ORIGINAL ARTICLE

# Association between $SpO_2/FiO_2$ Ratio and $PaO_2/FiO_2$ Ratio in Different Modes of Oxygen Supplementation

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## Abstract

**Background:** Acute hypoxemic respiratory failure (AHRF) is a major factor for increased mortality in the intensive care unit (ICU). We hypothesized that the noninvasive index $SpO_2/FiO_2$ (SF) ratio can be used as a surrogate to invasive index $PaO_2/FiO_2$ (PF) as SF ratio correlates with PF ratio in all modes of oxygen supplementation.

**Patients and methods:** Patients with acute respiratory failure admitted to the intensive care unit were enrolled in this retrospective cross-sectional study. Fraction of inspired oxygen ($FiO_2$), method of oxygen supplementation, and partial pressure of arterial oxygen ($PaO_2$) were noted from the ABG reports in the medical records. The corresponding $SpO_2$ was noted from the nurse's chart. The calculated SF and PF ratios were recorded, and correlation between the same was noted in different methods of oxygen administration.

**Results:** A total of 300-sample data were collected. Pearson's correlation was used to quantify the relationship between the variables. The study showed a positive correlation, $r = 0.66$ ($p < 0.001$), between PF ratio and SF ratio. SF threshold values were 285 and 323 for corresponding PF values of 200 and 300 with a sensitivity and specificity in the range of 70 to 80%. In addition, SF and PF could also be used interchangeably irrespective of the mode of oxygen supplementation, as the median values of PF ratio ($p = 0.06$) and SF ratio ($p = 0.88$) were not statistically significant.

**Conclusion:** In patients with AHRF, the noninvasive SF ratio can be used as a surrogate to invasive index PF in all modes of oxygen supplementation.

**Keywords:** Arterial blood gas (ABG), Acute hypoxemic respiratory failure (AHRF), Acute respiratory distress syndrome (ARDS), Oxygen supplementation, $PaO_2/FiO_2$ ratio, Pulse oximetry, $SaO_2/FiO_2$ ratio.

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## Introduction

Respiratory failure happens when the respiratory system fails in oxygenation or elimination of carbon dioxide. It can be due to either respiratory muscle pump impairment or lung dysfunction.[1] The classification, based on blood gases abnormalities, is divided into type 1/hypoxemic ($PaO_2$ <60 mm Hg) respiratory failure and type 2/hypercapneic ($PaCO_2$ >50 mm Hg) respiratory failure.[2] Acute respiratory distress syndrome (ARDS), a severe form of acute lung injury (ALI), is the main cause of acute severe hypoxemia. It is a syndrome of inflammation and increased pulmonary capillary permeability resulting from damage to the lung epithelium or endothelium, in the setting of a variety of clinical and physiological abnormalities, which may coexist with a cardiac event.[3] It has a high mortality of 30 to 45%. The diagnostic criteria for ALI and ARDS, as per the 2012 Berlin criteria, mainly include clinical presentation, arterial blood gas (ABG) analysis of PF ratio, chest X-ray demonstrating pulmonary infiltrates, higher ventilator settings in mechanically ventilated patients, and multiorgan failure.[4–6] There are very few studies showing classification and risk stratification in patients with non-ARDS acute hypoxemic respiratory failure (AHRF) vs ARDS AHRF though there is similarity in mortality rates in similar states of hypoxemia.[7] Expedited diagnosis and prompt management that include supportive measures and treatment of the precipitating event help to mitigate the morbidity and mortality. This requires a more easily available classification system for early recognition of respiratory failure, management, and assessment of response to treatment.[8] It helps in implementing, at timely stage, lung-protective mechanisms, which also includes early intubation and use of paralysis.[9–11]

Oxygen therapy is the mainstay of treatment for AHRF since hypoxemia is an independent risk factor for increased morbidity and mortality. Target $SpO_2$ is >88% in the presence of chronic respiratory failure and in the absence of chronic symptoms is >92%. Oxygen delivery systems include simple face mask, nasal cannula, non-rebreathing mask, venturi mask, and oxygen mask with a filter. In patients with AHRF, noninvasive ventilation (NIV) or high-flow nasal oxygen (HFNO) is preferred over conventional oxygen therapy as it reduces the risk of intubation. NIV is the first-line treatment for approximately 20% of patients in the intensive care unit with acute respiratory failure. ARDS patients have statistically higher intubation rates and increased ICU morbidity and mortality rates than non-ARDS patients. Since respiratory failure has multifactorial etiology,

