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VALIDITY OF USING THE SPO_2/FIO_2 RATIO TO DETERMINE THE DYNAMICS AND CORRECTION METHODS OF OXEMIA IN ACUTE LUNG INJURY AND ACUTE RESPIRATORY DISTRESS SYNDROME

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ABSTRACT — Continuous monitoring of oxemia in patients with acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) is essential for successful therapy.
AIM: To substantiate the validity of the use of pulse oximetry to determine the dynamics of oxemia in patients with ALI and ARDS and approbation of the «Mechanical Ventilation Expert» (MV Expert) smartphone application in a clinical setting.
MATERIALS AND METHODS: The study included 588 patients with ALI and ARDS. The interdependence of 1188 data pairs (SpO_2 and PaO_2) was analyzed. In case of hypoxemia, the parameters of respiratory support were corrected with and without the use of the «MV Expert» application. ROC curves and linear regression analysis were used for data processing.
RESULTS: The prognostic value of SpO_2 and PaO_2 in this group of patients was almost equivalent. At SpO_2 values from 91% to 93%, hypoxemia (PaO_2 < 60 mmHg) was noted in 11.9% (142/1189) of data pairs, and at SpO_2 from 94% to 96% this condition was confirmed in 1.3% (16/1189) of data pairs. In cases where the recommendations of the «MV Expert» application were followed, oxemia indicators increased significantly more often ($p = 0.002$) and by more significant values (with $p=0.007$ for SpO_2 and $p = 0.001$ for PaO_2) than in cases when doctors adjusted settings based on their own experience.
CONCLUSION: With a high degree of probability, SpO_2 dynamics shows significant changes in oxemia in patients with ALI and ARDS. At SpO_2 from 94% to 96%, the development of hypoxemia (PaO_2 < 60 mmHg) was observed in 1.3% of cases. The use of the «MV Expert» application increases the effectiveness of respiratory support.

KEYWORDS — oxygenation index, acute lung injury, acute respiratory distress syndrome.

INTRODUCTION

Respiratory support is one of the main components of the treatment of patients with acute lung injury (ALI) and acute respiratory distress syndrome (ARDS) [1, 2].

At the same time, both hypoxia and hyperoxia have a negative effect on mortality rates in severely ill patients [1, 2, 3]. Therefore, an urgent task for the attending physician is to constantly monitor the level of oxemia, especially when using of invasive and non-invasive mechanical ventilation (MV).

Objectively, the most accurate indicator of blood oxygen saturation is the partial oxygen pressure (PaO_2). This indicator is also used in the calculation of the hypoxemia index (PaO_2/FiO_2) to assess external respiration dysfunction in most scales of severity and physical condition of the patient (SOFA, APACHE II–III, etc.). Measurement of arterial blood gas (ABG) is an invasive and costly procedure that requires both time and consumables, making it difficult to continuously monitor patients for oxemia. Moreover, multiple sampling of arterial blood entails certain risks for patients in terms of the development of adverse consequences (bleeding and thrombotic complications) [4].

A routine method for monitoring oxemia, which is used in most hospitals, is the non-invasive measurement of oxygen saturation (SpO_2) using pulse oximetry. However, there is no direct linear relationship between SpO_2 and PaO_2 [5, 8, 9]. SpO_2 parameters are influenced by hemoglobin and acid-base status, changes in body temperature and cardiac output [6], the level of perfusion of peripheral tissues and the use of vasoactive drugs [7, 9].

The second, but not the last, problem in the treatment of patients with ALI and ARDS is the choice of the ventilation parameter to be adjusted (positive end-expiratory pressure, respiratory rate, inspiratory pressure, etc.) to more effectively correct hypoxemia. Based on numerous publications and extensive practical experience, we have created an application for smartphones called «Mechanical Ventilation Expert» (MV Expert) to help doctors in solving these problems [10].

The objectives of this study were to substantiate the validity of the use of pulse oximetry to determine the dynamics of oxemia in patients with ALI and

ARDS and approbation of the «Mechanical Ventilation Expert» (MV Expert) application in a clinical setting.

MATERIALS AND METHODS

Between January 2019 and December 2021, a prospective comparative study was conducted, which included 637 patients aged 18 to 65 years with ALI and ARDS. All patients were treated in intensive care units of five clinical hospitals in Volgograd, Russia. The study was approved by the local ethics committee of the Volgograd State Medical University (ref: 127/2019/12/12). All patients signed a voluntary consent to participate in the study and also consented to the publication of the results.

