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Correlation Between PaO₂/FiO₂ and SpO₂/FiO₂ in Burned Children with Smoke Inhalation Injury

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Abstract

Objective—Determine whether the SpO₂/FiO₂ ratio correlates with the PaO₂/FiO₂ ratio in burned children with smoke inhalation injury (SII), with the goal of understanding if the SpO₂/FiO₂ ratio can serve as a surrogate for the PaO₂/FiO₂ ratio for the diagnosis of acute respiratory distress syndrome (ARDS).

Design—Retrospective chart review.

Setting—Shriners Hospitals for Children - Galveston.

Patients—All burned children with SII who were admitted from 1996 to 2014 and had simultaneously obtained SpO₂, FiO₂, and PaO₂ measurements.

Interventions—None.

Measurements and Main Results—Two hundred seventy-three patients (63% male, 8 ± 5 years, 53 ± 24% total body surface area burns) were analyzed. SpO₂/FiO₂ ratios were divided into 4 subgroups based on SpO₂ values (100%, 98%, 95%, 92%). Significance was accepted at r² > 0.81. The r² (number of matches) was 0.66 (23,072) for 100%, 0.87 (18,932) for 98%, 0.89 (7,056) for 95%, and 0.93 (4,229) for 92%. In the subgroup of patients who developed ARDS, r² was 0.65 (8,357) for 100%, 0.89 (7,578) for 98%, 0.89 (4,115) for 95%, and 0.91 (2,288) for 92%.

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Conclusions— $\text{PaO}_2/\text{FiO}_2$ and $\text{SpO}_2/\text{FiO}_2$ strongly correlate in burned children with SII, with a SpO_2 of $<92\%$ providing the strongest correlation. Thus, $\text{SpO}_2/\text{FiO}_2$ ratio may be able to serve as surrogate for $\text{PaO}_2/\text{FiO}_2$, especially when titrating FiO_2 to achieve a SpO_2 of 90–95% (i.e., in the ARDS range).

Keywords

Acute respiratory distress syndrome; PALICC; acute lung injury; trauma; critical care

INTRODUCTION

Severe burn injury requires prolonged intensive care and treatment (1). Although mortality and morbidity due to burn injuries have decreased radically in the last decades, particular factors such as extreme age (>60 or <2 years), a percentage of the total body surface area (TBSA) burned exceeding 60%, and presence of smoke inhalation injury (SII) still heavily influence survival rates (2) and outcomes (3, 4). The presence of SII is one of the 3 factors accounted for in the modified Baux score (5).

Acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) are frequent sequelae of SII (6, 7), occur in up to 34% of patients with SII, and are associated with a high mortality of up to 43% (8, 9). In 1994, the American European Consensus Conference (AECC) described ALI and ARDS using the ratio of the partial pressure of oxygen in arterial blood (PaO_2) to the fraction of inspired oxygen (FiO_2 ; P/F)(10). Later, the Berlin ARDS definition defined 3 different grades or severity of ARDS: mild (P/F ratio, 200–300), moderate (P/F ratio, 100–200), and severe (P/F ratio, <100)(11). These guidelines were updated in 2015 for children by the Pediatric Acute Lung Injury Consensus Conference (PALICC). The resulting definition sets forth various criteria to define pediatric ARDS, including P/F ratio <300 or in cases where PaO_2 is not available, a peripheral capillary oxygenation (SpO_2)-to- FiO_2 (S/F) ratio <264 . In addition, criteria for grading severity in patients with invasive mechanical ventilated were introduced. These utilize the oxygenation index (OI), calculated with the FiO_2 , mean airway pressure, and PaO_2 as well as the oxygenation saturation index (OSI), calculated with SpO_2 (12).

According to this definition, ARDS diagnosis requires arterial blood gas samples, which can only be obtained intermittently and invasively or by continuous noninvasive pulse oximetry measurements. The S/F ratio has previously been shown to correlate with the P/F ratio in healthy patients as well as ICU patients with ALI or ARDS; however, there are no data for severely burned children with SII and the PALICC definition was developed without consideration of burned children (13–17). In this study, we investigated whether the S/F ratio correlates with P/F ratio in burned children with SII. We hypothesized that SpO_2 could be used as a complementary measurement or surrogate parameter for PaO_2 , especially for SpO_2 in the ARDS range (SpO_2 90–95%), for preventive diagnosis and consequent earlier therapy.

