Original Article

Correlation of SpO_2/FiO_2 Ratio and PaO_2/FiO_2 Ratio in Hypoxemic Patient While Breathing in Room Air

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Background: Hypoxemia is a common situation and arterial blood gas [ABG] analysis is the standard tool for diagnosing hypoxemia. PaO_2/FiO_2 [P/F] ratio is a crucial parameter to identify degree of hypoxemia but ABG machine is required. Pulse oximetry is a tool to evaluate oxygenation of patients, it is non-invasive, rapid, and widely available.

Objective: To evaluate the correlation between SpO_2/FiO_2 [S/F] and PaO_2/FiO_2 [P/F] ratio.

Materials and Methods: The present report was an observational study in the hypoxemic patients who need ABG analysis at room air, SpO_2 were also recorded at the same time of arterial puncture. The correlation and linear regression analysis were analyzed to find the relationship between P/F and S/F ratio.

Results: One hundred seventy-nine patients were enrolled . The mean PaO_2 and SpO_2 were 64.43±10.8 and 89.63±5.22, respectively. The mean P/F and S/F were 306.79±51.45 and 426.82±24.86. The correlation between P/F and S/F was significant (r = 0.771), *p*-value was <0.0001, the equation as calculated P/F = -375 + 1.6 (S/F); r = 0.771 and r^2 = 0.595.

Conclusion: S/F from pulse oximetry was significantly correlated with P/F from ABG analysis but the exact equation was not as good enough to estimate P/F calculated from the S/F of the pulse oximetry.

Keywords: Correlation PaO_2/FiO_2, SpO_2/FiO_2

J Med Assoc Thai 2018; 101 (10): 1365-9
Website: http://www.jmatonline.com

Hypoxemia is one of the common clinical problems and required a prompt medical treatment to reduce morbidity and mortality. To determine patient with hypoxemia, physical examination is neither a sensitive nor reliable test[1,2]. When cyanosis is detected, arterial oxygen saturation, SaO_2 is about 67 percent[3,4]. There are many methods to evaluate the degree of hypoxemia in clinics such as arterial blood gas [ABG] analysis, pulse oximetry, indwelling of arterial catheter for oxygen monitoring, and transcutaneous oxygen monitoring. The first two methods are practical. ABG is the standard tool to evaluate not only the degree of hypoxemia but also the degree of hypercarbia, acidemia or alkalemia, and calculation for A-a oxygen gradient (the alveolar oxygen tension [PAO_2] minus the amount of oxygen dissolved in the plasma [PaO_2]). In some developing countries such as Thailand, ABG analyzing machine is not widely available in every hospital. The pulse oximetry has become widely used for bedside evaluating patient with hypoxemia[5]. According to its feasibility, portability, and accuracy, the pulse oximetry is available in almost every hospital, even in the suburb[6-8].

Rice et al[9] studied in patients diagnosed with acute lung injury [ALI] or acute respiratory distress syndrome [ARDS] in ARDS Network trial (n = 1,074) found that SpO_2/FiO_2 [S/F] was significantly correlated with PaO_2/FiO_2 [P/F]. The relationship between S/F and P/F was described by the following equation: S/F = 64 + 0.84 * (P/F) (p<0.0001; r = 0.89). A S/F ratio of 235 corresponded with a P/F ratio of 200 (85% sensitivity and 85% specificity), while an S/F ratio of 315 corresponded with a P/F ratio of 300 (91% sensitivity and 56% specificity). Pandharipande et al[10] studied in mechanically ventilated surgical and trauma patients found the correlation of S/F ratio and P/F ratio in assessing the respiratory parameters of the sequential organ failure assessment [SOFA] score. The present study also found that (S/F) SOFA score was correlated with the original (P/F) SOFA score in clinical outcome (Spearman's rho 0.853, p<0.0001). Although, these two studies enrolled different patients, all of them were using mechanical ventilators and positive end

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How to cite this article: Oer-areemitr N, Piyavechviratana K. Correlation of SpO_2/FiO_2 ratio and PaO_2/FiO_2 ratio in hypoxemic patient while breathing in room air. J Med Assoc Thai 2018;101:1365-9.

expiratory pressure [PEEP], which directly affected the ratio. Therefore, the objective of the present study was to find the correlation between S/F and P/F ratio in hypoxemic patient breathing room air and to create an equation by using S/F to calculate P/F ratio.

Materials and Methods

The STROBE statement was followed in the present study.

