

A New Approach to the Selection of Respiratory Support Methods in Pulmonology

DOI: 10.17691/stm2018.10.2.16

Received February 13, 2017



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The aim of the study was to evaluate the efficacy of the new approach to the selection of respiratory support methods based on the analysis of arterial blood acid-base balance and gas composition in treatment of severe community-acquired pneumonia complicated by acute respiratory failure.

Materials and Methods. Conventional pulse oximetry (SpO₂) was used (G40 Patient Monitor), arterial blood acid-base balance and gas composition were analyzed (EasyStat device) to detect hypoxemia. Respiratory support of three types was carried out: 1) oxygen therapy (O₂-therapy) with the use of oral nasal oxygen masks; 2) non-invasive lung ventilation (VENTIllogic 2 and BiPAP Vision devices); 3) artificial lung ventilation (Engström Carestation device).

The work was carried out in two sequential stages. At the first stage, a respiratory support method was selected according to the results of pulse oximetry (SpO₂). At the second stage, a respiratory support method was selected on the basis of arterial blood acid-base balance and gas composition indices (pO₂, pH, pCO₂). Recovery of pulse oximetry indices, arterial blood acid-base balance, and gas composition indices as well as presence of positive clinical dynamics were considered to be criteria of treatment efficacy.

Results. Comparative analysis of the results of the used methods has provided the possibility to develop the algorithm of choosing the respiratory support method in severe community-acquired pneumonia on the basis of arterial blood acid-base balance and gas composition with pulse oximetry indices equalling 91.0±0.8%. On admission of a patient to the intensive care unit, oxygen therapy is administered at pH>7.3; pO₂>60 mm Hg; pCO₂≤45 mm Hg; non-invasive lung ventilation — at pH<7.3; pO₂≤60 mm Hg; pCO₂≤45 mm Hg; artificial lung ventilation — at pH<7.3; pO₂<60 mm Hg; pCO₂>45 mm Hg. Selection of respiratory support based on blood acid-base balance and gas composition indices without taking into account pulse oximetry indices allows us to increase treatment efficacy, reduce the period of stay in the intensive care unit by 1.5 times, mortality — by 4.3 times.

Key words: acute respiratory failure; respiratory support; artificial lung ventilation; non-invasive ventilation; pulse oximetry.

Introduction

In addition to medical treatment, the main strategy of intensive therapy for acute respiratory failure (ARF) in the pulmonary intensive care unit (ICU) is respiratory support, including O₂-therapy with oral nasal oxygen masks; non-invasive ventilation (NIV) creating positive pressure in the airway; artificial lung ventilation (ALV) [1–3].

In the first hours of admission of a patient with ARF to the ICU, the issue of selecting a respiratory support method is urgent. Pulse oximetry indices (SpO₂) and general condition of the patient are commonly the main indicators for the selection [4–6].

Given the fact that the main physical disorders indicating the severity of the patient's condition are determined by changes in the respiratory metabolism in case of ARF developing due to severe community-acquired pneumonia, we considered it appropriate to look at the values of the patients' arterial blood acid-base balance (ABB) and gas composition as indications for selection of respiratory support methods on admission to ICU [5–7].

The aim of the study was to develop the algorithm (criteria) of selecting respiratory support methods in treatment of severe community-acquired pneumonia complicated by acute respiratory failure in the pulmonary intensive care unit.

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Materials and Methods

Comparative analysis of the results of using two approaches to the selection of treatment modality was carried out in patients with ARF: the conventional approach (according to pulse oximetry index (SpO₂)) and that proposed by the authors, according to ABB and gas composition of the arterial blood. The idea was implemented at Samara City Hospital No.4 in two stages.

At the first stage, we made observations and evaluated treatment results in 350 patients with severe community-acquired pneumonia complicated by ARF. SpO₂ value was 91.0±0.8%. On admission, all patients were administered O₂-therapy using oral nasal masks. If the general state of the patients worsened, which manifested itself as increase in respiratory work accompanied by increase in the respiratory rate of more than 30 per minute, the patients were transferred to NIV. If NIV proved to be ineffective, SpO₂ declined (<90%), changes in the neurological status (coma, psychomotor excitation) and hemodynamic disorders appeared, the patients were transferred to ALV.