49 patients with hyperbilirubinemia (n = 38) and those who underwent extracorporeal membrane oxygenation (n = 11) were excluded from the study. The PaO2/FiO2 ratio was used to differentiate between ALI and ARDS (≤ 300 for ALI and ≤ 200 for ARDS). The first cohort (n = 225) included patients with ALI, the second cohort (n = 363) included patients with ARDS. All patients used non-invasive (low and high flow oxygen therapy, CPAP) and invasive (MV) methods of respiratory support.

In intensive care units, PaO_2 was measured using a combined blood gas analyzer (ABL800 FLEX, Denmark) within 5 minutes after sampling. Simultaneously with blood sampling, SpO_2 was measured using a bedside monitor pulse oximeter (BSM-3763, Nihon Kohden Corporation, Japan). In some patients, up to 5 pairs of data (SpO_2 and PaO_2) were collected at least 2 hours apart.

To evaluate the operation of «MV Expert», we checked changes in SpO_2 values 5–10 minutes after following the application's recommendations to correct respiratory support parameters.

The obtained data were analyzed using the SPSS statistical software package (version 26, IBM, USA). The variables were presented as mean with standard deviation (SD). When comparing unrelated groups, the Mann-Whitney U-test (for quantitative values) and Fisher's exact test (for nominal variables) were used. The Wilcoxon test was used for the analysis of related groups. To determine the interdependence of indicators, ROC analysis and linear regression analysis were used. Significance of differences was confirmed by the value of the two-sided coefficient $p \le 0.05$.

RESULTS AND DISCUSSION

Demographic and clinical data of the included patients are shown in Table 1. At admission to the intensive care unit, 20.4% (46/225) of patients in the ALI group and 55.4% (201/363) of patients in the ARDS group had a hypoxic profile (PaO_2 < 60 mmHg).

The study groups were comparable in terms of comorbidity. In patients of the ARDS group, vasopressors were used significantly more often ($p = 0.001$) to stabilize hemodynamics.

ROC analysis was performed to determine the relationship between PaO_2 and SpO_2 in 1189 data pairs (Fig. 1). According to the results of the ROC analysis, the area under the ROC curve corresponding to the relationship between ALI prognosis and PaO_2 and SpO_2 values was 0.648±0.02 with 95% CI: 0.610–0.686 ($p = 0.000$) for PaO_2 and 0.615±0.02 with 95% CI: 0.576–0.654 ($p = 0.000$) for SpO_2. Cut-off thresholds for PaO_2 and SpO_2 were 61.5 mmHg for PaO_2 and 91.5% for SpO_2. With a decrease in indicators below the threshold values, a high risk of developing ARDS was predicted. The sensitivity and specificity of the method were 76.0% and 70.5% for PaO_2 and 73.1% and 68.6% for SpO_2, respectively. The prognostic value of SpO_2 and PaO_2 in this group of patients was almost equivalent. At SpO_2 values from 91% to 93%, hypoxemia (PaO2 < 60 mmHg) was noted in 11.9% (142/1189) of data pairs, and at SpO_2 from 94% to 96% this condition was confirmed in 1.3% (16/1189) of data pairs.

Linear regression analysis was performed to identify the dependence of PaO_2/FiO_2 on SpO_2/FiO_2 (Table 2).

The observed dependence of PaO_2/FiO_2 on SpO2/FiO2 is described by the equation: $PaO_2/FiO_2 = 1.29 + 0.73*SpO_2/FiO_2$. With an increase in SpO_2/FiO_2 by 1 unit, an increase in PaO_2/FiO_2 by 0.73 units is expected (95% CI 0.718–0.749). The significance level of the model (p) was less than 0.001. Based on the value of the coefficient of determination, the factors included in the model determine 88.4% of the PaO_2/FiO_2 variance.

To test the validity of the recommendations given by the «MV Expert» application, we analyzed the dynamics of SpO_2 and PaO_2 after following those recommendations for patients with a decrease in SpO_2 and PaO_2 below the threshold value (Table 3).

In cases where the recommendations of the «MV Expert» application were followed, oxemia indicators increased significantly more often ($p = 0.002$) and by more significant values ($p = 0.007$ for SpO_2 and $p = 0.001$ for PaO_2) than in cases when doctors changed parameters based on their own experience. The use of the «MV Expert» application allowed to increase the effectiveness and validity of changes in respiratory support.