Study design and population

This observational study was conducted at the Phramongkutklao Hospital, after approval by the Ethics Committee of the Phramongkutklao Hospital in Bangkok, Thailand. The inclusion criteria were adult patients, 18 years or older diagnosed as hypoxemia by SpO_2 of less than 97% and had indication for ABG analysis. The factors that interfered with pulse oximetry were excluded, Hb of less than 10g/dL, methemoglobinemia, sickle cell anemia, the patients that were on a vasoactive agent, recent smoking[11] (less than seven days), severe tricuspid regurgitation, and nail painting[12]. We also excluded patients with severe hypoxemia that were unable to tolerate ambient air breathing.

The patients were recorded for their baseline characteristics, age, sex, diagnosis, chronic coexisting conditions, vital signs, baseline laboratory values, level of hemoglobin, baseline SpO_2, ABG data (include pH, PaO_2, $PaCO_2$, SaO_2), and FiO_2. Arterial punctures were performed by medical students or residents, using ABG kits (BD Preset™, Becton, Dickinson and Company, UK). After blood was drawn, syringes were capped then put in the iced container and analyzed within 10 minutes. While arterial punctures were performed, pulse oximetry was also recorded simultaneously for one minute, ensuring that the wave of pulse oximetry was qualified.

Because the enrolled patients were indicated for ABG analysis, informed consent was waived.

Statistical analysis

The primary end point was the correlation between P/F ratio and S/F ratio at room air. Analytical statistic of two continuous variables were done through correlation and linear regression. Correlation will be applied when testing for the relative values, whereas regression process will be applied when testing for forming of predicting a variable data from another. Data were analyzed using the statistical package SPSS for Windows 15.0 (SPSS Inc., Chicago, IL). Numerical variables were tested for normality using the Kolmogorov-Smirnov test. Variables with non-normal distribution were summarized as median and interquartile range [IQR]. Variables with normal distribution were summarized as means and standard deviation [SD]. The correlation between P/F and S/F ratios was analyzed using Pearson's correlation analysis. P/F and S/F ratio were plotted in scatterplot and linear regression modeling was utilized to compare the relationship between P/F and S/F ratios.

Results

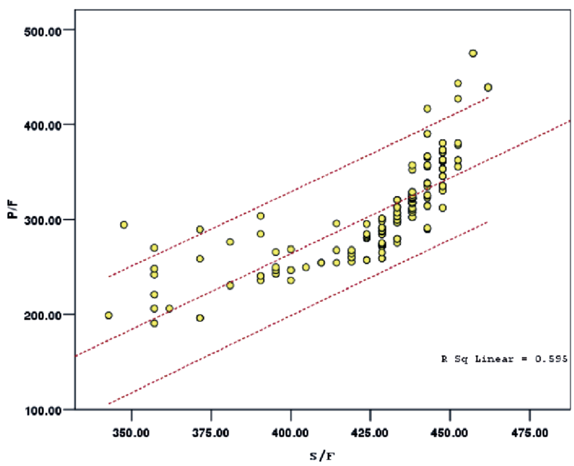
Baseline characteristics

Of the 204 adult patients with hypoxemia enrolled, nine patients were excluded due to hemoglobin level was less than 10 g/dL, 12 patients were excluded due to shock that required vasoactive agents, and four patients were excluded due to recent smoking. Thus, 179 patients were enrolled, 97 were female (54.2%). Mean age was 71.8±15.4 years (Table 1). Eighty-one patients were diagnosed as sepsis (45.3%), most of them were pneumonia (33 patients, 18.4%) and others were non-pulmonary infection (48 patients, 26.8%) such as urinary tract infection, intra-abdominal infection, skin and soft tissue infection, primary bacteraemia or unknown source of infection. Most patients had underlying diseases, which atherosclerotic disease

Table 1. Patients baseline characteristics

Parameter	n (%)
Age, mean ± SD	71.8±15.4
Sex	
Male	82 (45.8)
Female	97 (54.2)
Hemoglobin level (g/dL), mean ± SD	11.65±1.05
Chronic underlying diseases	
Atherosclerotic disease	81 (45.3)
Non-atherosclerotic disease	45 (25.1)
No underlying disease	53 (29.6)
Diagnosis	
Pneumonia	33 (18.4)
Non-pulmonary infection	48 (26.8)
Acute pulmonary edema	26 (14.5)
Acidosis	27 (15.1)
Diffuse parenchymal lung disease	23 (12.8)
COPD acute exacerbation	10 (5.6)
Pulmonary embolism	10 (5.6)
Others	9 (5.0)
Vital signs, mean ± SD	
Body temperature	37.64±0.67
Heart rate	99.00±18.18
Systolic blood pressure	124.94±18.53
Respiratory rate	22.67±4.56

