Evaluation of the effectiveness of vibroacoustic lung massage during spontaneous breathing in patients after cardiac surgery

Eremenko A.A., Zyulyaeva T.P., Kalinina A.A., Rozina N.A.

Petrovsky National Research Center of Surgery, 119991, Moscow, Russian Federation

FOR CORRESPONDENCE
Zyulyaeva Tatyana Petrovna- Candidate of Medical Sciences, Leading researcher of the Department of Cardiac Resuscitation and Intensive Care of the Russian National Research Center of the Russian Academy of Medical Sciences. acad. B. V. Petrovsky (Moscow, Russian Federation)
E-mail: zyulyaeva@mail.ru
https://orcid.org/0000-0002-33752300

Keywords: vibroacoustic lung massage, Percuton, intensive care unit, cardiac surgery patients

Aim – To study the efficacy of vibroacoustic lung massage with the help of postoperative Percuton apparatus in cardiosurgical patients by its effect on gas exchange indices, parameters of external breathing and sputum passage.

Material and methods. The prospective study included 55 patients aged 19–80 years after elective cardiac surgery in Petrovsky National Research Center of Surgery in 2019.

Inclusion criteria: age over 18 years, self-breathing after trachea extubation, possibility to maintain adequate gas exchange against the background of oxygen inhalation, clear consciousness and productive contact with the patient, adequate pain relief (VAS <2 on a 10-score scale). Exclusion criteria: necessity to carry out artificial pulmonary ventilation (IVL), non-invasive mask pulmonary ventilation or high-flow oxygenotherapy, acute cerebral circulation disorder, shocks of various etiologies, extracorporeal detoxification methods. All gas exchange indices were carried out when breathing with air.

Results. It has been found that 96.4% of cardiosurgical patients have difficulties in evacuating sputum during coughing in early times after trachea extubation. Vibration-acoustic massage of lungs by Percuton apparatus is accompanied by significant improvement of sputum passage. After the session, the sputum pumping efficiency increased on average from 0.04±0.19 to 0.64±0.79 points ($p<0.001$). As a result of vibromassage, the number of patients with maximum inspiratory volume less than 500 ml decreased from 32.7 to 7.3%, and with MIO more than 1500 ml – increased from 14.5 to 45.1% ($p<0.05$).

Conclusions. Statistically significant increase of maximum inspiratory volume after vibromassage on average by 44.1% ($p<0.001$) along with decrease by 19.7% ($p=0.002$) of fraction of intralegal shunning can be observed. Vibroacoustic lung massage was accompanied by improvement of gas exchange indices, as evidenced by statistically significant increase of O2 partial pressure in arterial blood and p/f index with simultaneous decrease of PaCO2 and increase of blood oxygen saturation.

Funding. This work was not sponsored.

Conflict of interests. The authors declare no conflict of interests.

Contribution. The concept and design of the study, editing the work – Eremenko A.A.; writing an article, partial processing of the material and collecting literature – Zyulyaeva T.P.; collection of material – Kalinina A.A.; statistics – Rozina N.A

For citation: Eremenko A.A., Zyulyaeva T.P., Kalinina A.A., Rozina N.A. Evaluation of effectiveness of vibroacoustic lung massage in self-breathing patients after cardiosurgical operations. Clinical and Experimental Surgery. Petrovsky Journal. 2020; 8 (4): 126–34. DOI: https://doi.org/10.33029/2308-1198-2020-8-4-126-134

(in Russian) Received 29.04.2020. Accepted 08.10.2020.

Evaluation of effectiveness of vibroacoustic lung massage self-breathing in patients after cardiosurgical operations

Eremenko A.A., Zyulyaeva T.P., Kalinina A.A., Rozina N.A.

Petrovsky National Research Center of Surgery, 119991, Moscow, Russian Federation

Aim. To study the efficacy of vibroacoustic lung massage with the help of postoperative Percuton apparatus in cardiosurgical patients by its effect on gas exchange indices, parameters of external breathing and sputum passage.

Material and methods. The prospective study included 55 patients aged 19–80 years after elective cardiac surgery in Petrovsky National Research Center of Surgery in 2019. Inclusion criteria: age over 18 years, self-breathing after trachea extubation, possibility to maintain adequate gas exchange against the background of oxygen inhalation, clear consciousness and productive contact with the patient, adequate pain relief (VAS <2 on a 10-score scale). Exclusion criteria: necessity to carry out artificial pulmonary ventilation (IVL), non-invasive mask pulmonary ventilation or high-flow oxygenotherapy, acute cerebral circulation disorder, shocks of various etiologies, extracorporeal detoxification methods. All gas exchange indices were carried out when breathing with air.

Results. It has been found that 96.4% of cardiosurgical patients have difficulties in evacuating sputum during coughing in early times after trachea extubation. Vibration-acoustic massage of lungs by Percuton apparatus is accompanied by significant improvement of sputum passage. After the session, the sputum pumping efficiency increased on average from 0.04±0.19 to 0.64±0.79 points (p<0.001). As a result of vibromassage, the number of patients with maximum inspiratory volume less than 500 ml decreased from 32.7 to 7.3%, and with MIO more than 1500 ml – increased from 14.5 to 45.1% (p<0.05).

