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Correlation of oxygen saturation as measured by pulse oximetry/fraction of inspired oxygen ratio with Pa_{O_2}/fraction of inspired oxygen ratio in a heterogeneous sample of critically ill children☆

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Abstract

Purpose: Oxygen saturation as measured by pulse oximetry (Sp_{O_2})/fraction of inspired oxygen (F_{IO_2}) (SF) ratio has demonstrated to be an adequate marker for lung disease severity in children under mechanical ventilation. We sought to validate the utility of SF ratio in a population of critically ill children under mechanical ventilation, noninvasive ventilation support, and breathing spontaneously.

Materials and methods: A retrospective database study was conducted in a pediatric intensive care unit of a university hospital. Children with Sp_{O_2} less than or equal to 97% and an indwelling arterial catheter were included. Simultaneous blood gas and pulse oximetry were collected in a database. Derivation and validation data sets were generated, and a linear mixed modeling was used to derive predictive equations. Model performance and fit were evaluated using the validation data set.

Results: Three thousand two hundred forty-eight blood gas and Sp_{O_2} values from 298 patients were included. 1/SF ratio had a strong linear association with 1/Pa_{O_2}/F_{IO_2} (PF) ratio in both derivation and validation data sets, given by the equation 1/SF = 0.00164 + 0.521/PF (derivation). Oxygen saturation as measured by pulse oximetry/F_{IO_2} values for PF criteria of 100, 200, and 300 were 146 (95% confidence interval [CI], 142-150), 236 (95% CI, 228-244), and 296 (95% CI, 285-308). Areas under receiver operating characteristic curves for diagnosis of PF ratio less than 100, 200, and 300 with the SF ratio were 0.978, 0.952, and 0.951, respectively, in the validation data set.

Conclusions: Oxygen saturation as measured by pulse oximetry/F_{IO_2} ratio is an adequate noninvasive surrogate marker for PF ratio. Oxygen saturation as measured by pulse oximetry/F_{IO_2} ratio may be an ideal noninvasive marker for patients with acute hypoxemic respiratory failure.

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1. Introduction

Acute lung injury and acute respiratory distress syndrome (ARDS) have a low incidence but with a large mortality in children admitted to pediatric intensive care units (PICUs) [1,2]. The diagnosis of acute lung injury/ARDS according to American-European Consensus Conference definition required arterial blood gas (ABG) sampling [3]. Similarly, the recent Berlin definition of ARDS also includes arterial PaO_2, setting 3 categories of ARDS based on the degree of hypoxemia: mild (200 mm Hg < PaO_2/fraction of inspired oxygen [FIO_2] ≤ 300 mm Hg), moderate (100 mm Hg < PaO_2/FIO_2 ≤ 200 mm Hg), and severe (PaO_2/FIO_2 [PF] ≤ 100 mm Hg) [4].

However, in current clinical practice, ABG performed in PICUs is much less common than in the past. An early diagnosis in these pathologies is essential because an earlier establishment of the lung protective ventilation strategies may improve the outcome of children [5-7]. Furthermore, there has been a great increase of noninvasive ventilation (NIV) use to effectively treat respiratory failure in children in recent years. Acute respiratory distress syndrome, acute hypoxemic respiratory failure, and high oxygen requirements have also been identified as NIV failure predictors in both pediatric and adult patients [8-16]. In fact, PF ratio has been suggested as a useful figure to decide whether to intubate a patient during NIV therapy [12]. Similarly, oxygen saturation as measured by pulse oximetry (SpO_2)/FIO_2 (SF) ratio has also been described as a NIV failure predictor in adults [17], whereas in children, SF ratio has also been suggested as a NIV outcome predictor in a preliminary study [18]. Because of being noninvasive and continuously available, SF ratio might be very useful during NIV.

Arterial PaO_2 is also included in many pediatric severity scores, such as Pediatric Index of Mortality 2 [19] and Pediatric Risk of Mortality III [20]. As previously stated, because of the scarcity of arterial simples nowadays, this item is frequently lost. A noninvasive surrogate could improve the usefulness of these scores if it was always available. In a similar way, the oxygenation index has been recently described to have a strong linear association to oxygen saturation index [21].

Oxygen saturation as measured by pulse oximetry/FIO_2 ratio has been demonstrated to correlate well with the PF ratio in both adult and pediatric studies [21-24], and it may be used to diagnose ARDS in a noninvasive manner [21]. In children, SF ratios of 221 and 264 correspond to PF ratios of 200 and 300. In this pediatric study, the population was very homogeneous because 95% of the observations met oxygenation criteria for mild ARDS (PF ratio < 300) and close to 80% met oxygenation criteria for moderate ARDS (PF ratio < 200) [21].

We hypothesized that the correlation between SF ratio and PF ratio may be different in a sample of children under mechanical ventilation, NIV support, and breathing spontaneously without supplementary oxygen. The main objective of our study was to validate the SF ratio/PF ratio correlation in a heterogeneous sample of critically ill children. Secondary objective was to compare our results with previously published works.

2. Materials and methods

We conducted a retrospective study of ABG and SpO_2 values in a population of children, under mechanical ventilation, noninvasive ventilation support, and breathing spontaneously, who were admitted to a tertiary care noncardiac surgery PICU. Data were extracted from a clinical and research database, maintained and monitored by the PICU physicians delivering patient care. This database integrates components of the intensive care unit flow sheet and laboratories as well as diagnostic and demographic information. Corresponding measurements of SpO_2, PaO_2, and FIO_2 were included in the database at the time of the extraction of ABG. According to our PICU protocol, these data were recorded simultaneously. Before SpO_2 was recorded, it was checked the correct positioning of the sensor, adequate waveforms, and that no ventilators changes had been made in the previous 30 minutes. Data were excluded from analysis if the patient had a diagnosis of methemoglobinemia or carbon monoxide poisoning. Oxygen saturation as measured by pulse oximetry values over 97% were also excluded. Patients on nasal cannula or mask oxygen were excluded because of the inaccuracy to calculate the delivered FIO_2. We used Philips FAST (Fourier Artifact Suppression Technology) pulse oximeters (Philips Healthcare, Eindhoven, Netherlands). The study was approved by the institutional review board with a waiver of written consent.

2.1. Analysis

Data set was divided into derivation and validation groups through randomization with 50% of observations in each group. The random split was done on an observation level.

2.2. Derivation data set

We transformed data (1/PF and 1/SF) to satisfy assumptions of normality and improve model fit. The data set was first analyzed using 2-way scatter plots to characterize the relationship between 1/PF and 1/SF ratios. Simple correlation with Pearson correlation coefficient was obtained, and linear regression analysis was used to derive a predictive equation for 1/PF ratio prediction from 1/SF ratio. Given that multiple measurements were possible from the same patient, a general mixed model was used.

Based on the derived regression equation, SF ratio values that corresponded to PF ratio values of 100, 200, and 300 were determined. Receiver operating characteristic (ROC) curves were plotted with the area under the curve (AUC) and calculated to assess the degree of SF ratio discrimination for diagnostic real PF ratio less than 100, 200, and 300. We calculated the