

Validity of Peripheral Capillary Oxygen Saturation and Normal Mixed Venous Oxygen Tension in Measurement of O₂ Content

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Abstract

Background

The change in venous oxygen saturation occurs earlier, and even its reduction is faster than arterial oxygen saturation. The aim of this study was to validate SvO₂ and PvO₂ for O₂ content measurement in children hospitalized with respiratory distress.

Materials and Methods

In this cross-sectional study, 80 children who were admitted with respiratory distress were included in the study according to the study inclusion and exclusion criteria. Baseline characteristics such as age and gender were recorded in the data collection form, designed by the researcher. In order to determine the amount of SaO₂ and PaO₂ the arterial blood sample was prepared, venous blood sample was prepared to determine the amount of hemoglobin, SvO₂ and PvO₂. The gold standard for the determination of O₂ content was the arterial blood sample. All samples were examined by a blood gas analyzer and then calculated using the formula of O₂ content values. For SvO₂ and PvO₂ validation, we used diagnostic analysis methods including sensitivity, specificity, positive and negative predictive values. Cut-point value for SvO₂ and PvO₂ were 76.50 and 44.30, respectively.

Results

In this study, the patients' mean age was 5.15 ± 4.20 years. 62.5% (n=50) were male and 38.5% (n=30) were female. The values of arterial and venous O₂ content were 14.13 ± 3.05 and 11.95 ± 3.04 from a total of 80 patients. SvO₂ and PvO₂ for measuring O₂ content had a sensitivity of 80.5 and 71.80%, respectively, and specificity of 80.5 and 78%, respectively.

Conclusion

SvO₂ and PvO₂ have good validity for evaluating O₂ content in patients admitted to PICU. So that SvO₂ had a sensitivity and specificity of over 80%, and PvO₂ had a sensitivity and specificity of over 70%.

Key Words: Children, Respiratory Distress, SvO₂, PvO₂, Oxygen Content, Validity.

*Please cite this article as: Bilan N, Eskandartash E. Validity of Peripheral Capillary Oxygen Saturation and Normal Mixed Venous Oxygen Tension in Measurement of O₂ Content. Int J Pediatr 2019; 7(9): 10019-27. DOI: [10.22038/ijp.2019.41833.3522](https://doi.org/10.22038/ijp.2019.41833.3522)

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Received date: Jan.25, 2019; Accepted date: Aug. 12, 2019

1- INTRODUCTION

Oxygen is a colorless, tasteless and odorless gas used in the body for aerobic metabolism. Oxygen plays an important role in the treatment of respiratory diseases in children and adults. Over the past years, there have been many important points about the advantages and disadvantages of this matter. Today, oxygen is a cheap drug that is easily found everywhere and administered. In children's medicine, due to the effects of hypoxia and hyperoxia, knowledge about tissue oxygenation is very important. A chronic shortage of oxygen due to respiratory distress can lead to long-term brain damage (1). In the lungs alveoli, respiratory gas is exposed to blood and is rapidly displaced from the capillary walls of the alveoli between blood and alveoli. Oxygen gas is rapidly dissolved in the plasma and released into red blood cells (2). Pulse oximetry is used to measure the oxygen saturation of arterial blood. Pulse oximetry is a non-invasive method for continuous measurement of arterial oxygen saturation. The parameter of this measurement method is not, contrary to the general impression Oxygen saturation (SaO₂), and is actually called Peripheral pulse oximetry (SpO₂).

The measured value of SpO₂ obtained from pulse oximetry is also used as a function of oxygen saturation. There is another factor for measuring the amount of oxygen intake that is called influence of mixed venous oxygen tension (PvO₂) or the pressure of a mixture of venous oxygen (3). The normal value of PvO₂ in a person is approximately 40 mm Hg (4). This factor shows the balance between the amount of respiratory oxygen and the amount of oxygen consumed. Oxygen consumed is defined as the difference between arterial and venous oxygen saturation. For accurate measurement of PvO₂, a blood sample is prepared from the superior vena cava (SVC), inferior vena cava (IVC) and heart (5).