Conclusions. Statistically significant increase of maximum inspiratory volume after vibromassage on average by 44.1% (p<0.001) along with decrease by 19.7% (p=0.002) of fraction of intralegal shunning can be observed. Vibroacoustic lung massage was accompanied by improvement of gas exchange indices, as evidenced by statistically significant increase of O_2 partial pressure in arterial blood and p/f index with simultaneous decrease of $PaCO_2$ and increase of blood oxygen saturation.

Funding. This work was not sponsored.

Conflict of interests. The authors declare no conflict of interests.

Contribution. The concept and design of the study, editing the work – Eremenko A.A.; writing an article, partial processing of the material and collecting literature – Zyulyaeva T.P.; collection of material – Kalinina A.A.; statistics – Rozina N.A.

For citation: Eremenko A.A., Zyulyaeva T.P., Kalinina A.A., Rozina N.A. Evaluation of effectiveness of vibroacoustic lung massage in self-breathing patients after cardiosurgical operations. Clinical and Experimental Surgery. Petrovsky Journal. 2020; 8 (4): 126–34. DOI: https://doi.org/10.33029/2308-1198-2020-8-4-126-134 (in Russian) **Received** 29.04.2020. **Accepted** 08.10.2020.

CORRESPONDENCE

Tatiana P. Zyulyaeva – MD, Leading Researcher of Department of Cardiac Resuscitation and Intensive Care, Petrovsky National Research Center of Surgery (Moscow, Russian Federation)

E-mail: zyulyaeva@mail.ru

https://orcid.org/0000-0002-33752300

Keywords:
vibroacoustic lung massage Percuton, ICU, cardiac surgery

Acute respiratory failure (ARF) is one of the most common complications that develop in the postoperative period in cardiac surgery patients. Violation of alveolar oxygenation after such operations is observed in almost all patients, and the frequency of clinically significant ODN remains quite high, especially during operations on the aorta, reaching 3.2-28.6% [1-5]. ODN contributes to an increase in mortality among cardiac surgery patients and significantly increases the economic costs associated with its treatment.

According to the literature, the most common causes of postoperative acute obstructive pulmonary disease (COPD) are exacerbation of chronic obstructive pulmonary disease (COPD), atelectasis, and ventilator-associated pneumonia [3-7]. Atelectasis of the alveoli can contribute to the special features of the performed surgical intervention: lung injury during cardiac surgery and on the thoracoabdominal aorta, single-lung ventilation, opening of pleural cavities, pneumothorax, damage to the diaphragmatic joints with the development of diaphragm paresis. Such unfavourable factors as damage to the lungs associated with artificial ventilation (ventilator), prolonged forced position on the operating table, the use of hyperoxic respiratory mixture and the cessation of ventilation and perfusion of the lungs during artificial blood circulation (IC), as well as a violation of the chest frame and pain syndrome are also significant [8-13].

In intensive care units, various methods of preventing hypoventilation and alveolar atelectasis have been used for a long time: incentive and stress spirometry, oscillating PEEP therapy, vibration massage using vibrating massagers or special vests. When using these high-frequency massage devices, due to chest wall vibrations, which are transmitted to the patient's lungs, the evacuation of sputum during coughing is greatly facilitated, which improves respiratory function, reduces the frequency and severity of alveolar atelectasis [14–19].

Relatively recently, a fundamentally new method of vibroacoustic lung massage using the BARK Percuton device has appeared, based on the effect on the lung tissue of a sound signal of various frequencies. According to the manufacturer, the frequency of the stimulating signal is constantly changing and has a complex modulation, which ensures the maximum efficiency of the procedure. The therapeutic effect of the device is due to three main mechanisms: improvement of bronchial drainage, recruitment of alveoli and improvement of ventilation-perfusion ratios in the lungs. However, at present, there are practically no data in the literature on the effectiveness of this method in patients of cardiac resuscitation and intensive care units.

The aim of the study was to evaluate the effectiveness of vibroacoustic massage of the lungs using the Percuton apparatus in the postoperative period in cardiac surgery patients by its effect on gas exchange parameters, external respiration parameters and sputum passage.

Material and methods

The work was performed on the basis of a prospective study of 55 patients (39 men and 16 women, mean age - 59 ± 11.7 years) after planned cardiac surgery, reconstructive interventions on the aorta or on its branches, performed at the N.N. Academician B.V. Petrovsky in 2019. Heart valve replacement was performed in 20 patients, myocardial revascularization - in 20 patients, including 9 in combination with heart valve replacement, carotid endarterectomy - in 2 patients, reconstructive aortic surgery - in 13 patients.

Inclusion criteria: age over 18 years, independent breathing after tracheal extubation, the ability to maintain adequate gas exchange against the background of oxygen inhalation, clear consciousness and productive contact with the patient, adequate anesthesia [score <2 on the 10-point Visual-Analog Pain Scale (VAS)].

Exclusion criteria: the need for mechanical ventilation, non-invasive mask ventilation or high-flow oxygen therapy, acute cerebrovascular accident, shocks of various etiologies, extracorporeal detoxification methods.