During respiratory support, arterial blood ABB and gas composition were measured in all patients. When analysing treatment efficacy, arterial blood ABB and gas composition indices for NIV to be administered were taken into account, SpO₂ values remained 91.0±0.8%.

At the second stage, 350 patients admitted to the ICU with severe community-acquired pneumonia were administered respiratory support methods according to specific arterial blood ABB and gas composition indices. Thus, two groups of 350 individuals were formed depending on the algorithm used to select the method:

group 1 — the respiratory support method was selected according to pulse oximetry indices (SpO₂);

group 2 — the respiratory support method was selected according to arterial blood ABB and gas composition indices (pO₂, pH, pCO₂).

Statistical evaluation of the efficacy of respiratory support methods in groups of patients was carried out using contingency tables based on calculation of Pearson criteria (χ^2) enabling us to make judgements about randomness (nonrandomness) of distribution in contingency tables.

The following clinical, laboratory and instrumental signs served as criteria for ICU hospitalization: X-ray evidence of lower respiratory tract infection with bilateral damage to the lung tissue; rapid development of a clinical picture; progression of ARF and alveolar pulmonary edema, severe hypoxemia and/or hypercapnia, encephalopathy in early stages, tachycardia, hyperthermia and arterial hypotension [7–11].

The criteria for exclusion from the study comprised: age over 60 years; myocardial infarction and acute coronary pathology; pulmonary edema due to left ventricular failure; development of ARF against the background of chronic systemic diseases; concomitant surgical pathology and traumatic vascular lesions of the brain.

The groups were representative for the comparative analysis as there were no significant differences between them. Basic descriptive statistics were calculated for the analyzed parameters (mean value, dispersion, standard deviation, coefficient of variation, standard error), which confirmed the absence of statistically significant differences in the parameters of both groups (see the Table).

The severity of community-acquired pneumonia was assessed in accordance with clinical recommendations [1, 3].

The main methods selected for detecting hypoxemia were conventional pulse oximetry (G40 Patient Monitor; Philips-Goldway, Netherlands) and analysis of arterial blood ABB and gas composition: pO₂, pH, pCO₂ (EasyStat blood gas analyzer; Medica Corporation, USA). The examination was performed directly in ICU, the parameters were evaluated immediately upon admission of the patient to ICU, control measurements being performed every hour. On admission to ICU, all patients received the same standard pharmacological therapy, which ensured exclusion of this factor when assessing the efficacy of the proposed algorithm for selecting a respiratory support method.

Three types of respiratory support were used: 1) O₂-therapy with the use of oral nasal oxygen masks; 2) NIV using VENTiLogic 2 (Weinmann, Germany) and BiPAP Vision (Respironics Inc., United Kingdom) devices; 3) ALV using Engström Carestation device (GE Healthcare, USA).

Presence of positive clinical dynamics, recovery of pulse oximetry, arterial blood ABB and gas composition indices were considered to be the criteria of efficacy.

Comparative statistical evaluation of patient groups

Indices	Mean rank value	Dispersion	Standard deviation	Coefficient of variation	Standard error
<i>Group 1</i>					
pH	0.762	0.186	0.431	56.766	0.061
pO ₂	0.661	0.223	0.451	70.757	0.069
SpO ₂	0.487	0.255	0.505	75.140	0.071
pCO ₂	0.729	0.296	0.544	77.712	0.076
<i>Group 2</i>					
pH	0.789	0.155	0.406	53.119	0.062
pO ₂	0.592	0.247	0.497	83.906	0.071
SpO ₂	0.673	0.224	0.474	70.353	0.068
pCO ₂	0.735	0.249	0.486	68.715	0.063

Note. The descriptive statistics were calculated by nonparametric methods using ordinal random variables.

This study was approved by the Ethic Committee of Samara State Medical University and compliant with the Declaration of Helsinki (2013). All patients gave written informed consent for the scientific analysis of their data.