So this sample should be made from a pulmonary artery catheter. The factors that affect PvO₂ include cardiac outflow, oxygen consumption, total hemoglobin, and hemoglobin saturation with oxygen. The factors that increase PvO₂ levels include reduced oxygen consumption (due to hypothermia), left to right shunt, high cardiac outflow, sepsis, and reduced oxygen supply by tissues (due to toxicity or cyanide); in contrast, the factors that lead to reduced levels of PvO₂ include increased levels of respiratory oxygen (due to fever and shivering, exercise and malignant factors), hyperthermia, and reduced oxygen delivery (due to hypoxia, low cardiac outflow and hemoglobin abnormalities or deficiency) (6). Measuring arterial and venous oxygen saturation together can be used to achieve the amount of oxygen supply and consumption, and then to determine the oxygen status of the body (1, 7-9). The changes in venous oxygen saturation occurred earlier, and even its reduction was observed faster than arterial oxygen saturation (7-9).

Venous oxygen saturation is mainly measured in children in cases of suspected respiratory distress, and Phase Doppler Anemometry (PDA) is measured to increase the accuracy of arterial blood saturation measurement. Arterial oxygen content (CaO₂) is the amount of oxygen bound to the hemoglobin plus the amount of oxygen dissolved in the blood. The normal amount of CaO₂ is approximately equal to 20 ml of O₂/dl. The conditions that lead to pathological changes in CaO₂ include reduced oxygenation (due to low cardiac outflow, and hypotension due to respiratory distress), and increased metabolic rate (due to acute respiratory distress syndrome, sepsis and septic shock) (10). According to literature review, few studies reported complete information on SvO₂ and PvO₂ validation in children (11). Therefore, the aim of this study was to

confirm the validity of peripheral capillary oxygen saturation (SvO₂), and normal mixed venous oxygen tension (PvO₂) in measurement of O₂ content.

2- MATERIALS AND METHODS

2-1. Study design and population

The present cross-sectional study was conducted in Tabriz Children's Hospital, Tabriz, North West of Iran, for 9 months from 2018 to 2019. Regarding the literature review and reference (12), using software power to determine the sample size, taking into account alpha error value of 5% and power = 81%, 73 samples were obtained. Considering the probable rate of 10% drop in samples during the study, the final number of 80 samples were studied. Sampling was done as a census of patients according to the study inclusion and exclusion criteria.

2-2. Laboratory measurements

Patients were enrolled by inclusion criteria. Respiratory distress was diagnosed by PICU expert pediatric pulmonologist. Demographic information such as age and gender were recorded in the data collection form, designed by the researcher. In order to determine the amount of SaO₂ and PaO₂, the arterial blood sample was prepared and the venous blood sample was prepared to determine the amount of hemoglobin, SaO₂ and PaO₂. All arterial blood samples were taken by PICU nurse 2 ml with heparinoid insulin syringe and immediately sent to laboratory in ice for blood gas measurement. Venous blood samples were also taken by the same PICU nurse, 5 ml with heparinoid insulin syringe and immediately sent to laboratory for blood gas and other tests (Hb and MCV) measurement. SaO₂ and PaO₂ derived from arterial blood were considered as the gold standard for O₂ content measurement. All samples were analyzed using blood gas analysis machine (Gem Premier 3000,

model 5700; Instrumentation Laboratory, Lexington, MA) calibrated according to standard quality assurance protocols. Hb and MCV measurement were done by Cell Counter Machine (Sysmex Cell Counter, Model XP-300, Automated Hematology Analyzer, Lincolnshire, USA). The following formula was used to calculate arterial O₂ content (the normal values are 16-20%):

$$CaO_2 = (Hb \times 1.34 \times SaO_2) + (PaO_2 \times 0.003) \quad (12)$$

The description of the formula used is shown in the **Table.1**.