General anesthesia was performed using the method of balanced multicomponent anesthesia (propofol, midazolam, ketamine, fentanyl, sevoflurane). Myoplegia was maintained by fractional administration of pipecuronium bromide. To protect the myocardium, cardioplegic solutions Consol, Custodiol or blood cardioplegia were used.

Most of the patients underwent surgery with CP in conditions of normothermia or moderate hypothermia. For patients undergoing reconstructive interventions on the aortic arch, operations were performed under conditions of hypothermia, circulatory arrest, and antegrade cerebral perfusion. Postoperative anesthesia was performed according to the scheme adopted in the department using intravenous acetaminophen at a dose of 1 g 4 times a day with the addition of 50-100 mg of tramadol intravenously or 20 mg of trimeperidine intramuscularly.

In the postoperative period, vibroacoustic massage of the lungs was performed using the BARK Percuton apparatus (manufactured by BARK Technology LLP, Kazakhstan). The procedure was performed 10–12 h after tracheal extubation. Sessions lasting 5 min were carried out in the prophylaxis mode with 100% power of the vibroacoustic signal. The session began with applying the spoons of the emitters to the subscapularis, going up the surface of the back, then the emitters were applied to the lateral surface of the body, and then the session was continued on the front surface of the chest, from bottom to top along the midline.

Before the vibromassage session and 10 min after its end, the following arterial blood parameters were recorded in each patient while breathing air: pH, blood oxygen saturation, the level of partial pressure of oxygen and carbon dioxide ($SatO_2$, PaO_2, $PaCO_2$, respectively); PaO_2 / FiO_2 was calculated using conventional formulas (p / f index), CaO_2 - blood oxygen capacity, P (A – a) O_2 - alveolar-arterial oxygen difference, Qs / Qt - intrapulmonary blood shunting. In addition, the respiratory rate (RR) was measured and the maximum inspiratory volume was recorded using a Couch 2 incentive spirometer from Portex. The effectiveness of sputum discharge before and after the session was assessed in points: 0 - sputum coughs up poorly; 1 - sputum is coughing up satisfactorily; 2 - sputum clears up well.

Data were statistically processed using Jamovi version 1.1.9.0 for MacOS. Compliance with the law of normal distribution was assessed using the Shapiro – Wilk test. For each assessed indicator, the arithmetic mean, median, standard deviation, minimum and maximum values of the indicator, mean difference, 95% confidence interval were calculated. To assess the significance of statistical differences with a normal distribution of signs, the Student's test was used for paired samples, with an abnormal distribution - the Wilcoxon test. Values were considered significant at $p < 0.05$.

Results

Changes in gas exchange parameters and external respiration parameters in cardiac surgery patients during Percuton vibroacoustic lung massage are presented in Table. 1 and 2. From the data in Table. 1 it can be seen that in the vast majority of patients (96.4%), prior to vibroacoustic lung massage, poor sputum discharge was recorded during coughing, which corresponded to an assessment of 0 points (on average, it was 0.04±0.19 points). After the session, sputum discharge significantly improved-this is evidenced by an increase in the number of patients with a sputum discharge score of 1 point to 23.6% and 2 points to 20% (the average value is 0.64±0.79 points). The differences are statistically significant (upper 95% confidence interval – 1.5; lower-1.0; p<0.001) (see Table 1).

The average indicator of the maximum inspiratory volume (MIV) before vibroacoustic massage (Table 2) was at a fairly high level (> 1000 ml). However, in almost half of the patients (50.9%), the MIV was in the range of low values (200–800 ml), which indicates a dysfunction of external respiration, and only in 14.5% of patients it exceeded 1500 ml. After a session of vibroacoustic massage, the increase in MIV in the group increased by an average of 44.1% (the average difference was 500 ml, 95% confidence interval was 400–600 ml, p <0.01), and the number of patients with MIV> 1500 ml increased to 45.4%, i.e. more than 3 times. The absence of an increase in MIV after a session of vibroacoustic massage was noted only in 4 (7.3%) patients, and all of them had low MIV values in the range of 200–500 ml.

The initial indices of gas exchange before the session of vibroacoustic massage of the lungs showed (see Table 1) that the median of SatO2, PaO2, p / f index, PaCO2 were within the normal range. Only 7 (12.7%) patients had p / f index <300 mm Hg. After a session of vibro-acoustic massage, an improvement in the gas exchange function of the lungs is noted - this is evidenced by a significant increase in the level of partial pressure of O2 in arterial blood (95% confidence interval 3.5–6.5; p <0.001), p / f index by 6.1 % (p <0.001) with a simultaneous decrease in PaCO2 by 9.2% (95% confidence interval –4.0… –2.5; p <0.001). And although SatO2 significantly increased (p <0.001), the increase was the minimum percentage. In 7 (12.7%) patients, SatO2 either did not increase or decreased insignificantly. These patients also showed no improvement in sputum passage. Intrapulmonary blood shunting significantly decreased after the session by 19.7% (p = 0.002).

The pH and CaO2 levels did not change significantly. The alveolar-arterial oxygen difference both before and after the session was significantly increased and did not change significantly (p = 0.68). Only 3 (5.4%) patients showed a decrease in this indicator by an average of 60%, while they had a significant (more than 3 times) increase in the MIV.

RR before and after the session was on average within the normal range and did not change significantly. RR> 20 / min was recorded only in 3 (5.4%) patients at the outcome and in 2 (3.6%) patients after the session.