COPD = chronic obstructive pulmonary disease



P/F = -375 + 1.6 (S/F); r = 0.771, r_2 = 0.595

Figure 1. P/F ratio vs. S/F ratio scatterplot. The line represents the best fit linear relationship.

was the most common underlying disease (81 patients, 45.3%). The mean hemoglobin was 11.65±1.05 g/dL. Baseline vital signs were collected at the same time of arterial punctures were performed, mean body temperature was 37.64±0.67°C, mean heart rate was 99±18.18 beat per minute, mean systolic blood pressure and mean respiratory rate were 124.94±18.53 mmHg and 22.67±4.56 per minute, respectively.

Oxygen saturation was recorded during arterial puncture for ABG analysis, shown in Table 2. Mean PaO_2 of patients was 64.43±10.8 mmHg, $PaCO_2$ and SaO_2 37.27±10.44 mmHg and 91.68±5.12 percent, respectively. Mean SpO_2 at the time of arterial puncture was 89.63±5.22 percent. The ratio of P/F ratio and S/F ratio were calculated, and the mean P/F and S/F was 306.79±51.45 and 426.82±24.86, respectively. Data of P/F and S/F ratio were plotted in scatter plot (Figure 1). S/F ratio was significantly correlated with P/F ratio ($p<0.001$) and according to linear regression model, the equation was P/F = -375 + 1.6 (S/F); r = 0.771, r^2 = 0.595 (Table 3).

The correlations were also analyzed in sub-populations, according to the severity of hypoxemia, whether acidemia or alkalemia, the level of $PaCO_2$ and body temperature. In the mild hypoxemic patient group (n = 113) or the moderate hypoxemic patient group (n = 66), the correlation between P/F and S/F was also significant ($p<0.01$; r = 0.572 and 0.768, respectively). The pH from ABG analysis were categorized into three groups, acidemia (pH <7.35, n = 76), normal (pH 7.35 to 7.45, n = 72), and alkalemia (pH >7.45, n = 31), the correlations of P/F and S/F ratio were analyzed and showed significantly correlated in each group ($p<0.01$, r = 0.764, 0.749, and 0.823, respectively). The body temperature was categorized into two groups, BT below 37°C (n = 34) and BT of 37°C or above (n = 145), P/F and S/F ratio were also well correlated in both groups ($p<0.01$, r = 0.716 and 0.795, respectively). The level of $PaCO_2$ from blood gas analysis were classified into hypercarbia ($PaCO_2$ greater than 40 mmHg, n = 52) and non-hypercarbia group ($PaCO_2$ of 40 mmHg or less, n = 127), the P/F and S/F ratio correlations were statistically significant in both groups ($p<0.01$, r = 0.831 and 0.722, respectively) (Table 4).

Table 2. Arterial blood gas data and SpO_2

Parameter	Mean ± SD
Arterial blood gas	
SaO_2	91.68±5.12
PaO_2	64.43±10.8
$PaCO_2$	37.27±10.44
SpO_2	89.63±5.22
P/F ratio	306.79±51.45
S/F ratio	426.82±24.86

SaO_2 = arterial oxygen saturation; PaO_2 = arterial partial pressure of oxygen; $PaCO_2$ = arterial partial pressure of carbondioxide; SpO_2 = arterial oxygen satuation from pulse oximetry; P/F = PaO_2/FiO_2; S/F = SpO_2/FiO_2

Table 3. The Pearson's correlation of P/F and S/F ratio

Model	Unstandardized coefficients		t	*p*-value
	B	Standard error		
Constant	-374.633[#]	42.329	-8.850	<0.001
S/F	1.597[#]	0.099	16.125	<0.001

P/F = PaO_2/FiO_2; S/F = SpO_2/FiO_2

[#] P/F = -374.633 + 1.597 (S/F), R 0.771, R square 0.595

Table 4. The Pearson's correlation of P/F and S/F ratio in subgroup analysis

Subgroup	Number of patients, n (%)	Pearson's correlation, r
Mild hypoxemia (PaO_2 60 to 80 mmHg)	113 (63)	0.572*
Moderate hypoxemia (PaO_2 40 to 59 mmHg)	66 (37)	0.768*
pH <7.35	76 (42)	0.764*
pH 7.35 to 7.45	72 (40)	0.749*
pH >7.45	31 (17)	0.823*
BT <37°C	145 (81)	0.716*
BT ≥37°C	34 (19)	0.795*
$PaCO_2$ ≤40	127 (91)	0.722*
$PaCO_2$ >40	52 (29)	0.831*