Table-1: Calculation of arterial O₂ content.

CaO ₂	Arterial oxygen content in vol%
Hb	Hemoglobin content in grams per deciliter
1.34	Amount of oxygen that can be kept in 1 gram of hemoglobin completely saturated
SaO ₂	Arterial Oxygen Saturation Percentage
PaO ₂	Arterial Oxygen Pressure in mm Hg
0.003	Amount of oxygen dissolved in the plasma
CaO ₂ : Arterial O ₂ content, SaO ₂ : Oxygen saturation, PaO ₂ : Partial pressure of oxygen, Hb: Hemoglobin.	

The following formula was used to calculate mixed venous O₂ content (the normal values are equal to 12-15%):

$$CvO_2 = (Hb \times 1.34 \times SvO_2) + (PvO_2 \times 0.003) \quad (12)$$

The description of the formula used is shown in the **Table.2**.

Table-2: Calculation of mixed venous O₂ content

CvO ₂	Venous oxygen content in vol%
Hb	Hemoglobin content in grams per deciliter
1.34	Amount of oxygen that can be kept in 1 gram of hemoglobin completely saturated
SvO ₂	Venous Oxygen Saturation Percentage
PvO ₂	Venous Oxygen Pressure in mm Hg
0.003	Amount of oxygen dissolved in the plasma
CvO ₂ : Venous O ₂ content, SvO ₂ : Peripheral capillary oxygen saturation, PvO ₂ : Normal mixed venous oxygen tension, Hb: Hemoglobin.	

2-3. Ethical consideration

The project was approved by the Ethics Committee of Tabriz University of Medical Sciences with the code IR.TBZMED.REC.1397.901. All patient information was kept completely confidential. No additional costs were imposed on the patients. In the course of the project, we adhered to Helsinki Statement. The written informed consent form was obtained from patients for the study and all stages of the study were explained to them. The patients at each stage of the study were completely free to be excluded.

2-4. Inclusion and exclusion criteria

The study inclusion criteria included: age below 14 years old, satisfaction to participate in the study, respiratory distress and patients under intubation and mechanical ventilation. The study exclusion criteria included heart disease, congenital malformations such as pulmonary fibrosis and sarcoidosis, hemoglobinopathy such as thalassemia and others.

2-5. Data Analyses

All data were analyzed by software SPSS software (version 21.0). Demographic results were presented as Tables and Figures of frequency and mean \pm standard deviation (SD). In order to calculate the normality of the data, q-q plot and Kolmogorov-Smirnov test (K-S) were used. If no normality was found, the mean (25-75 percentile) was presented. In order to compare the quantitative variables, parametric and non-parametric data were first determined using Mann Whitney U test. Non-independent t-test and multiple analysis of variance (ANCOVA) were used if the data were parametric.

Kruskal Wallis test was used if the data were non-parametric. The p-value less than 0.05 were statistically significant. Diagnostic statistical methods were used to

determine the value and validity of variables. Therefore, receiver operating characteristic (ROC) curve was used to determine the area under the curve (AUC), as well as the report of sensitivity, specificity, positive and negative predictive value was used. For comparison of quantitative variables linear regression with 95% confidence interval (95% CI), and Spearman's rho test were used.

3- RESULTS

In the present study, 80 children with respiratory distress admitted in PICU and intubated and under mechanical ventilation were enrolled in the study. In the study of gender distribution in the studied patients, 50 patients (62.5%) were male and 30 patients (38.5%) were female. The mean \pm SD of patient's age was 5.15 ± 4.20 years with a median of 4 years. The minimum age was one month and the maximum age was 13 years old. The mean \pm SD of the values of patients' laboratory samples, including arterial and venous blood gases analysis, is shown in **Table.3**.