Table 1. Changes in some indicators of gas exchange and parameters of external respiration in cardiac surgery patients in the postoperative period during vibroacoustic lung massage with the Percuton device

Indicator	Before the session	15 min after the session	Average difference	Lower 95% confidence interval	Upper 95% confidence interval	p
pH	7.31±0.99	7.32±0.	-0.01	-0.01	0.02	-0.053
P / f index, mm Hg	352±5.8	374±3.1	21.5	14.3	28.6	<0.001
PaCO2, mmHg	39.0±4.41	35.7±3.65	-3.5	-4	-2.5	<0.001
PaO2, mmHg	74.1±9.4	78.5±10.4	5	3.5	6.5	<0.001
SatO2, %	95.0±2.15	96.0±2.39	1	-0.1	0.3	<0.001
CaO2, vol. %	13.5±3.7	13.6±3.6	0.15	-0.3	0.1	0.205
P(A–a)O2, mmHg	26.7±10.6	27.5±10.5	0.5	1.5	2.5	0.532
Qs/Qt, %	13.7±7.2	11.0±8.2	3.5	-5.2	-1.35	0.002
Maximum inspiratory volume, ml	1043.6±747.6	1503.6±862.6	500	400	600	<0.001
Sputum discharge, points	0.04±0.19	0.64±0.8	1.5	-1.5	-1.0	<0.001
Number of breaths per minute	18.0±2.5	18.1±2.0	0.1	-0.5	1.5	0.83

Discussion

The frequent development of postoperative complications in the respiratory system in cardiac surgery patients is well known. An increase in the risk of their occurrence is noted with prolonged cardiopulmonary bypass, large blood transfusions, prolonged mechanical ventilation, intraoperative lung injuries, etc. In addition, among cardiac surgical patients, there is a large percentage of patients with such preoperative risk factors for postoperative ARF, such as obesity, COPD, especially in moderate and severe, bronchial asthma, chronic heart failure and pulmonary hypertension [3, 4, 6, 8–12].

Experimental studies have shown that at the initial stages of cardiac surgery, microatelectasis is detected, which violates the ventilation-perfusion ratio in the lungs. During and after cardiac surgery, X-ray negative microatelectasis can cover a significant part of the lung tissue (up to ⍰50%), increasing intrapulmonary blood shunting (Qs / Qt) and relative arterial hypoxemia [20-22].

Satisfactory oxygenating function of the lungs is a prerequisite for early activation after cardiopulmonary bypass surgery. The problem of preventing pulmonary complications, respiratory rehabilitation and early activation of patients after cardiac surgery is currently of great importance. Various methods are proposed for these purposes, but they are not yet well studied and covered in the literature.

There are several methods aimed at clearing the airways in patients with increased sputum production and broncho-obstructive syndrome. These include incentive spirometry, which has a positive effect on the oxygenating function of the lungs: it has been shown to be effective in the prevention and treatment of atelectasis of the lung tissue after various surgical interventions, primarily in cardiac and thoracic patients [22, 23].

Positive expiratory pressure therapy was developed in the late 20th century. and was introduced in the United States as an alternative to conventional physiotherapy [16], and PEEP devices with a vibration component are widely used to treat patients with respiratory diseases and to train breathing in the postoperative period. Small clinical studies have shown improvements in tracheobronchial clearance and patient comfort with PEEP devices compared to standard physiotherapy methods [24, 25]

In the literature, there are reports on the use of external high-frequency compression devices (vests) for respiratory rehabilitation to cleanse the airways using forced high-frequency low-amplitude chest oscillations (up to 25 times per second). This system consists of an inflatable vest and a compressor that generates air pulses. The compressor inflates the vest, rapidly changing the air pressure in it. Due to this, a rhythmic squeezing effect is exerted on the patient's chest, imitating natural coughing movements. Several studies [26, 27] report that such a device improves the passage of sputum during coughing in patients with chronic pulmonary fibrosis, helps to stabilize or improve the oxygenating function of the lungs.

The amount of published information on the use of the above methods in cardiac surgery patients is very limited, more research is needed to determine the effectiveness of respiratory physiotherapy devices and their place in the prevention and treatment of respiratory complications.

In our work, we used the vibroacoustic method of lung massage using the Percuton apparatus. This is a fundamentally new method of vibroacoustic massage of the lungs using a device that, through special emitters, affects the lung tissue. Depending on the selected program, the signal can cause the effect of percussion, soft vibration, smooth alternation of the acoustic signal and vibration, and their combinations. The device is effective in the treatment of both obstructive and restrictive lung pathologies. An important role is given to the prevention of diseases of the respiratory system, which can contribute to the early prevention of the development of pulmonary complications, especially in cardiac surgery patients, in patients with a predisposition to pulmonary diseases or with chronic pulmonary pathology. In obstructive pathology, the apparatus improves sputum passage, stimulates its drainage, and improves bronchial permeability.

The analysis of the data obtained by us on the use of vibroacoustic lung massage in cardiac surgery patients showed its good effectiveness and tolerability. This is confirmed by the positive effect of the session both on the indicators of external respiration, and on some indicators of gas exchange.