MATERIALS AND METHODS

After approval of the Institutional Review Board (IRB 140361), a retrospective chart review was performed on medical records of all pediatric patients admitted to Shriners Hospitals for

Children - Galveston between 1996 and 2014. A total of 932 patients with burns and SII (confirmed by direct bronchoscopy at our institution) were identified, and 28 were excluded because they were admitted more than 14 days after their injury. FiO_2 , SpO_2 , and PaO_2 measurements recorded for these patients were taken at the Shriners Hospitals for Children - Galveston ICU (0 m in altitude) in a similar manner. All recorded values of FiO_2 , PaO_2 , and SpO_2 were collected at the same time, with PaO_2 values being separated from SpO_2 and FiO_2 measures by a maximum interval of 60 seconds, and were used to calculate the corresponding P/F ratio and S/F ratios. The corresponding P/F and S/F ratio values were then matched and used for correlation analysis. Of the 904 patients, 627 were excluded from the study owing to the inability to match P/F ratio and S/F ratio values. In the remaining 276 patients, all matches in which the PaO_2 value was more than 100 mmHg (100 torr) and the simultaneous SpO_2 value was less than 92% were excluded from the analysis. These data were excluded because PaO_2 was considered more reliable than SpO_2 , given the retrospective study design, and because these matches were certainly influenced by temporary malposition of the pulse oximeter and could not be considered clinically trustworthy. The total number of removed matches was less than 1,000. Additionally, all matches during 100% oxygen therapy were excluded. This yielded a total of 273 patients for analysis. ARDS was diagnosed when patients met all American Burn Association Burn Quality Improvement Criteria as outlined in Table 1. These criteria differ from the PALICC criteria not considering special populations and the age of the patient and the timing of insult. All patients received a chest x-ray every morning while under mechanical ventilation. Demographic data were also collected from these patient's records.

Correlation between the P/F and S/F ratios was determined for the entire patient group as well for subgroups of patients who developed ARDS and patients who died of ARDS. The S/F ratios were divided into 4 subgroups, which were used to obtain 4 different correlations for each analysis. These groups were based on the different cutoff values of SpO_2 : 1) SpO_2 to 100% of the S/F ratio; 2) SpO_2 to 98% (<) of the S/F ratio; 3) SpO_2 to 95% (<) of the S/F ratio; and 4) SpO_2 to 92% (<) of the S/F ratio. These S/F ratio subgroups were stratified based on the sigmoidal characteristics of the oxygen-hemoglobin dissociation curve (i.e., to account for the fact that small increases in PaO_2 dramatically increase SpO_2 on the steep portion of the curve, and large changes in PaO_2 minimally increase SpO_2 on the plateau portion of the curve)(18).

Finally, the demographics of all patients were analyzed to identify factors influencing the development of ARDS.

Statistical Analysis

To determine the strength of the linear relationship between the P/F and S/F ratios, we used Pearson product-moment correlations to investigate relationships in groups of greater or less than 100%, 98%, 95%, and 92% SpO_2 for all patients and patients with diagnosed ARDS. Goodness-of-fit of linear regressions were then developed for each group comparison. In determining characteristic differences in TBSA burned, length of stay, age, sex, admission time post burn between the patients that did or did not develop ARDS, an unpaired t-test was used. Ethnicity (White, Black, and Hispanic) differences between the groups that developed

ARDS or not utilized a one-way analysis of variance. Within the specific group analysis, and all variables, data were determined to be appropriate for analysis without transformation of the data. PaO₂, SpO₂, and FiO₂ matches with PaO₂ above 100 mmHg and SpO₂ under 92% were considered outliers and removed from the analysis. Data were analyzed with Graphpad Prism 6.0 (La Jolla, CA, USA) with significance set at $p < 0.05$. All data were reported as mean $\pm$ standard deviation (SD).

