

Application of the “VibroLUNG” Device in Comprehensive Intensive Care of Nosocomial Pneumonia in Patients with Combined Trauma

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Abstract The aim of the study was to analyze and evaluate the efficiency of vibroacoustic therapy using the “VibroLUNG” device as part of respiratory therapy in patients with combined severe traumatic brain injury, as well as to evaluate the results of the applied antibacterial protocol in the treatment of nosocomial pneumonia. A study of peripheral and central hemodynamics, as well as the dynamics of cerebrovascular parameters, was conducted under conditions of using various lung ventilation modes with vibroacoustic therapy using the “VibroLUNG” device in patients with combined severe traumatic brain injury complicated by nosocomial pneumonia. The data obtained showed that comprehensive antibacterial and respiratory therapy combined with vibroacoustic therapy reduced mortality by 19.2% in this patient group. The advantage and feasibility of using vibroacoustic therapy with the VibroLUNG device in a complex respiratory support system for patients with combined severe traumatic brain injury was proved.

Keywords Nosocomial pneumonia, Pneumonia, Combined trauma, Traumatic brain injury

1. Introduction

Today, the possibilities of intensive care in the treatment of patients with combined trauma have expanded [1]. The appearance of new drugs and technologies in intensive care units has reduced patient mortality due to traumatic shock. In most cases, the treatment of patients with severe trauma involves artificial lung ventilation (ALV), which is the most important method of correcting acute respiratory failure syndrome in neurosurgical patients. All these factors explain the importance of studying complications arising during respiratory support, one of which is nosocomial pneumonia (NP) [2-3].

Despite certain successes achieved in recent decades in the treatment of patients with pneumonia, mortality rates remain high [4]. The NPs rank second in the structure of all hospital-acquired infectious complications, accounting for 15–18% [5-6], with ALV-associated pneumonia being associated with high mortality, with 33–70% of fatalities directly related to NPs [5]. According to various authors, the incidence of ventilator-associated pneumonia (VAP) ranges from 21.3 to 100%. Complications occur in 51.1% of ALV cases, and in 20.1% of deaths, they are the primary cause of death [2,6-7]. The diagnostics of NP is often quite a challenging task. A significant proportion of patients requiring long-term

ALV have some form of respiratory pathology complicating differential diagnosis with pneumonia. It is most relevant for people with acute lung injury syndrome, chest injuries, pulmonary edema, concomitant chronic inflammatory pathology of the respiratory tract, etc. The high incidence of pneumonia in patients with combined trauma caused by resistant pathogens, as well as high attributable mortality rates and the inadequacy of initial empirical antibiotic therapy in general intensive care units, have led to the need to implement a strict protocol defining the initial empirical antimicrobial therapy in patients with severe combined trauma [6-9]. In recent years, convincing data has been obtained showing that in cases of timely and adequate empirical antibiotic therapy, the prognosis is significantly better than with delayed or inadequate therapy [8].

The main cause of severe and sometimes terminal conditions in patients with pneumonia is hypoxemia caused by acute respiratory failure. It should be noted that in pneumonia, as a rule, hypoxemia is initially combined with hypocapnia. Hypercapnia usually accompanies hypoxemia in the late stages of the disease, when treatment is unsuccessful. The most important pathogenetic factors causing the development of hypoxemia are: 1) exclusion of large areas of the lungs (segments, lobes, sometimes an entire lung) from ventilation, i.e., right-to-left intrapulmonary shunt; 2) interstitial pulmonary edema; 3) pulmonary circulation disorders; 4) intoxication impairing the oxygen-transport functions of the blood, leading to heart failure and alveolar

pulmonary edema [10-11].

The high incidence of nosocomial infections among patients with severe combined trauma, including severe traumatic brain injury, and an initial APACHE II score of more than 15 points leads to increased duration and cost of treatment in intensive care units, as well as high mortality rates [1,5,12]. Therefore, preventing the development of severe nosocomial infections is one of the most important tasks in treating this type of patients.

The aim of the study was to analyze and evaluate the efficiency of vibroacoustic therapy using the “VibroLUNG” device as part of respiratory therapy in patients with combined severe traumatic brain injury, as well as to evaluate the results of the applied antibacterial protocol in the treatment of nosocomial pneumonia.