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it is difficult to understand how beneficial is NIV in this group of patients and it invariably involves the risk of delaying intubation.[12] Mechanical ventilation is the key to management of patients with ARDS. The standard of care is lung-protective ventilation strategy targeting a lower tidal volume and limiting the inspiratory plateau pressures.[13–16]

$PaO_2/FiO_2$ (PF) ratio calculation requires arterial blood gas (ABG) sampling. $SpO_2/FiO_2$ (SF) ratio as a surrogate for PF ratio is desirable as the only value required is a pulse oximeter reading of $SpO_2$.[17–20] Pulse oximetry is the most basic technique to monitor oxygenation. In this method, the property of hemoglobin to absorb light at the different wavelengths of 660 nm (red) and 940 nm (infrared) is used to distinguish oxyhemoglobin from deoxyhemoglobin.[21] There have been a few studies which show that SF and PF ratios are reasonably well correlated in patients with ARDS, particularly when PF ratios are less than 300 and the mortality and ventilator days are similar when disease severity is defined by SF ratios.[22–26]

In this study, we will determine if SF ratio can be used against PF ratio values in AHRF patients. Additionally, we will derive the threshold values for SF that correlate with PF ratios in AHRF, note if it is comparable with similar studies in the subset of ARDS patients (mild 201–300, moderate 101–200, and severe <101 mm Hg) and check for any discrepancy in different modes of oxygen supplementation. The mode of oxygen supplementation is grossly classified as invasive and noninvasive. Noninvasive includes nasal cannula, simple face mask, venturi mask, reservoir bag mask, and tracheostomy mask for patients with tracheostomy, HFNO, and NIV. Invasive includes mechanical ventilation via endotracheal tube or tracheostomy.

## Methods

### Study Design and Setting

This is a retrospective cross-sectional study conducted in the department of surgical intensive care unit.

### Participants

All patients admitted with hypoxia or respiratory failure in the surgical intensive therapy unit, except those satisfying exclusion criteria. Exclusion criteria included patients in severe shock with cold clammy peripheries, hypothermia (<95°F), unreliable pulse oximetry waveform and patients with severe congenital heart disease or ejection fraction <50% or congestive cardiac failure.

### Study Period

December 2020 to February 2021 (3 months).

### Variables

The variables recorded were patient demographics, peripheral oxygen saturation ($SpO_2$), partial pressure of arterial oxygen ($PaO_2$), fraction of inspired oxygen ($FiO_2$), and ventilator settings. $PaO_2$, $FiO_2$, and method of oxygen delivery were noted from the ABG report, and $SpO_2$ was noted from the pulse oximeter readings documented in the nurse's record.

### Bias

This is a retrospective study. Target group was patients satisfying the inclusion criteria with up-to-date medical records. Data was collected by the principal investigator. The outcome assessment was not a part of the study.

### Sample Size Calculation

In this study, the primary objective was to find the correlation between PF ratio and SF ratio. With a Pearson correlation value of 0.66, a sample size of 300 provided an adequate power of the study more than 90%. These calculations were performed for the variable P/F ratio with a power of 90% and alpha level of 5%. A sample size of 300 was considered with a confidence level of 95%, effect size of 0.3, and anticipated attrition of 10%.

### Statistical Analysis

The data analysis was performed using STATA IC/16.0. Data was summarized using mean (SD)/median (IQR) and percentage for continuous variables and categorical variables, respectively. The analysis was performed on skewed variables, which were log-transformed. The variables between the different methods of oxygen supplementation were compared using independent *t*-test. Pearson's correlation was used to derive the correlation between PF ratio and SF ratio. The discriminating ability of PF ratio in classifying SF ratio cutoff was analyzed using ROC curves, and area under the curve (AUC) was presented with 95% CI. Diagnostic accuracies (sensitivity and specificity) were presented.

## Results

A total of 300 patients were a part of this study as per the inclusion criteria. The study consisted of 188 (62%) males and 112 (38%) females mostly in the age-group of 40 to 60 years. One hundred and twelve samples were taken on low dose of single inotrope/vasopressor support. Two hundred and fifty patients out of 300 had warm peripheries, 105 had neutral temp/cold peripheries but with good pulse oximeter waveform, whereas 7 had bad traces; hence, $SpO_2$ readings were not reliable in this group. One hundred and fifty-eight (52%) had a recorded mean arterial pressure (MAP) of 80 to 100 mm Hg at the time of sampling, and 89 (30%) had MAP of 70 to 80 mm Hg or >100 mm Hg.

Table 1 gives an analysis of the data collected. The variables studied were mainly $SpO_2$, $PaO_2$, and $FiO_2$. Based on the data, the median value of $SpO_2$ was 99%, $PaO_2$ was 82 mm Hg. The median value of PF ratio was 256 and SF ratio was 312.