RESULTS

Of the 273 patients included in the analysis, 172 were male and 101 female. Patient demographics are summarized in Table 2. The predominant burn injury was flame injury (252/273; 92%), followed by electrical flame injury (7/273; 3%), contact burn (6/273; 2%), and other injury type (8/273; 3%). The length of ICU stay was 36 ± 36 days. Forty-seven patients (16%) developed ARDS, and 23 of the total 39 non-surviving patients (49%) had ARDS. Of these 23 patients, 16 (70%) had ARDS listed as the cause of death. FiO₂ values ranged from 21% to 100%, PaO₂ from 25 mmHg to 500 mmHg, and SpO₂ from 40% to 100% of saturation.

For the entire study population, there were 23,072 matches with SpO₂ 100% in 273 patients; 18,932 matches with SpO₂ 98% in 269 patients; 7,056 matches with SpO₂ 95% in 236 patients; and 4,229 matches with SpO₂ 92% in 209 patients. The relationships between the P/F ratio and S/F ratio are summarized in Figure 1, while the r^2 correlations and p -values were respectively: $r^2=0.66$, $p < 0.0001$; $r^2=0.87$, $p < 0.0001$; $r^2=0.89$, $p < 0.0001$; and $r^2=0.93$, $p < 0.0001$ (Fig. 1).

For the ARDS patient group, there were 8,357 matches with SpO₂ 100 in 40 patients; 7,578 matches with SpO₂ 98 in 40 patients; 4,115 matches with SpO₂ 95 in 39 patients; and 2,288 matches with SpO₂ 92 in 38 patients. In this subgroup, the r^2 correlation index was 0.65 for 100%, 0.89 for 98%, 0.89 for 95%, and 0.91 for 92% (Fig. 2).

TBSA burned and length of stay were significantly higher in patients who developed ARDS ($p < 0.0001$ and $p = 0.02$, respectively), while age, sex, admission post burn, and race showed no interaction.

DISCUSSION

While others have reported the relationship between the S/F ratio and P/F ratio, we are unaware of previous comparisons in burn patients. We hypothesized that simultaneous calculations of the S/F ratio and P/F ratio are highly correlated in burned children with SII, especially during ARDS, when SpO₂ and PaO₂ levels are less than 100 mmHg (100 torr). Our data, in 273 patients, revealed strong correlations in all groups and extremely strong correlations when SpO₂ was less than 95%.

The P/F ratio is used to diagnose and classify ARDS. Currently, oxygenation measurements for determining the PaO₂ require an invasive sample of arterial blood. There are several limitations in obtaining this measurement. First, continuous PaO₂ monitoring is not performed routinely, which is problematic since arterial blood saturation can rapidly change.

Flori et al. showed that P/F ratio poorly correlates with the severity of pulmonary impairment in children (19). In many patients, an arterial line is not standard of care, especially in those that are not mechanically ventilated. This creates complications when arterial blood samples must be collected for every desired PaO₂ measurement (20). Other measurement inconsistencies include patient positioning and endotracheal suctioning (21, 22). Finally, arterial blood sampling is increasingly scrutinized in ICUs due to cost, greater appreciation that excess blood sampling contributes to ICU anemia, and the general trend towards banked blood restriction (23, 24).

SpO₂ readings are obtained through pulse oximetry devices, which have become standard monitors and widely used in the ICU (25). Continuous and noninvasive readings are major advantages of these devices. Nonetheless, pulse oximetry measurements can be affected by different variables. Dyshemoglobin states (carboxyhemoglobin and methemoglobin) can alter readings because they influence light absorption and accordingly, calibration of the pulse oximeter (26, 27). However, carboxyhemoglobin is unlikely to have significantly influenced SpO₂ measurements in our study, as carboxyhemoglobin elimination primarily occurs during the first 48 hours after inhalation injury and we removed all matches occurring within this time. Additionally, we eliminated all matches occurring while patients received 100% oxygen therapy. Other factors influencing SpO₂ measurements are states of impaired peripheral perfusion (25) and factors affecting the oxyhemoglobin dissociation curve (18). The sigmoidal shape of the curve affects the accuracy and reliability of the readings around its inflection point, where small changes in SpO₂ correspond to big changes in PaO₂. This effect has very limited influence in the presence of ARDS, in which the SpO₂ range is around 90–95%. Our data are consistent with this, as greatest concordance occurred in this range. Severe anemia and use of dyes also influence the readings (28, 29); however, both red blood cell transfusion and the use of dyes are limited in our institution, making it unlikely that either factor significantly influenced the outcome. Skin pigmentation is another confounding factor (30). Lastly, motion artifacts (31) similar to those seen in PaO₂ measurements cannot be avoided and are a confounding factor for both types of measurements. Intensive care nurses are properly trained on the working principles of pulse oximetry, and faulty use is rare (32). Motion tolerant SpO₂ sensors are now commercially available, which will likely reduce this artifact in the near future.