SaO₂, PaO₂ and arterial O₂ content values were considered as the golden standard. The results showed that the use of venous O₂ content instead of arterial O₂ content in the present study had a sensitivity of 90.91% (70.87-98.88, 95% confidence interval [CI]), and the specificity was equal to 67.24% (53.66-78.99, 95% CI). The positive diagnostic value of venous O₂ content was 51.28% (41.57-60.90, 95%CI), and the negative diagnostic value was 95.12% (83.71-98.67, 95%CI). For SvO₂ and PvO₂ validation when calculating O₂ content of the patients, the results were as follows. **Figure.1**, shows the results of SvO₂ and PvO₂ validation for the calculation of O₂ Content. **A) SvO₂**: For SvO₂ validation, AUC obtained was 0.936 (0.887-0.985, 95%CI) with p-value of 0.001. The sensitivity of SvO₂ was 87.2% and its specificity was 80.5%. The value of cut-off point was 76.50.

B) PvO₂: For PvO₂ validation, AUC was 0.818 (0.728-0.909, 95%CI) with p-value of 0.001. The sensitivity of PvO₂ was

71.8% and its specificity was 78%. Cut-off point value was 44.30.

Table-3: Mean of para-clinical test values of children with respiratory distress admitted in PICU (n=80).

Variables	Mean ± SD (Min - Max)
ABG	
pH	7.37 ± 0.14 (7.00 – 7.98)
PCO ₂	39.76 ± 22.74 (12 - 173)
HCO ₃ ⁻	21.56 ± 7.24 (3.70 – 41.60)
PO ₂	87.53 ± 34.96 (32 - 160)
Sat O ₂	87.35 ± 12.73 (43 - 99)
VBG	
pH	7.32 ± 0.11 (7.04 – 7.65)
PCO ₂	45.48 ± 19.05 (12 – 105/10)
HCO ₃ ⁻	23.08 ± 7.74 (3.70 – 37.20)
PO ₂	51.30 ± 23.90 (12 -120)
Sat O ₂	74.30 ± 14.56 (31 - 97)
Hb	11.76 ± 2.30 (4/20 – 16.20)
MCV	77.88 ± 8.84 (33.90 - 93)
O₂ Content	
Arterial	14.13 ± 3.05 (3.87 – 21.68)
Mixed Venous	11.95 ± 3.04 (3.16 ± 19.12)
ABG: Arterial blood gas, VBG: Venous blood gas, Hb: Hemoglobin, MCV: Mean corpuscular volume, PCO ₂ : Carbon-dioxide partial pressure, HCO ₃ ⁻ : Bicarbonate, PO ₂ : Oxygen partial pressure, Sat O ₂ : Oxygen saturation. SD: Standard deviation.	

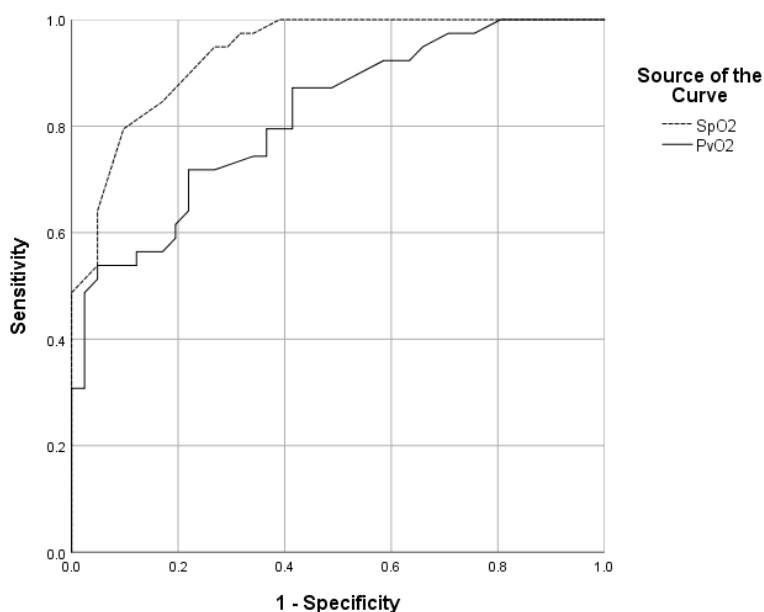


Fig.1: Roc curve- SvO₂ and PvO₂ validation for O₂ content measurement.