Figure 1 shows the correlation coefficient of PF ratio and SF ratio. A strong positive linear correlation was noted between PF ratio and SF ratio, $r = 0.66$ ($p < 0.001$, highly significant). Hence, our primary objective that SF ratio could be used as a surrogate for PF ratio in patients with respiratory failure was satisfied.

The next objective was to find the cutoff value for SF ratio to PF ratio. Figures 2 and 3 show the receiver-operating curve (ROC) of SF ratio. The area under the curve (AUC) summarizes that SF ratio has excellent discrimination ability; hence, diagnostic accuracy for AHRF (AUC of 0.8399 for PF values of >200 and AUC of 0.8049 for PF values >300).

We got the respective cutoffs of SF ratio for PF ratio. SF ratio of 285 corresponded to PF ratio of 200 with sensitivity of 73% and specificity of 77%. Similarly, SF ratio of 323 corresponded to PF ratio of 300 with sensitivity of 72% and specificity of 73%.

The third objective was to identify if there is any variation in different methods of oxygen administration. From Table 1, of 300 ABG samples, 174 (58%) were on invasive methods and 126 (42%) were on noninvasive methods. There were no significant statistical differences, in PF ratio ($p = 0.07$) and SF ratio ($p = 0.88$), between the different methods of oxygen supplementation implying that SF

**Table 1:** Characteristics of the data

| | *Overall* | *Invasive* | *Noninvasive* | |
|---|---|---|---|---|
| *Variable* | *Median (IQR) (n = 300)* | *Median (IQR) (n = 160)* | *Median (IQR) (n = 116)* | *p value* |
| $PaO_2$ | 82.40 (66.65,110.00) | 114.50 (86.45, 49.70) | 108.50 (77.55, 37.90) | 0.008 |
| $SpO_2$ | 99.00 (96.00, 100.00) | 100.00 (100.00, 89.00) | 100.00 (98.00, 75.00) | <0.001 |
| PF ratio | 256.83 (177.43, 340.00) | 332.20 (255.78, 66.80) | 328.97 (224.09, 63.17) | 0.06 |
| SF ratio | 312.90 (222.22, 333.33) | 333.33 (285.71, 92.00) | 333.33 (301.61, 93.00) | 0.88 |

Table 1 shows that the median value of $SpO_2$ was 99%, $PaO_2$ was 82 mm Hg. The median value of PF ratio was 256 and SF ratio was 312. There were no significant statistical differences, in PF ratio ($p = 0.07$) and SF ratio ($p = 0.88$), between the different methods of oxygen supplementation

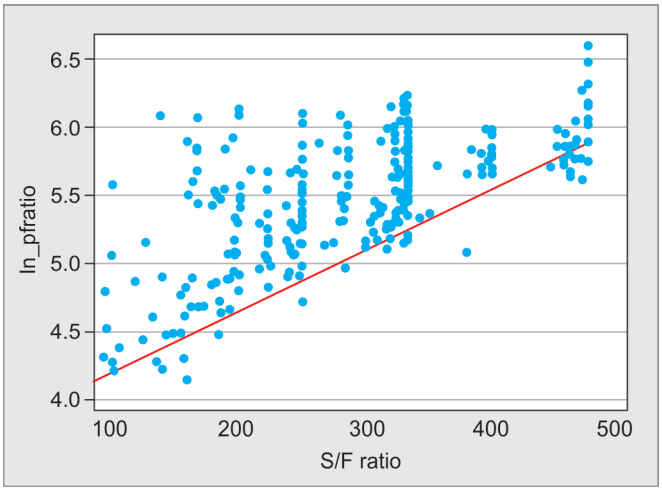


**Fig. 1:** Correlation coefficient curve SF, PF. The graph goes uphill, linear with a correlation coefficient of $r = +0.66$ ($p < 0.001$, highly significant). This shows strong positive correlation between PF ratio and SF ratio

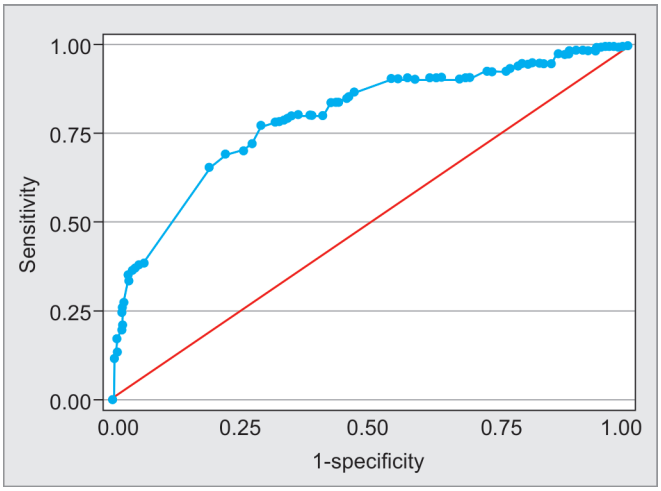


**Fig. 3:** ROC curve of SF ratio for PF >200. AUC of 0.8049 (0.8–0.9) shows excellent discrimination ability of SF ratio for PF values of >300