P/F = PaO_2/FiO_2; S/F = SpO_2/FiO_2; BT = body temperature
* $p<0.001$

Discussion

The hypothesis of the present study was that the continuously available S/F ratio can serve as a surrogate for P/F ratio in hypoxemic patients while breathing room air. Using data from the pulse oximetry and the ABG analysis, we found that the S/F ratio correlates well with a simultaneously obtained P/F ratio ($p<0.001$). The correlation was also consistent in the moderate hypoxemic patient group. According to scatterplot of P/F and S/F ratio correlation, the authors proposed the equation P/F = -375 + 1.6 (S/F); $r = 0.771$, $r^2 = 0.595$.

The authors acknowledge that blood pH, 2,3-diphosphoglycerate, and body temperature have an effect to oxy-hemoglobin dissociation curve. The authors also analyzed whether these factors affected to the correlation of P/F and S/F ratio. Subgroup analysis were categorized in pH (acidemia, normal acid-base, alkalemia), level of $PaCO_2$ (40 mmHg or less and more than 40 mmHg) and body temperature (below 37°C or 37°C and above). None of these factors would interfere the correlation of P/F and S/F ratio. Thus, the authors could use the correlation of P/F and S/F ratio even when there are confounding factors that would shift the oxy-hemoglobin dissociation curve. To standardize S/F ratio, larger, multicenter studies should be done to clarify the limitation of variability of the pulse oximetry in hospitals. Furthermore, to apply S/F ratio in predict prognosis of patient (substitute P/F ratio) in multiorgan failure score such APACHE II, SOFA score[10], would need further studies.

To our knowledge, the present report was the first study to determine the correlation between P/F and S/F ratio in patients breathing room air. We found the equation to calculate P/F ratio from bedside S/F ratio. There are many clinical applications from the present study. According to the significant correlation between P/F and S/F ratio, the authors propose using S/F ratio instead of performing ABG analysis to evaluate P/F ratio in screening the severity of hypoxemia and to follow-up patients because it could save time and provide good cost-benefit. Theoretically, S/F ratio should apply to any FiO_2. However, in the present study hospitals, high flow oxygen device that provides constant FiO_2 is unavailable in every ward. With the low flow oxygen device, FiO_2 was not constant. Therefore, the exact ratio could not be calculated. The present study used FiO_2 ambient air to calculate the ratio. Even though, the S/F ratio could apply with any FiO_2, the patients must be breathing without using positive airway pressure ventilation. Many scoring system, APACHE II, SOFA score, could use S/F ratio as the surrogate but may need to revise the equation. There were several limitations of the present study. The first is the small number of patients and only single center study. Secondly, although most of the SpO_2 and PaO_2 measurements were made simultaneously, the pulse oximeters were varied. Thirdly, the measurements made with SpO_2 greater than 97% were excluded from the analysis. At these levels of oxygen saturations, the slope of the relationship between SpO_2 and PaO_2 becomes almost zero, and large change in PaO_2 may result in little or no change in SpO_2[9].

Conclusion

P/F and S/F ratio are well statistically significant correlated, and the correlations are consistent even when there are many confounding factors that would shift the oxy-hemoglobin dissociation curve. S/F ratio is non-invasive, cheap, user-friendly, and widely available. Although, it can be used as a good parameter to monitor and follow-up patients, it cannot be used as diagnostic criteria for ALI/ARDS. Furthermore, S/F ratio does not allow the evaluation of acid-base status or $PaCO_2$ levels, two other potentially important clinical reasons for performing blood gas analysis.

What is already known on this topic?

The correlation between SpO_2 and PaO_2 has been well established and represented in oxy-hemoglobin dissociation curve. Nowadays, P/F ratio is considered as standard parameter for evaluating hypoxemic patients. Correlation between P/F and S/F ratio was previously studied in ARDS patients, which the result showed good correlation between P/F and S/F ratio. All of them were ventilated with mechanical ventilator with PEEP, and used FiO_2 higher than 0.21. PEEP, mechanical ventilator setting, and high FiO_2 affect PaO_2 level; therefore, they affect the P/F ratio.

What this study adds?

Correlation between P/F and S/F ratio in hypoxemic patients was studied. All patients in this study were breathing ambient air. P/F and S/F ratio are significantly correlated in hypoxemia patient breathing in ambient air. The correlation was also significant in subgroup analysis.

Potential conflicts of interest

The authors declare no conflict of interest.

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