Data management and analysis were performed using statistics package IBM SPSS Advanced Statistics 24.0.

Results and Discussion

In the first part of the investigation (group 1), all patients admitted to ICU with $\text{SpO}_2 \geq 90\%$ received respiratory support in stages, with all three methods used in succession. At first, O_2 -therapy was administered via an oral nasal mask with a reservoir bag at the oxygen-air mixture flow rate of 10–15 L/min. In cases of $\text{SpO}_2 \leq 90\%$, NIV by means of VENTIllogic 2 device was administered in addition to O_2 -therapy. When NIV proved ineffective, SpO_2 kept declining, shortness of breath increased, there were changes in neurological status, hyperthermia, and hemodynamic disorders, the patients were transferred to ALV by means of Engström Carestation apparatus.

The efficacy of respiratory support was assessed by increase in SpO_2 , lowering in the respiratory rate, stabilization of hemodynamics, the absence of post-hypoxic encephalopathy and hyperthermia during dynamic observation.

Positive dynamics was observed in 80 out of 350 cases (23%) during O_2 -therapy, ($\chi^2_{emp} = 116.92$ at $p = 0.00000$, $\chi^2 = 3.841$, degrees of freedom $f = 1$). These patients remained on O_2 -therapy for 3 days, after that they were transferred in a stable condition to the Pulmonology Department for follow-up care.

270 patients (77%) showed increase in clinical signs of hypoxia and dyspnea, there was observed participation of intercostal muscles in the breathing mechanics, agitation or, the opposite, inhibition. Decrease in saturation ($\text{SpO}_2 \leq 90\%$), arterial blood ABB and gas composition indices ($\text{pH} \leq 7.3$; $\text{pO}_2 \leq 60$ mm Hg; $\text{pCO}_2 \geq 45$ mm Hg) continued. All these patients were transferred to NIV. Among them, positive dynamics was observed during an hour in 115 out of 270 individuals (42.6%) ($\chi^2_{emp} = 73.99$ at $p = 0.00000$), their general state stabilized, SpO_2 became more than 91%, dyspnea decreased, neurological symptoms increased no more. When measuring blood gas composition, positive dynamics was also observed: $\text{pH} > 7.3$; $\text{pO}_2 > 60$ mm Hg; $\text{pCO}_2 \leq 45$ mm Hg.

The patients were on NIV for about 2–3 days and were transferred to O_2 -therapy after stabilization of hemodynamic parameters and positive dynamics of X-ray picture. The average ICU bed-day for patients with positive dynamics ($n = 115$) was 7.0 ± 0.7 days, all of them were transferred to the Pulmonology Department for follow-up care.

Lack of effect (the continuing decline in SpO_2 to a

level $< 90\%$) was regarded as NIV ineffectiveness in 155 of 270 patients (57.4%). Their blood ABB and gas composition indices were: $\text{pH} < 7.3$; $\text{pO}_2 < 60$ mm Hg; $\text{pCO}_2 > 45$ mm Hg. All these patients were transferred to prolonged ALV and underwent tracheostomy three days later. Intensive care in ICU was aimed at nosocomial infection prevention and included changed antibiotic therapy, enteral and parenteral nutrition, immunocorrection, adjuvant therapy. Positive dynamics was observed in 83 of 155 patients (53.5%) ($\chi^2_{emp} = 9.96$ at $p = 0.0016$). On day 10–12, they were decannulated, then transferred to independent breathing and directed to the Pulmonology Department. The average ICU bed-day was 15.0 ± 2.3 days for these patients.

Among the patients of group 1 transferred to ALV, 72 individuals died (46.5%) ($\chi^2_{emp} = 40.76$ at $p = 0.00000$). Mortality in the group amounted to 20%. Analysis of treatment results showed that O_2 -therapy administered with due regard for SpO_2 indices was effective only in 22.9% of cases.

In view of this, we developed an algorithm for selecting respiratory support, irrespective of saturation indices. We applied this algorithm at the second stage (group 2) of our study in treatment of 350 patients.