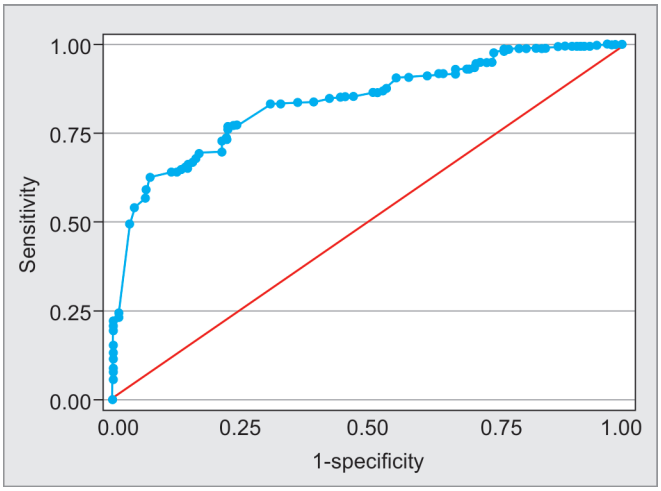


**Fig. 2:** ROC curve of SF ratio for PF >200. AUC of 0.8399 (0.8–0.9) shows excellent discrimination ability of SF ratio for PF >200

ratio and PF ratio can be used universally irrespective of the type of oxygen delivery system used.

The study hence proved that SF ratio can be used as a surrogate to PF ratio irrespective of the mode of oxygen supplementation.

## Discussion

This study showed a positive correlation between PF ratio and SF ratio. We also derived the SF threshold values for AHRF as 285 and 323 corresponding to PF ratios of 200 and 300 with a sensitivity and specificity around 70 to 80%. It was also inferred that PF ratio or SF ratio can be used in any method of oxygen supplementation and there is no variability in results. Hence, it may be concluded that SF ratio can be universally used as a surrogate for PF ratio.

Our findings agree with a study conducted by Pandharipande et al. in adult patients under general anesthesia. He found a strong positive correlation between S/F and P/F ratios when he included S/F ratio as a component of SOFA score instead of P/F ratio and the outcomes were relatable.[27] The result was not satisfactory in a similar study conducted by Laila et al. in the pediatric population.[28] A study by Rice et al. reached a conclusion that an SF of 235 had 85% sensitivity and 85% specificity and 315 had 91% sensitivity and 56% specificity to predict ARDS and ALI, respectively. $PaO_2$ and $SpO_2$ were measured 5 minutes apart. The PF ratios defined by the AECC were used to determine the SF thresholds.[29]

Hence, S/F ratio is a rapid and convenient diagnostic tool for the early recognition and intervention of AHRF in patients admitted to the intensive therapy unit, especially since pulse oximeter is an easily available tool for continuous oxygen saturation monitoring.[30] This circumvents the need for arterial blood gas sampling, which is invasive and more expensive. SF ratio might also be included as a

surrogate to PF ratio in organ failure scores like lung injury scores and sequential organ failure assessment scores to determine the degree of hypoxia.

There were some limitations to this study. Despite the advantages of pulse oximetry, there are conditions which limit its use, like methemoglobinemia, hypothermia, nail polish or nail abnormalities, cardiogenic shock, ambient light, patient's cognition, and position. Hence, a good waveform is a necessity for an accurate reading.[31] We also did not control for pH, hemoglobin, $PaCO_2$, and ventilator setup, which could also affect the results. Respiratory mechanics also vary in pulmonary vs extrapulmonary ARDS. All these mentioned factors could affect the relationship between $SpO_2$ and $PaO_2$ and need to be examined in further studies.[32]

## Conclusion

Our study showed a positive correlation of SF ratio and PF ratio with SF threshold values for AHRF of 285 and 323 corresponding to PF values of 200 and 300 in any mode of oxygen supplementation. Hence, we conclude that the noninvasive SF ratio is a valuable surrogate to invasive PF ratio.

### Research Quality and Ethics Statement

The authors attest that this clinical study has been sent for approval by Ethics Committee Review/Institutional Review Board. We also certify that the contents of this study have not been plagiarized in this submission.

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