We used spirometry as one of the methods of monitoring the work of vibroacoustic massage. A significant increase in the maximum inspiratory volume on average in the group by 44.1% and an

Table 2. Change in the maximum inspiratory volume in cardiac surgery patients (55 people) before and after a session of vibroacoustic massage with the apparatus Percuton

Maximum inspiratory volume, ml	Number of patients and % of the total number before the session	Number of patients and % of the total number after the session	*p*
200–500	18 (32,7)	4 (7,3)	>0,05
>500–800	10 (18,2)	12 (21,8)	>0,05
>800–1200	9 (16,4)	10 (18,2)	>0,05
>1200–1500	10 (18,2)	4 (7,3)	>0,05
>1500	8 (14,5)	25 (45,4)	<0,01

increase of more than 3 times in patients with MIV >1500 ml may indicate an increase in the volume of ventilated lung tissue.

Considering that almost half of the patients included in the study (43.6%) note a positive dynamics of sputum discharge after the session (p <0.001), we can talk about the positive effect of vibroacoustic massage of the lungs on its passage. These effects are close to those obtained with the use of vibrating vests and oscillatory therapy with positive end-expiratory pressure (PEEP-therapy), which help to cough up sputum and help stabilize or improve oxygenating lung function in patients of various profiles (surgical, in patients with chronic bronchiectasis and obstructive disease. lungs) [24-29].

We have also demonstrated a positive effect of vibroacoustic massage on gas exchange indicators, as evidenced by a significant increase in the level of partial pressure of O2 in arterial blood and the p / f index to 6.1% with a simultaneous decrease in PaCO2 by 11.4% with an increase in blood oxygen saturation (p < 0.001). In addition, the significant (p = 0.002) decrease in intrapulmonary shunting of blood by 19.7% obtained after vibromassage with an increase in MIR can be explained by an improvement in airway patency and the volume of ventilated alveoli, which is confirmed by the data of other authors.

Thus, the work [22] showed the high effectiveness of incentive spirometry as a preventive measure for postoperative reduction of oxygenating lung function (OLF) due to a violation of the ventilation-perfusion ratio. The authors showed that incentive spirometry performed in the early postoperative period has a positive effect on gas exchange and external respiration function, since in 98% of cases it increases MIV by an average of 0.5±0.04 litres and 2-fold reduces the frequency of episodes of p/f index decline after operations with IR, which may indicate a decrease in alveolar microatectasis.

Thus, our data have shown that the effectiveness of incentive spirometry can be significantly increased when combined with vibroacoustic massage of the lungs. It has been proven that the latter has a positive effect on the oxygenating function of the lungs and can further shorten the rehabilitation period for patients after cardiac surgery. Further comparative studies of the effectiveness of vibroacoustic massage of the lungs and other methods of respiratory rehabilitation are needed.

Conclusion

1. Difficulties in sputum evacuation during coughing in the early stages after tracheal extubation are observed in 96.4% of cardiac surgery patients. Vibroacoustic massage of the lungs with the Percuton apparatus is accompanied by a significant improvement in the passage of sputum. After the session, the indicator of efficiency of sputum coughing increased on average from 0.04 ± 0.19 to 0.64 ± 0.79 points (p <0.001).
2. As a result of vibratory massage, the number of patients with MIV <500 ml decreased from 32.7 to 7.3%, and with MIV> 1500 ml increased from 14.5 to 45.1% (p <0.001). The statistically significant increase in MIV obtained after vibration massage by an average of 44.1% (p <0.001) along with a 19.7% decrease (p = 0.02) in the fraction of intrapulmonary shunting may indicate an improvement in alveolar ventilation.
3. Vibroacoustic lung massage was accompanied by an improvement in gas exchange indicators, as evidenced by a statistically significant increase in the partial pressure of O2 in arterial blood and the p/f index, while reducing PaCO2 and increasing blood oxygen saturation.