2. Material and Methods

The study included 377 patients who were treated in the neurosurgical intensive care unit of the Republican Research Center of Emergency Medicine from 2019 to 2024. Only patients with combined severe traumatic brain injury (SCTBI) in whom nosocomial pneumonia (NP) was developed against the background of ongoing mechanical ventilation and based on the results of clinical and radiological examination were included in the comparative analysis. The mean age of men was 37.62 ± 12.07 years (18-59 years), while the mean age of women was 41.07 ± 12.66 years (21-58 years). Level of consciousness was not less than 7 points on the Glasgow Coma Scale.

The inclusion criterion was a duration of mechanical ventilation exceeding 48 hours. The diagnosis of NP was considered probable in the presence of at least two of the following signs: body temperature above 38°C or below 36°C ; white blood cell count $>12 \times 10^9/\text{L}$ or $<4 \times 10^9/\text{L}$; appearance of new infiltrates on the radiograph; purulent nature of sputum.

All patients underwent a clinical and neurological examination, monitoring of laboratory parameters (complete blood count, acid-base balance, arteriovenous oxygen difference - AVDO₂, hemoglobin oxygen saturation in the jugular vein - SO₂). The gas composition was studied in capillary, arterial and venous blood. The parameters were recorded at least 4 times a day on the EasyStat gas analyzer (Medical, USA), Roche OMNI C (Japan) from the blood of the radial or femoral artery, internal jugular vein with the calculation of the arteriovenous oxygen difference (AVO₂) and the oxygen extraction coefficient (OEC).

Measurement of cerebral hemodynamics. In patients of the second stage, cerebral blood flow was additionally examined using an HD 11 XE ultrasound scanner (Philips). The following hemodynamic parameters were evaluated through the middle cerebral artery (MCA): average linear blood flow velocity (V_m, cm/s); pulsatility index (Pi), characterizing vascular resistance; overshoot coefficient (OC), reflecting the dilation reserve. Standard access –

temporal “window”.

Calculation formulas:

- $Pi = (Vs - Vd) / Vm$,
- $Vm = (Vs + 2Vd) / 3$,
- $OC = V_2 / V_1$ (based on the results of the carotid compression test).

The studies were conducted on the 2nd day of admission and on the 7-8th day of hospital stay.

In case of autoregulation disorder, intracranial pressure (ICP) was calculated using the formula: $ICP = APm \times RI \times Vm^{-1}$, where $RI = (Vs - Vd)/Vs$.

Systemic hemodynamic indicators. Assessed by mean arterial pressure (MAP) and cerebral perfusion pressure (CPP): $CPP = ADs \times Vm \times Vm^{-1}$, where ADs — systolic blood pressure.

Upon admission to the intensive care unit, patients received respiratory support in traditional SIMV VC, SIMV PC, and BiPAP modes (Drager, Hamelton device), as well as vibroacoustic therapy (VAT) using the “VibroLUNG” device. VAT is a non-invasive procedure of intensive vibroacoustic and resonance stimulation of the chest wall, both on the lung parenchyma and on the airways. [13-14]. The method is used for obstructive and restrictive pathology and inflammatory diseases of the lungs; it improves ventilation parameters by opening the functional reserve of the lungs, improving the drainage functions of the tracheobronchial tree and redistributing pulmonary perfusion. Vibroacoustic therapy also plays a significant role in the complex of resuscitation measures for respiratory failure.

The VAT “VibroLung” device affects the respiratory tract with a generated sound signal from a bifocal position by two emitters in the range of 20-300 Hz. The floating effect of the sound wave causes a resonance effect, which has a safe and efficient impact on any type of damage to the lung parenchyma itself, as well as the bronchial tree, alveoli, and vessels. It allows to achieve better results with less intensity and exposure time, which is due to the oscillation of the vibroacoustic wave in the inhomogeneous pulmonary parenchyma and intrapulmonary component (edema, mucus, infiltration, hypostatic transudate), which improves drainage, ventilation, aeration, and reduces infiltration and proliferation [13-14]. The use of VAT against the background of mechanical ventilation reduces the area of lung collapse and atelectasis due to the effect on external pressure, the evacuation of bronchial secretions, promotes the acceleration of the processes of gravitational redistribution of intrapulmonary fluid and the improvement of ventilation-perfusion ratios. This, in turn, potentiates PEEP without additional increases in ventilation parameters.