(SvO₂: Peripheral capillary oxygen saturation, PvO₂: Normal mixed venous oxygen tension).

4- DISCUSSION

As a golden standard, the patient's respiratory state is assessed by analyzing arterial blood gas, which is primarily invasive and, secondly, requires expert personnel to properly retrieve the arteries. In children's medicine, due to the high sensitivity of patients, arterial blood gas is difficult to assess in a routine and repetitive manner. On the other hand, the analysis of venous blood gases can also be helpful in evaluating the status of oxygen delivery in patients. Therefore, we decided to investigate the validity of SvO₂ and PvO₂ in O₂ content measurement in children hospitalized with respiratory distress. The main goal of this study is to assess whether O₂ content can be measured by analyzing venous blood gas instead of analyzing arterial blood gas.

Enough oxygen supply is required for body tissues and normal functioning. The concentration of oxygen can be effective on cardiovascular health, proper blood circulation, and other tissues associated with blood circulation. Several techniques have been devised to assess the amount of oxygen supply, most of which are not comprehensively accepted. Arterial blood gas analysis plays an important role in assessing the status of patients with respiratory problems.

On the other hand, this test is a time consuming, painful and invasive process. It has been shown in studies that the analysis of venous blood gases has an associated level with arterial blood, but the difference between arterial and venous blood gases is sometimes high and unpredictable, so that it does not allow complete replacement (13-16). The main determinant of O₂ content of venous blood is determined by the amount of oxygen delivered to the tissue (DO₂), and the amount of oxygen used by the tissue (VO₂). DO₂ is determined by O₂ content of arterial blood and cardiac output, while VO₂ is determined by various factors

affecting the amount of tissue respiration. The relationship between these two variables is illustrated by the changes shown in Fick formula in the following (17):

$$CvO_2 = CaO_2 - \frac{VO_2}{CO}$$

If CvO₂ and CaO₂ are considered as venous and arterial blood O₂ content, respectively, these are measured by measuring the concentration of oxygenated hemoglobin and the amount of oxygen dissolved in the blood. Our study showed that no significant difference was found in the values of O₂ content calculated using arterial and venous blood gas analysis parameters. Also, in the present study, the results showed that in linear regression analysis a positive relationship was found between PvO₂ and SvO₂ (p=0.001, F=110.56), so that for each unit increase in SvO₂, we have a 0.766 unit increase in PvO₂.

On the other hand, the comparison of the monotonic PvO₂ and SvO₂ values by Spearman's rho test showed that PvO₂ was significantly correlated with SvO₂ (p = 0.001, r = 0.996). This result shows that by increasing SvO₂ of 1 unit, we see an increase of up to 0.996 units in PvO₂. According to the study results of clinical criteria of the patients it was found that the results obtained from Pearson test are significant and reasonable.

Acid-base analysis is one of the most prominent methods used in PICU to determine the status of patients with respiratory distress (18, 19). The non-invasive methods efficiency such as pulse oximetry, oxygen-bound monitoring, and exhaled carbon dioxide has been confirmed (18), but these variables do not provide information on pH, bicarbonate, and PO₂. For this reason, in PICU we use arterial blood gases' analysis. However, this method is invasive and has some problems, including the effect of

hemostasis on blood sampling from the arteries. It is also a painful problem in children. In patients admitted to PICU, the arteries are basically available, but in some cases, these arteries are not available. The clinicians use central and peripheral veins to assess the status of blood gases. We took venous blood samples of approximately all patients admitted to assess the status of para-clinical tests. If the blood gas status of patients can be evaluated by intravenous blood, it can easily be sampled and analyzed. For many years, clinicians have been looking for alternative methods for ABG in children and adults, and in this regard various studies have been conducted to assess the relationship between the values of venous and capillary blood gases (16, 18-20).