Literature

1. Баутин А.Е., Кашерининов И.Ю., Лалетин Д.А., Мазурок В.А., Рубинчик В.Е., Наймушин А.В., Маричев А.О., Гордеев М.Л. Распространенность и структура острой дыхательной недостаточности в раннем послеоперационном периоде кардиохирургических вмешательств // Вестник интенсивной терапии. 2016. №4. С.19-26. (in Russian)
2. Faker Ali Ahmed Al-Qubati, Abdulkarim Damag, Tarek Norman. Incidence and outcome of pulmonary complications after open cardiac surgery // J. Chest Dis. Tuberc. 2013. Vol. 62, N 4. P. 775–780. DOI: https://doi. org/10.1016/j.ejcdt.2013.08.008
3. Gupta H., Gupta P.K., Fang X., Miller W.J., Cemaj S., Forse R.A. et al. Development and validation of a risk calculator predicting postoperative respiratory failure // Chest. 2011. Vol. 140. P. 581–595. DOI: https://doi. org/10.1378/chest.11-0466
4. Ji Q., Mei Y., Wang X., Feng J., Cai J., Ding W. Risk factors for pulmonary complications cardiac surgery with cardiopulmonary bypass // Int. J. Med. Sci. 2013. Vol. 10, N 11. P. 1578–1583. DOI: https://doi.org/10.7150/ ijms.6904
5. Esmaeili R., Nasiri E., Ghafari R., Mousavinasab S.N., Saffari N.H.N. Frequency rate of atelectasis in patients following coronary artery bypass graft and its associated factors at mazandaran heart center in 2013–2014 // Med. Arch. 2015. Vol. 69, N 2. P. 72–76. DOI: https://doi. org/10.5455/medarh.2015.69.72-76
6. Bailey M.L., Richter S.M., Mullany D.V., Tesar P.J., Fraser J.F. Risk factors and survival in patients with respiratory failure after cardiac operations // Ann. Thorac. Surg. 2011. Vol. 92. P. 1573–1579. DOI: https:// doi.org/10.1016/j.athoracsur.2011.04.019
7. He S., Chen B., Li W., Yan J., Chen L., Wang X., Xiao Y. Ventilator-associated pneumonia after cardiac surgery: a meta-analysis and systematic review // J. Thorac. Cardiovasc. Surg. 2014. Vol. 148, N 6. P. 3148–3155. DOI: https://doi.org/10.1016/j.tcvs.2014.07.107
8. Баутин А.Е., Солнцев В.Н., Наумов А.Б.. Изменение проницаемости альвеолокапиллярной мембраны и состояния легочного сурфактанта во время операций на сердце и аорте // Вестник анестезиологии и реаниматологии. 2010. №5. С.11-17. (in Russian)
9. Naughton P.J., Park M.S., Morasch Rodriguez H.E., Garsia M.T., Wang C.E., Eskandari M.K. Emergent repair of acute thoracic

aortic catastrophes // Arch. Surg. 2012. Vol. 147, N 3. P. 243–249. DOI: https://doi.org/10.1001/ archsurg.2011.1476

10. Talwar S., Agarwala S., Mittal C.M., Choudhary S.K., Airan B. Diaphragmatic palsy after cardiac surgical procedures in patients with congenital heart // Ann. Pediatr. Cardiol. 2010. Vol. 3, N 1. P. 50–57. DOI: https:// doi.org/10.4103/0974-2069.64370

11. Haynes D., Baumann M.H. Management of pneumothorax // Semin. Respir. Crit. Care Med. 2010. Vol. 31. P. 769–780. DOI: https://doi.org/10/1055/s-0030-1269837

12. Wynne R., Botti M. Postoperative pulmonary dysfunction in adult after cardiac surgery with cardiopulmonary bypass: clinical signifi cance and implications for practice // Am. J. Crit. Care. 2004. Vol. 13, N 5. P. 384–393.

13. Hedenstierna G. Alveolar collapse and closure of airways: regular effects of anaesthesia // Clin. Physiol. Funct. Imaging 2003. Vol. 23, N 3. P. 123–129.

14. Warwick W.J., Hansen L.G. The long term effect of high frequency compression therapy on pulmonary complications of cystic fi brosis // Pediatr. Pulmonol. 1994. Vol. 88. P. 677–681.

15. Agostini P., Singh S. Incentive spirometry following thoracic surgery: what should we be doing? // Physiotherapy. 2009. Vol. 95, N 2. P. 76–82. DOI: https:// doi.org/10.1016/j.physio.2008.11.003

16. Gaskin L., Corey M., Shin J., Reisman J.J., Thomas J., Tullis D.E. Long-term trial of conventional postural drainage and percussion versus positive expiratory pressure // J. Pediatr. Pulmonol. 1997. Vol. 131. P. 570–574.

17. Wilson L.M., Morrison L., Robinson K.A. Airway clearance techniques for cystic fi brosis: an overview of Cochrane systematic reviews // Cochrane Database Syst. Rev. 2019. Vol. 1. CD011231. DOI: https://doi. org/10.1002/14651858.CD011231.pub2

18. Lee A.L., Burge A.T., Holland A.E. Positive expiratory pressure therapy versus other airway clearance techniques for bronchiectasis // Cochrane Database Syst. Rev. 2017. Vol. 9. CD011699. DOI: https://doi. org/10.1002/14651858.CD011699.pub2

19. Nicolini A., Cardini F., Landucci N., Lanata S., Ferrari-Bravo M., Barlascini C. Effectiveness of treatment with high-frequency chest wall oscillation in patients with bronchiectasis // BMC Pulm. Med. 2013. Vol. 13. P. 21. https://doi.org/10.1186/1471-2466-13-21

20. Magnusson L., Spahn D.R. New concepts of atelectasis during general anaesthesia // Br. J. Anaesth. 2003. Vol. 91, N 1. P. 61–72.