Immediately upon admission to ICU, arterial blood gas composition is measured. With values of $\text{pH} \geq 7.3$; $\text{pO}_2 > 60$ mm Hg; $\text{pCO}_2 \leq 45$ mm Hg, O_2 -therapy is administered, its efficacy being assessed within 1 h. With $\text{pH} < 7.3$; $\text{pO}_2 \leq 60$ mm Hg; $\text{pCO}_2 \geq 45$ mm Hg, despite the stable condition of the patient, NIV is administered, its efficacy being assessed within 1 h. At $\text{pH} < 7.3$; $\text{pO}_2 < 60$ mm Hg; $\text{pCO}_2 > 45$ mm Hg after 1 h of NIV, the patient is transferred to ALV without waiting for changes in the neurological status and hemodynamic parameters.

In group 2, oxygen therapy was conducted only in 49 of 350 patients (14%) ($\chi^2_{emp} = 40.76$ at $p = 0.00000$). Within one hour, all of them showed good dynamics, increase and stabilization of arterial blood ABB and gas composition indices, none of them needed change in respiratory support and all of them were transferred to the Pulmonology Department for follow-up care on day 2. The average ICU bed-day was 2.0 ± 0.4 days for these patients. In this case, the method proved to be effective in 100% of cases.

The indices of $\text{pH} < 7.3$; $\text{pO}_2 \leq 60$ mm Hg; $\text{pCO}_2 \geq 45$ mm Hg were observed in 301 patients (86%), in whom NIV was immediately initiated using VENTIllogic 2 device in CPAP and ST modes with 50% concentration of oxygen in the inspired mixture of FiO_2 . Inspiratory pressure IPAP — 10 to 23 cm H_2O , expiratory pressure EPAP — 6 to 10 cm H_2O , the ratio of inspiration to expiration (Insp:Exp) — 1:2 or 1:1. After 1 h of observation, the condition of 234 out of 301 patients (77.7%) stabilized, ARF symptoms stopped increasing, positive dynamics of arterial blood ABB and gas composition was noted ($\chi^2_{emp} = 73.99$ at $p = 0.00000$), all patients remained on NIV for further treatment. On stabilization of indices:

pH \geq 7.3; pO₂>60 mm Hg; pCO₂≤45 mm Hg (after the average of 2 days), the patients were weaned from the respirator and transferred to O₂-therapy.

The respiratory support method was considered efficacious as patients were transferred to the specialized department in better condition. The average ICU bed-day was 3.0±0.9 days. NIV proved to be ineffective in 67 of 301 individuals (22.3%).

Patients in whom NIV was qualified as ineffective (n=67) were transferred to ALV using Engström Carestation device in PSV ventilation mode (pressure support ventilation) with PEEP (positive end-expiratory pressure) — 10–16 mm H₂O, 40% to 60% concentration of oxygen mixture FiO₂. Breathing rate was 16–20 per minute. After 1 h of monitoring, positive dynamics was observed in 51 of 67 individuals (76%) (χ^2_{emp} =9.96 at p=0.0016).

Patients remained on ALV and were transferred to auxiliary modes of ventilation on day 3, on average. Transfer to spontaneous breathing was performed on day 7–9. On admission to the specialized department, oxygen dependence in these patients was within the normal range. The average ICU bed-day for patients with positive dynamics was 10.0±2.3 days.

At this stage of the investigation, 16 patients transferred to ALV died (χ^2_{emp} =40.76 at p=0.00000). Mortality rate was 4.5%.

Comparative evaluation of the results of the applied respiratory support methods showed greater efficacy in group 2 (Figure 1).

The average ICU bed-day was less in group 2 than in group 1 with all types of respiratory support used (Figure 2).

Thus, in all patients with severe community-acquired pneumonia complicated by ARF, arterial blood ABB and gas composition indices (pH, pO₂, pCO₂) are more significant for selecting intensive therapy modality, irrespective of pulse oximetry indices.