All patients initially received antibiotic therapy according to a protocol developed based on two regimens:

- regimen 1 - cefoperazone/sulbactam 4 g/day + amikacin 1500–2000 mg/day;
- regimen 2 - cefoperazone/sulbactam 4 g/day + levofloxacin 1000 mg/day.

Subsequently, antibiotic therapy was adjusted based on the results of bacteriological studies.

Patients were divided into two groups depending on the method of respiratory support:

- *Group I* (n=190) — traditional mechanical ventilation, average duration - 10.9 ± 1.3 days. The following modes were used: SIMV: FiO₂ 40–50%, P_{asb} 20–25 mbar, P_{ins} 10–25 mbar, PEEP >7 mbar;
- *Group II zpyyma* (n=187) — a combination of traditional mechanical ventilation (SIMV) with vibroacoustic therapy (VAT) using the “VibroLUNG” device. The procedure lasted 5 minutes and was administered 3 to 10 times per day. The average duration of mechanical ventilation was 8.3 ± 1.2 days.

All patients in all groups were individually selected for mechanical ventilation parameters. Efficiency was assessed based on the following parameters: SpO₂ — 96–99%, PaCO₂ — 34.7–35.2 mmHg, C, VCO.

Data analysis was performed using STATISTICA 10 (StatSoft, Inc., 2011). The significance of differences was assessed using the Pearson χ^2 test at a $p < 0.05$ level.

3. Results

Microbial landscape and antibiotic resistance analysis data were used to determine antibiotic sensitivity, which was distributed as follows: ceftriaxone 3%, ceftriaxone + sulbactam 84%, amikacin 82%, ciprofloxacin 86%, pefloxacin 23%, levofloxacin 81% (Tab. 1).

Table 1. Microorganisms isolated during bacteriological examination in patients on mechanical ventilation

Microorganism	Percent (%)
<i>Klebsiella pneumoniae</i>	84
<i>Pseudomonas aeruginosa</i>	78
<i>Staphylococcus aureus</i>	3
<i>Staphylococcus viridans</i>	2
<i>Enterobacter aeruginosa</i>	8
Fungi of the genus <i>Candida</i>	13

The implementation of the protocol developed by us led to a change in the structure of antibiotic prescriptions for patients with neurosurgical pathology undergoing prolonged mechanical ventilation and was a determining factor in reducing mortality in these patients by 19.2%. Clinically, this was manifested by a decrease in signs of intoxication: a decrease in leukocytosis, leukocyte intoxication index, and the level of “medium molecules” in the blood. One of the significant results was a reduction in the duration of prolonged mechanical ventilation (on average by 3 days), as well as a reduction in the length of stay of patients in the intensive care unit (on average by 3-5 days).

Respiratory complications, such as NP and ventilator-associated pneumonia (VAP), in neurosurgical patients undergoing treatment in intensive care units often occur during prolonged mechanical ventilation. These complications occupy second place in the structure of all hospital infectious complications and make up from 15 to 51%. Our analysis at the first stage of the study showed that early diagnostics and the use of adequate regimens of empirical antibacterial therapy do not lead to a decrease in the incidence of NP and VAP in patients with SCTBI. [12]. Moreover, in patients with SCTBI, with an initial APACHE II score of more than 15 points, the incidence of respiratory complications such as NP and VAP ranges from 21% to 59%. The problem is further complicated by the fact that in most cases patients require prolonged mechanical ventilation. It explains the high incidence of NP and VAP in neurosurgical patients treated in intensive care units, which in turn significantly prolongs the duration of the patient's stay in ICU and significantly increases the mortality rate [10].

Gas exchange dynamics. The use of a combination of traditional mechanical ventilation with “VibroLUNG” at the initial stage of respiratory support in patients with SCTBI improved blood PaO₂ by 48.98% on day 3, by 54.76% on day 6, by 55.60% at stage 4, and by 57.55% at stage 5 from the baseline level. The PaO₂/FiO₂ ratio increased by 76.38% on the 3rd day, reaching the normal limit, by 81.11% on the 6th day, by 82.22% on the 10th day, and upon transfer from intensive care, the increase was 83.56% ($p \leq 0.05$). The level of PaCO₂ remained within the physiological norm (on average 38.2 ± 5.7 mmHg) at all stages of the study.