21. Кричевский Л.А., Баландюк А.Е., Козлов И.А. Внесосудистая вода и оксигенирующая функция легких при операциях с искусственным кровообращением // Вестник трансплантологии и искусственных органов. 2004. №2. С. 24-28. (in Russian)

22. Козлов И.А., Дзыбинская Е.В., Романов А.А., Баландюк А.Е. Коррекция легочной оксигенизирующей дисфункции при ранней активации кардиохирургических больных // Общая реаниматология. 2009. №2). С. 37–43. (in Russian)

23. Agostini P., Singh S. Incentive spirometry following thoracic surgery: what should we be doing? // Physiotherapy. 2009. Vol. 95, N 2. P. 76–82. DOI: https:// doi.org/10.1016/j.physio.2008.11.003

24. Beningfi eld A., Jones A. Peri-operative chest physiotherapy for paediatric cardiac patients: a systematic review and meta-analysis // Physiotherapy. 2018. Vol. 104, N 3. P. 251–263. DOI: https://doi.org/10.1016/ j.physio.2017.08.011

25. Zhang X., Wang Q., Zhang S., Tan W., Wang Z., Li J. The use of a modifi ed, oscillating positive expiratory pressure device reduced fever and length of hospital stay in patients after thoracic and upper abdominal surgery: a randomised trial // J. Physiother. 2015. Vol. 61, N 1. P. 16–20. DOI: https://doi.org/10.1016/ j.jphys.2014.11.013

26. Li P., Lai Y., Zhou K., Su J., Che G. Can perioperative oscillating positive expiratory pressure practice enhance recovery in lung cancer patients undergoing thorascopic lobectomy? // Zhongguo Fei Ai Za Zhi. 2018. Vol. 21, N 12. P. 890–895. DOI: https://doi. org/10.3779/j.issn.1009-3419.2018.12.06

27. Nicolini A., Cardini F., Landucci N., Lanata S., Ferrari-Bravo M., Barlascini C. Effectiveness of treatment with high-frequency chest wall oscillation in patients with bronchiectasis // BMC Pulm. Med. 2013. Vol. 13. P. 21.

28. Alam M., Hussain S., Shehzad M.I., Mushtaq A., Rauf A., Ishaq S. Comparing the effect of incentive spirometry with Acapella on blood gases in physiotherapy after coronary artery bypass graft // Cureus. 2020. Vol. 12, N 2. Article ID e6851. DOI: https://doi. org/10.7759/cureus.6851

29. Wheatley C.M., Baker S.E., Daines C.M., Phan H., Martinez M.G., Morgan W.J. et al. Infl uence of the Vibralung Acoustical Percussor on pulmonary function and sputum expectoration in individuals with cystic fi brosis // Ther. Adv. Respir. Dis. 2018. Vol. 12. P. 1–15. DOI: https://doi.org/10.1177/1753466618770997

References

1. Bautin A.E., Kasherininov I.Yu., Latetin D.A., Mazurok V.A., Rubinchik V.E., Naymushin A.V., et al. Prevalence and causes of the postoperative acute respiratory failure in cardiac surgery. Vestnik intensivnoy terapii [Bulletin of Intensive Care]. 2016; (4): 19–26. (in Russian)

2. Faker Ali Ahmed Al-Qubati, Abdulkarim Damag, Tarek Norman. Incidence and outcome of pulmonary complications after open cardiac surgery. J Chest Dis Tuberc. 2013; 62 (4): 775–80. DOI: https://doi.org/10.1016/ j.ejcdt.2013.08.008

3. Gupta H., Gupta P.K., Fang X., Miller W.J., Cemaj S., Forse R.A., et al. Development and validation of a risk calculator predicting postoperative respiratory failure. Chest. 2011; 140: 581–95. DOI: https://doi.org/10.1378/ chest.11-0466

4. Ji Q., Mei Y., Wang X., Feng J., Cai J., Ding W. Risk factors for pulmonary complications cardiac surgery with cardiopulmonary bypass. Int J Med Sci. 2013; 10 (11): 1578–83. DOI: https://doi.org/10.7150/ijms. 6904

5. Esmaeili R., Nasiri E., Ghafari R., Mousavinasab S.N., Saffari N.H.N. Frequency rate of atelectasis in patients following coronary artery bypass graft and its associated factors at mazandaran heart center in 2013–2014. Med Arch. 2015; 69 (2): 72–6. DOI: https://doi.org/10.5455/ medarh.2015.69.72-76

6. Bailey M.L., Richter S.M., Mullany D.V., Tesar P.J., Fraser J.F. Risk factors and survival in patients with respiratory failure after cardiac operations. Ann Thorac Surg. 2011; 92: 1573–79. DOI: https://doi.org/10.1016/ j.athoracsur.2011.04.019

7. He S., Chen B., Li W., Yan J., Chen L., Wang X., Xiao Y. Ventilator-associated pneumonia after cardiac surgery: a meta-analysis and systematic review. J Thorac Cardiovasc Surg. 2014; 148 (6): 3148–55. DOI: https://doi.
org/10.1016/j.tcvs.2014.07.107

8. Bautin A.E., Solnchev V.N., Naumov A.B., et al. Chance in alveolar-capillary membrane permeability and in the pulmonary surfactant complex during opetations on the heart and aorta. Vestnik anesteziologii i reanimatologii [Bulletin of Anesthesiology and Resuscitation]. 2010; (5): 11–7. (in Russian)

9. Naughton P.J., Park M.S., Morasch Rodriguez H.E., Garsia M.T., Wang C.E., Eskandari M.K. Emergent repair of acute thoracic aortic catastrophes. Arch Surg. 2012; 147 (3): 243–49. DOI: https://doi.org/10.1001/archsurg.2011.1476

10. Talwar S., Agarwala S., Mittal C.M., Choudhary S.K., Airan B. Diaphragmatic palsy after cardiac surgical procedures in patients with congenital heart. Ann Pediatr Cardiol. 2010; 3 (1): 50–7. DOI: https://doi. org/10.4103/0974-2069.64370

11. Haynes D., Baumann M.H. Management of pneumothorax. Semin Respir Crit Care Med. 2010; 31: 769–80. DOI: https://doi.org/10/1055/s-0030-1269837

12. Wynne R., Botti M. Postoperative pulmonary dysfunction in adult after cardiac surgery with cardiopulmonary bypass: clinical signifi cance and implications for practice. Am J Crit Care 2004; 13 (5): 384–93.