Conclusion

Selection of respiratory support based on arterial blood acid-base balance and gas composition indices for intensive care of patients with severe community-acquired pneumonia on admission to the intensive care unit allows optimizing the treatment.

The following selection algorithm has been proposed: when pH 7.3; pO₂ — 80–100 mm Hg; pCO₂ — 35 to 40 mm Hg, oxygen therapy is administered via an oral nasal mask with a reservoir bag; at pH 7.20–7.27; pO₂ — 60 to 80 mm Hg; pCO₂ — 45 to 50 mm Hg — is administered via an oral nasal mask; when pH<7.3; pO₂<60 mm Hg; pCO₂>45 mm Hg on admission to the intensive care unit or in addition to non-invasive

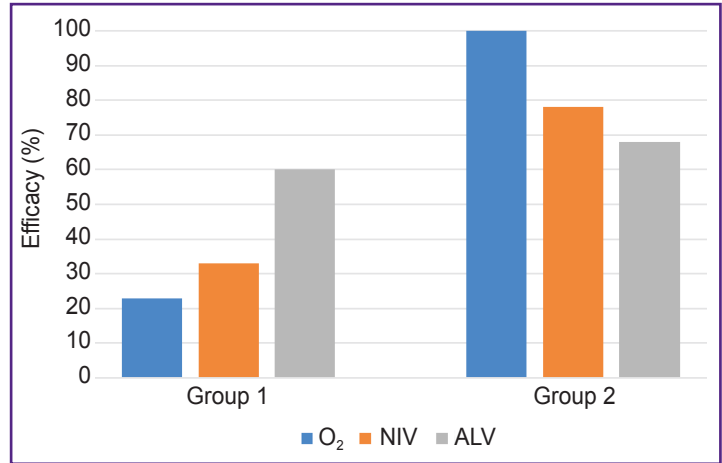


Figure 1. Comparative evaluation of the efficacy of two approaches to respiratory support:

O₂ — oxygen therapy via oral nasal oxygen mask; NIV — non-invasive ventilation (VENTIlogic 2 and BiPAP Vision); ALV — artificial lung ventilation (Engström Carestation)

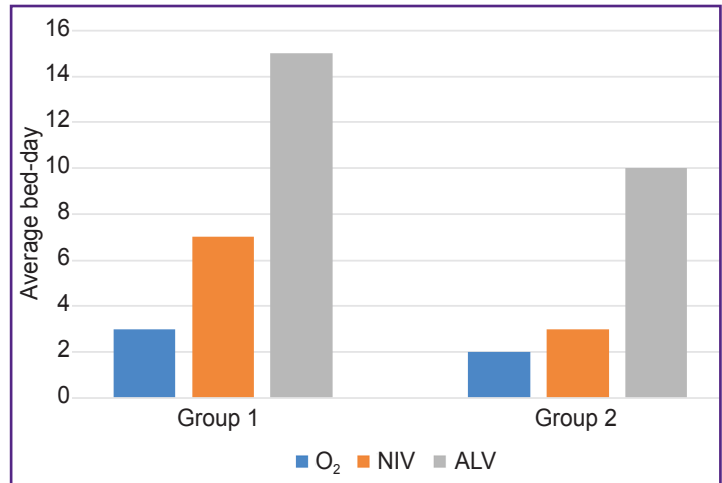


Figure 2. The average bed-day spent in the intensive care unit by patients with severe community-acquired pneumonia treated using different respiratory support approaches:

O₂ — oxygen therapy via oral nasal oxygen mask; NIV — non-invasive ventilation (VENTIlogic 2 and BiPAP Vision); ALV — artificial lung ventilation (Engström Carestation)

ventilation, patients are transferred to artificial lung ventilation within 1 h.

Intensive therapy using the respiratory support method selected in the first hour of hospitalization on the basis of arterial blood acid-base balance and gas composition indices promotes optimization of treatment and precludes various complications reducing stay in the intensive care unit by 1.5 times, mortality by 4.3 times.

Study funding. This work was funded by the authors.

Conflict of interests. The authors have no financial or other conflict of interest related to their study.

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