Van de Louw et al.,[10] have shown that SpO_2 underestimates SaO_2 at low oxygen saturation in non-COVID patients. They also noted a great difference between SpO_2 and SaO_2 in a study on 102 non-COVID patients in ICU. Seguin et al.,[11] in their study in non-COVID patients, noted that SpO_2 overestimated SaO_2 and the limits of agreements were also large.

Wilson–Baig et al.,[12] noted that SpO_2 underestimated arterial blood gas saturation measurements in COVID-19 patients (n=17), the probable reasons cited for this being tissue hypoxia, different spectral properties of d-dimer and ferritin, formation of complexes between the coronavirus and hemoglobin and proposed that the situation of "happy hypoxemia" noted in COVID-19 patients might be due to these reasons. The limits of agreement values of our study indicate that caution should be advised when oxygen therapy is titrated solely based on SpO_2 measurements.

The pulse oximeter value of 90% or less had poor sensitivity in detecting low PaO_2 (≤60 mmHg) and SaO_2 of 90% or less in our study. This shows poor diagnostic accuracy of SpO_2 readings in estimating hypoxemia. Sensitivity of SpO_2 <90% to detect a PaO_2 of <60 mmHg in non-COVID patients was much higher in some studies but low sensitivity has been shown in others. Pilcher *et al.,*[13] showed a sensitivity of 88.6% and specificity 95.1% for SpO_2 < 90% to detect SaO_2 <90% and a sensitivity of 70.5% and specificity of 98.2% to detect PaO_2 <60 mmHg in their study on non-COVID patients.

Our study has various strengths. Single paired measurement was taken from each patient. The measurements were taken simultaneously; the arterial blood gas analysis was done immediately, so there was almost no time lag between both measurements. As the measurements were taken simultaneously, fluctuations in oxygen levels[14] which could have happened over time were negated. This was useful in improving the validity and removing any bias from collecting data from the same patient by repeated measurements.[13]

Ethnicity and skin color[15,16] could affect the agreement between SpO_2 and SaO_2 but all our patients were of same South Indian ethnicity. SpO_2 can overestimate SaO_2, especially when saturation is low in individuals who are dark skinned.[17]

We excluded smokers, people with methemoglobinemia, and patients with nail polish from our study thereby avoiding some factors which could potentially affect the pulse oximeter accuracy as seen in the previous studies.[13,18,19] Other local factors which could affect SpO_2 measurements such as poor signal and motion artifacts were not observed in any patient during measurement.

These findings are from a single hospital in a single geographical area. More extensive studies with higher sample size, different clinical situations, and with different models of pulse oximeters have to be done to extrapolate the findings to other COVID-19-positive patients during the pandemic. Different models and low-quality finger pulse oximeter probes are widely available in the market and are being used extensively as many hospitals are stretched beyond their admission capacities.

Limitations of the study

There are some limitations for the study that has to be considered. Original planned sample size using Yamane equation[20] was 100, considering 135 COVID-19 admissions as population size and degree of error 0.05. However, the admissions of COVID-19-positive patients decreased during the study time as the first wave of the pandemic had already peaked; we were able to get data of 65 eligible patients during the study period.

Values such as ferritin and d-dimers which could have different spectral properties[21] at 660 and 940 nanometers as suggested by Wilson–Baig et al.,[12] were not considered in this study. Studying these values in COVID-19 patients will aid in understanding the relation with SpO_2 better, if any exists.

CONCLUSION

Oxygen therapy and titration are mostly guided by pulse oximeter in almost all COVID treatment centers as it is non-invasive and simple method and offers continuous monitoring. However, our study shows that SpO_2 values are not completely dependable in estimating SaO_2 in COVID-19 patients in ICU/HDU due to suboptimal limits of agreement. Arterial blood gas measurements have to be obtained depending on the clinical scenario of the patient.

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NR- Conception, acquisition, analysis, interpretation of data, drafting, approval of final version, and agrees to be accountable for all aspects of work; **RBS-** Acquisition, drafting, approval of final version, and agrees to be accountable for all aspects of work; **KGS-** Analysis, revising critically, approval of final version, and agrees to be accountable for all aspects of work; **SMJ-** Acquisition, interpretation of data, drafting, approval of final version, and agrees to be accountable for all aspects of work; and **SR-** Interpretation of data, revising critically, approval of final version, and agrees to be accountable for all aspects of work

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