Significant improvement in arterial blood oxygen saturation and stabilization of partial carbon dioxide pressure within target values (34.7–35.2 mmHg) were observed in Group II (mechanical ventilation + VibroLUNG). In Group I, we recorded episodes of hypercapnia and hypoxemia.

Cerebral blood flow. According to transcranial Doppler ultrasound, patients receiving VAP showed more favorable dynamics in their indicators:

- the average linear blood flow velocity (V_m) increased to physiological values;
- the pulsatility index (Pi), which reflects vascular resistance, decreased;
- the overshoot coefficient (OC), which characterizes the dilation reserve, remained within normal limits.

These changes indicate optimization of cerebral perfusion and improvement of autoregulatory mechanisms of cerebral circulation (Tab. 2).

Intracranial pressure (ICP). The calculated ICP values in patients in the Group II were lower compared to the Group I, indicating a reduced risk of intracranial hypertension (Tab. 3).

Table 2. Cerebral blood flow indicators

Respiratory support (group)	PaCO ₂ , mmHg	V _m , cm*sec ⁻¹	Pi	OC
Group I (n=190)	33.8±0.3	77.0±6.5*	1.23±0.13	1.24±0.02
Group II (n=187)	34.8±1.5 *	95.9±7.5 *	1.04±0.49	1.36±0.01*

Note: * $p < 0.05$ – in relation to SIMV

Table 3. Changes in intracranial and cerebral perfusion pressures two hours after ventilation with particular mode

Respiratory support (group)	CPP, mmHg	ICP, mmHg	MAP, mmHg
Group I (n=190)	70.1±2.8	23.7±1.7	86.1±3.6
Group II (n=187)	88.2±3.5*	18.4±1.7*	99.4±6.5

Note: * $p < 0.05$ – in relation to SIMV

4. Discussion

Nosocomial pneumonia. The use of combined ventilation was accompanied by a decrease in the incidence of pneumonia and a more favorable course of the infectious process, which was probably due to a reduction in the duration of mechanical ventilation (8.3 vs. 10.9 days) and improved mucociliary clearance.

Survivability and outcomes. The average duration of coma in Group I was 6.63 ± 1.89 days, and in Group II – 3.53 ± 1.42 days. In the intergroup analysis, we did not find any statistically significant differences ($p \geq 0.05$).

Among patients in Group I, favorable outcomes according to GOS were recorded in 18 (45%) patients, in Group II – in 43 (97.73%) patients (the difference with group I is statistically significant – $p < 0.001$). Good recovery was achieved in 10% of patients in Group I, and in 40.91% of patients in Group II. We found a statistically significant difference between Group II and Group I at a level of $p = 0.003$.

All the data presented allow us to conclude that comprehensive respiratory support consisting of standard mechanical ventilation with sessions of high-frequency jet ventilation (HFJV) and vibroacoustic therapy using the “VibroLUNG” device is the most efficient.

When conducting a comparative analysis of the clinical dynamics of Group II, we recorded the formation of cerebral ischemia due to the development of cerebral vasospasm in the intensive care unit, diagnosed clinically and instrumentally. A trend towards reduced mortality and improved neurological outcomes was recorded in Group II.

5. Conclusions

The use of combined artificial lung ventilation with sessions of vibroacoustic therapy using the “VibroLUNG” device in patients with combined severe traumatic brain injury allows: to recruit the lungs, improve oxygenation and gas exchange parameters; to optimize cerebral hemodynamics and to reduce intracranial pressure; to shorten the duration of mechanical ventilation and to reduce the incidence of nosocomial pneumonia.

Vibroacoustic therapy can be considered an efficient additional method in comprehensive intensive care for patients with SCTBI requiring long-term respiratory support, as well as in the prevention of secondary pulmonary complications.

The antibacterial therapy protocol developed by us and applied according to schemes 1 and 2 in the ICU was the determining factor in reducing mortality in these patients

using VAT by 18% and by 7% with traditional mechanical ventilation.

Ethical Approval and Consent to Participate

Our institution's research ethics board does not require review or approval of case reports.

Our investigation is conducted in accordance with the World Medical Association's Code of Ethics (Declaration of Helsinki).

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Conflict of Interests

The authors declare no conflict of interest.

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