Studies conducted on the comparison of Arterial blood gases (ABGs) with Venous Blood gases (VBGs) in patients with diabetic ketoacidosis and those in PICU have shown a good correlation between the values of samples of ABG and VBG (1, 2, 9, 12), but few studies have been conducted which randomly studied a high sample size of stable and unstable patients admitted to PICU. In the present study, we studied 80 patients in PICU over 1 month of age and healthy cardiovascular disease with respiratory distress in relation to pH, PaO₂, PCO₂ and HCO₃⁻ levels, along with O₂ content by ABG and VBG. In the present study, SaO₂, PaO₂ and arterial O₂ content values were considered as the golden standard.

The results showed that the use of venous O₂ content instead of arterial O₂ content in the present study had a sensitivity of 90.91% (70.87-98.88, 95%CI) and the specificity was equal to 67.24% (53.66-78.99, 95%CI). The positive diagnostic value of venous O₂ content was 51.28% (41.57-60.90, 95%CI), and the negative diagnostic value was 95.12% (83.71-98.67, 95%CI). In a study conducted by McLain et al., a good correlation was observed

between pH and PCO₂ values compared with ABG with VBG, while this correlation was not observed in PO₂ study. The study results are consistent with our study (20). In a study conducted by Yusuf et al., consistent with our study, a good correlation was observed between pH and PCO₂ values in neonates with a maximum age of 3 hours (21), but this study was performed on subjects under 1 month which is not consistent with our study. Inconsistent with our study, Rath et al. showed no correlation between pH, PCO₂ and PO₂ values compared with ABG and VBG (18). For SvO₂ validation, AUC value obtained was 0.936 (0.887-0.985, 95%CI) with p-value of 0.001. The sensitivity of SvO₂ was equal to 87.2% and its specificity was equal to 80.5%. The value of Cutoff Point was equal to 76.50.

Also, for PvO₂ validation, AUC obtained was equal to 0.818 (0.728-0.909, 95%CI) with a p-value of 0.001. The sensitivity of PvO₂ was 71.8% and its specificity was 78%. Cutoff Point value was 44.30. These results for the calculation of O₂ content using SvO₂ and PvO₂ indicate that these are valid. For a large group of children with mild to moderate disease, including kidney disorders, dehydration, diabetic ketoacidosis and metabolic diseases; in such cases, the acquisition of ABG is not critical and VBG analysis can also be used.

A study by Razi et al. which was conducted on 102 VBG samples of children admitted to the PICU, venous blood gases, especially pH, Base excess, and PCO₂ levels have relatively good correlation with ABG values. Because this correlation is not close, VBG cannot substitute ABG in mechanically ventilated patients, which was not studied in our study (22). On the one hand, like our study, the majority of studies have been conducted on stable patients, while in some studies, a poor correlation was reported between arterial and venous blood gas levels in hypothermia, hypoperfusion

and shock (23, 24). On the other hand, these patients require continuous and serial evaluation of pH, PCO₂, PO₂ and HCO₃⁻.

4-1. Study Limitations

One of the limitations of this study is the low number of patients and the evaluation of patients with impaired hemodynamics, including patients with anemia, hypovolemia and hypothermia.

5- CONCLUSION

According to the study results, it can be concluded that SvO₂ and PvO₂ have a good validity for evaluating venous O₂ content instead of arterial in patients admitted to PICU. So that SvO₂ had a sensitivity and specificity of over 80%, and PvO₂ had a sensitivity and specificity of over 70%. It is suggested that future studies should consider the higher sample size and evaluate the patients with hemodynamic status disrupted and compared with healthy ones.

6- CONFLICT OF INTEREST: None.

7- ACKNOWLEDGMENTS

This Research was financially supported by Pediatric Health Research Center, Tabriz University of Medical Sciences, Tabriz, Iran (ID- code: 61891).

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