The current results, which were obtained using an extremely large database, are consistent with others showing an excellent correlation and agreement between S/F and P/F ratios in non-burned critically ill pediatric patients (13–17). Only Perkins et al. found a low correlation ($r = 0.60$), which was derived from analysis of 41 critical ill adults and 1,085 concomitant measurements (33).

According to the PALICC, OI and OSI index can be used in addition to the P/F ratio and S/F ratio for the diagnosis of ARDS, as well as for grading ARDS severity. The OI and OSI index are extremely useful, especially in children because they incorporate the effects of mean airway pressure. Use of the OI and OSI index has been widely adopted and considering our results, should also be considered in burned children with SSI. Unfortunately, we were not able to analyze these two indices in our cohort because the mean airway pressure data were not available.

The major limitation of our study is its retrospective design, which can potentially influence the results, as no precise data were available on events such as displacement of the pulse oximetry occurred simultaneously during the matching ratio measurements. However, eliminating the matches with PaO₂ greater than 100 mmHg (100 torr) and SpO₂ lower than 92% limited this effect. A second limitation is that we were unable to obtain end-tidal CO₂ measurements to investigate eventual minute ventilation management, since these values are not recorded at our institution. Additionally, the effect of acid-base disturbance on the oxyhemoglobin dissociation curve was not taken in consideration. Lastly, we were unable to quantify the possible interference of low perfusion rates and determine how these may have influenced the SpO₂ readings.

In conclusion, our results support a strong correlation between the S/F and P/F ratio in burned children with SII. Moreover, our results, suggest that SpO₂ values can be used as a surrogate for PaO₂ values, especially in patients with low oxygen saturation and at risk for development of ARDS. Nonetheless, arterial blood samples remain an invaluable part of the critical care armamentarium. Future prospective studies investigating OI and OSI index in burn patients with SII are needed to validate and confirm our findings and to further improve the diagnosis of ARDS.

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Figure 1. Scatterplots for the entire patient database with the 4 different SpO₂ subgroups. P/F = PaO₂/FiO₂, S/F = SpO₂/FiO₂.

Figure 2. Scatterplots for the ARDS patient database with the 4 different SpO_2 subgroups. $\text{P/F} = \text{PaO}_2/\text{FiO}_2$, $\text{S/F} = \text{SpO}_2/\text{FiO}_2$.

Table 1

American Burn Association Burn Quality Improvement ARDS Criteria

<ul style="list-style-type: none">• P / F ratio 300 mmHg with PEEP 5 cm H₂O<ul style="list-style-type: none">◦ and• Abnormal frontal chest x-ray with diffuse infiltrates in one or both lungs<ul style="list-style-type: none">◦ and• An absence of clearly demonstrable intravascular volume overload as signified by pulmonary wedge presence of > 18 mmHg or global and diastolic index of > 850 or other objective indicators of intravascular volume such as Echocardiography
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ARDS, acute respiratory distress syndrome; P / F, PaO₂ / FiO₂; PEEP, positive end expiratory pressure.

Table 2Patient Characteristics^a

Characteristic	Value
Gender, n	
Female	101
Male	172
Ethnicity, n (%)	
Hispanic	175 (64)
Caucasian	71 (26)
Black	27 (10)
Age, years	8 ± 5
TBSA burned, %	53 ± 24
Admission post burn, days	2 ± 3

ARDS, acute respiratory distress syndrome; SD, standard deviation; TBSA, total burn surface area.

^aData expressed as mean ± SD unless noted otherwise.