ALI and ARDS are major contributors to morbidity and mortality in intensive care units. The

Table 1. Demographic and clinical characteristics of included patients

Variable	ALI (n=225), M±SD	ARDS (n=363), M±SD	p
Age, years	56.8±7.6	55.9±8.8	0.776
Male, n (%)	132 (58.7)	189 (52.1)	0.118
Comorbidity:			
Obesity, n (%)	64 (28.4)	112 (30.9)	0.535
Arrhythmia, n (%)	24 (10.7)	41 (11.3)	0.813
Hypertension, n (%)	98 (43.6)	161 (44.4)	0.850
Cardiac ischemia, n (%)	37 (16.4)	52 (14.3)	0.486
Diabetes, n (%)	12 (5.3)	27 (7.4)	0.319
Vasopressors, n (%)	67 (40.1)	169 (59.9)	0.001
FiO2	0.27±0.01	0.56±0.02	0.000
SpO2, %	93.2±0.27	91.5±0.14	0.000
PaO2, mmHg	74.0±1.05	67.0±0.50	0.000
PaCO2, mmHg	43.6±9.07	43.9±6.12	0.184
pH	7.38±0.04	7.36±0.05	0.281
Arterial Bicarbonate, mmol/l	24.2±5.3	21.8±3.9	0.006
Lactate, mmol/l	2.23±0.17	2.36±0.25	0.012
Hemoglobin, g/l	148.3±7.44	154.6±8.08	0.371
Systolic blood pressure, mmHg	127±9.1	117±8.2	0.034
Diastolic blood pressure, mmHg	72±4.6	87±6.1	0.007

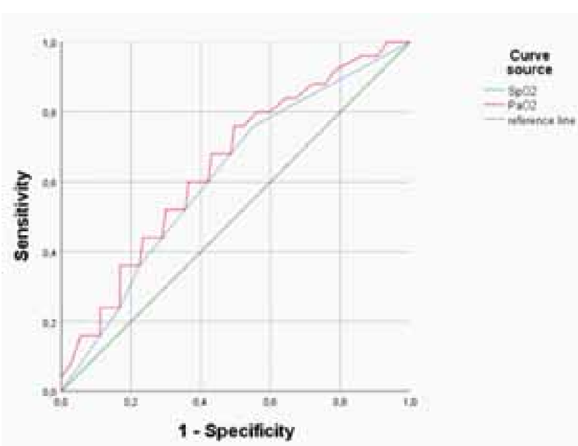

Fig. 1. ROC-curves of the relationship of ALI prediction by SpO_2 and PaO_2 values

routine use of pulse oximetry makes it possible to adequately assess the dynamics of oxemia in patients of this profile and avoid significant costs and possible harm to patients associated with the determination of blood gases.

Several formulas that allow the determination of the oxygenation index (PaO_2/FiO_2) from SpO_2 have been proposed [11]. This makes it possible to assess the degree of lung damage and the severity of the patient's condition using various scales [12].

This study has its limitations. First, the ABG and pulse oximetry measurements were not simultaneous. Given that changes in SpO_2 and PaO_2 can occur quickly, this may have affected our results. In addition, we did not control body temperature and initial parameters of the ventilator. These factors may also have influenced the relationship between SpO_2 and PaO_2.

CONCLUSION

With a high degree of probability, the dynamics of SpO2 describes significant changes in oxemia in patients with ALI and ARDS. With an SpO_2 of 94% to 96%, hypoxemia (PaO_2 < 60 mmHg) occurs in 1.3% of cases. Using the «MV Expert» application increases the effectiveness of respiratory support.

CONFLICT OF INTERESTS

The authors state that they have no conflict of interests.

CONTRIBUTORS

MIT and AMS collected, analysed, and interpreted data and made the figures. ASP did the literature review and collected data. AVE collected data and made the figures. MIT and ASP interpreted and analysed the data. MIT, ASP, AVE and AMS prepared the manuscript for submission.

Table 2. *PaO_2/FiO_2 versus SpO_2/FiO_2 from linear regression*

PaO_2/FiO_2	Model Summary						
	Model	R	R2	Скорр. R2	SD		
	SpO_2/FiO_2	0.940	0.884	0.884	26.9521		
	Coefficients						
	Model	B	SD (B)	β	t	p	95% CL for B	
	Constant	1.287	1.654		0.778	0.436	-1.957	4.531
	SpO_2/FiO_2	0.733	0.008	0.940	94.942	0.000	0.718	0.749

Table 3. *Results of respiratory support settings adjustments*

SpO_2	Adjusting respiratory support settings				
	With «MV Expert» (n = 218)		Without «MV Expert» (n = 223)		p
Increase, n (%)	187 (85.8)		164 (73.5)		0.002
No change, n (%)	24 (11.0)		46 (20.6)		0.006
Decrease, n (%)	7 (3.2)		13 (5.8)		0.253
	Before	After	Before	After	
SpO_2, M±SD	89.7±1.6	94.7±1.8	90.2±1.9	93.4±2.1	0.007
PaO_2, M±SD	57.7±0.87	74.9±1.11	58.3±0.74	67.3±0.98	0.001

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