13. Hedenstierna G. Alveolar collapse and closure of airways: regular effects of anaesthesia. Clin Physiol Funct Imaging 2003; 23 (3): 123–9.

14. Warwick W.J., Hansen L.G. The long term effect of high frequency compression therapy on pulmonary complications of cystic fi brosis. Pediatr Pulmonol. 1994; 88: 677–81.

15. Agostini P., Singh S. Incentive spirometry following thoracic surgery: what should we be doing?
Physiotherapy. 2009; 95 (2): 76–82. DOI: https://doi. org/10.1016/j.physio. 2008.11.003

16. Gaskin L., Corey M., Shin J., Reisman J.J., Thomas J., Tullis D.E. Long-term trial of conventional postural drainage and percussion versus positive expiratory pressure. J Pediatr Pulmonol. 1997; 131: 570–4.

17. Wilson L.M., Morrison L., Robinson K.A.. Airway clearance techniques for cystic fi brosis: an overview of Cochrane systematic reviews. Cochrane Database Syst Rev. 2019; 1: CD011231. DOI: https://doi. org/10.1002/14651858.CD011231.pub2

18. Lee A.L., Burge A.T., Holland A.E. Positive expiratory pressure therapy versus other airway clearance techniques for bronchiectasis. Cochrane Database Syst. Rev. 2017; 9: CD011699. DOI: https://doi. org/10.1002/14651858.CD011699.pub2

19. Nicolini A., Cardini F., Landucci N., Lanata S., Ferrari-Bravo M., Barlascini C. Effectiveness of treatment with high-frequency chest wall oscillation in patients with bronchiectasis. BMC Pulm Med. 2013; 13: 21. https:// doi.org/10.1186/1471-2466-13-21

20. Magnusson L., Spahn D.R. New concepts of atelectasis during general anaesthesia. Br J Anaesth. 2003; 91 (1): 61–72.

21. Krichevckiy L.A., Balandyuk A.Ye., Kozlov I.A. Non-vascular water and oxygenating function of lungs in operations with artifi cial circulation Vestnik transplantologii i iskusstvennykh organov [Bulletin of Transplantology and Artifi cial Organs]. 2004; (2): 24–8. (in Russian)

22. Kozlov I.A., Dzybinskaya Ye.V., Romanov A.A., Balandyuk A.Ye. Correction of pulmonary oxygenizing dysfunction in the early activation of cardiosurgical patients. Obshchaya reanimatologiya [General Resuscitation].
2009; (2): 37–43. (in Russian)

23. Agostini P., Singh S. Incentive spirometry following thoracic surgery: what should we be doing?
Physiotherapy. 2009; 95 (2): 76–82. DOI: https://doi. org/10.1016/j.physio.2008.11.003

24. Beningfi eld A., Jones A. Peri-operative chest physiotherapy for paediatric cardiac patients: a systematic review and meta-analysis. Physiotherapy. 2018; 104 (3): 251–63. DOI: https://doi.org/10.1016/j.physio.2017.08.011

25. Zhang X., Wang Q., Zhang S., Tan W., Wang Z., Li J. The use of a modifi ed, oscillating positive expiratory pressure device reduced fever and length of hospital stay in patients after thoracic and upper abdominal surgery: a randomised trial. J Physiother. 2015; 61 (1): 16–20.
DOI: https://doi.org/10.1016/j.jphys.2014.11.013

26. Li P., Lai Y., Zhou K., Su J., Che G. Can perioperative oscillating positive expiratory pressure practice enhance recovery in lung cancer patients undergoing thorascopic lobectomy? Zhongguo Fei Ai Za Zhi. 2018; 21
(12): 890–5. DOI: https://doi.org/10.3779/j.issn.1009-3419.2018.12.06

27. Nicolini A., Cardini F., Landucci N., Lanata S., Ferrari-Bravo M., Barlascini C. Effectiveness of treatment with high-frequency chest wall oscillation in patients with bronchiectasis. BMC Pulm Med. 2013; 13: 21.

28. Alam M., Hussain S., Shehzad M.I., Mushtaq A., Rauf A., Ishaq S. Comparing the effect of incentive spirometry with Acapella on blood gases in physiotherapy after coronary artery bypass graft. Cureus. 2020; 12 (2):
e6851. DOI: https://doi.org/10.7759/cureus.6851

29. Wheatley C.M., Baker S.E., Daines C.M., Phan H., Martinez M.G., Morgan W.J., et al. Infl uence of the Vibralung Acoustical Percussor on pulmonary function and sputum expectoration in individuals with cystic fi brosis.
Ther Adv Respir Dis. 2018; 12: 1–15. DOI: https://doi. org/10.1177/1753466618770997