https://doi.org/10.15360/1813-9779-2023-1-2256

Comparing the Inspiratory Capacity Measurements Obtained by Incentive Spirometry and Ultrasonic Spirography in the Early Postoperative Period in Cardiac Surgery Patients

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For citation: *Alexander A. Eremenko, Tatiana P. Zyulyaeva, Daria V. Ryabova, Marina S. Grekova, Alina P. Alferova, Alevtina V. Goncharova, Oksana O. Grin, Sofia S. Dmitrieva, Alexander S. Petrov.* Comparing the Inspiratory Capacity Measurements Obtained by Incentive Spirometry and Ultrasonic Spirography in the Early Postoperative Period in Cardiac Surgery Patients. *Obshchaya Reanimatologiya = General Reanimatology.* 2023; 19 (1): 13–19. https://doi.org/10.15360/1813-9779-2023-1-2256 [In Russ. and Engl.]

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Summary

Incentive spirometry is one of the most common methods used for respiratory rehabilitation in the early period after cardiac surgery. Inspiratory capacity values, obtained by a patient using spirometer, are not reliably trusted.

Objectives. To compare volumetric parameters measured with incentive spirometer and results obtained with bedside ultrasound-based spirometer to assure the feasibility of the use of incentive spirometry to assess the inspiratory capacity and effectiveness of postoperative respiratory rehabilitation.

Materials and methods. The study included 50 patients after elective cardiac surgery. Pulmonary rehabilitation involved the use of various respiratory therapy methods. Spirography was performed before and after each session. Both approaches were used simultaneously to obtain the spirometry maximum inspiratory capacity (SMIC) with a bedside ultrasonic spirography and maximum inspiratory capacity (MIC) index using an incentive spirometer. Patient's discomfort and adverse events during the procedures were recorded.

Results. The absolute values of the MIC measured before and after each session by the two methods were dissimilar, however, the average increment values (△) did not show statistically significant differences. The correlation analysis revealed a strong positive statistically significant relationship between △ SMIC and △ MIC ($R = 0.74$ before the session, $R = 0.79$ after the session, $R = 0.77$ across the whole data set, $P < 0.01$), also consistent with the Bland–Altman analysis, evidencing that more than 95% of all values fell within ± 1.96 SD of the mean difference. The inspiratory spirometry method showed good diagnostic accuracy (sensitivity 87%, specificity 85%, area under the curve (AUC) 0.8 (95% CI: [0.76; 0.83]), $P < 0.001$). Refusals of procedure were more often documented with ultrasonic spirography.

Conclusion. The increment in the inspiratory capacity index measured with incentive spirometer shows good agreement with ultrasonic spirography measurements. Therefore, incentive spirometry can be reliably used to assess the effectiveness of respiratory rehabilitation interventions in cardiac surgery patients during early postoperative period.

Keywords: respiratory rehabilitation; incentive spirometry; spirography; inspiratory capacity; lung drainage function

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

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Introduction

Cardiac surgery is associated with a high risk of respiratory complications in the immediate postoperative period due to the need for cardiopulmonary bypass and circulatory arrest, mechanical lung injury, relatively large blood loss and blood transfusion, prolonged «hard» mode mechanical lung ventilation (MLV), thoracic damage, drug-induced suppression of the respiratory center, respiratory muscle weakness, etc. [1–4].

All of the above may lead to impaired drainage function of the tracheobronchial tree, development of atelectasis, decreased number of ventilated alveoli, reduced lung vital capacity and respiratory failure.

Various methods of respiratory physical therapy are used to prevent and treat respiratory complications in the postoperative period. These include vibroacoustic lung massage, positive expiratory pressure (PEP) vibration therapy, and chest therapeutic massage using high-frequency compression devices (vests) [5–10]. The most common physiotherapeutic methods used in the postoperative period include incentive spirometry [11], which is based on measuring changes in inspiratory volume using a special device equipped with a piston and graded in ml. Thus, the patient can independently control the inspiratory volume during postoperative rehabilitation and strive to achieve target values, although, strictly speaking, incentive spirometry is not a measuring device. Meanwhile, the main effects of incentive spirometry include respiratory muscle training, improved expectoration and ventilatory parameters.

Aim of the study. To compare the volumetric parameters measured by incentive spirometry with the results of bedside ultrasound spirometry and to evaluate the feasibility of using incentive spirometry to assess inspiratory capacity and the effectiveness of postoperative respiratory physiotherapy.

Material and Methods

The study was conducted as a part of the «Evaluation of clinical and economic efficiency of various vibration therapy methods with regard to their effect on gas exchange, respiratory function parameters and expectoration in cardiac surgery patients in early postoperative period for prevention and treatment of postoperative respiratory complications» prospective randomized study conducted in Petrovsky Russian National Research Center for Cardiovascular Surgery. The trial record number on ClinicalTrials.gov is NCT05159401. The study was approved by the local ethics committee (protocol 12 dated 10/28/2021).

Inclusion criteria were as follows: age 18–80 years, spontaneous breathing after tracheal extubation, ability to maintain adequate gas exchange on inhaled oxygen, clear consciousness and good communication with the patient, adequate pain relief (⩽3 points) on a 10-point pain visual analog scale (VAS). Exclusion criteria were the need for mechanical ventilation, non-invasive mask ventilation or high-flow oxygen therapy, acute cerebrovascular accident, shock of various etiologies, ongoing bleeding, use of extracorporeal blood purification, neuromuscular diseases, pneumothorax, hydrothorax or hemothorax.

The analyzed group included 50 patients who underwent elective surgery, including valve replacement (mitral, aortic) (N = 15), plastic valve surgery (N = 7), septal myectomy (N = 10), aortic valve replacement combined with septal myectomy (N = 2), myocardial revascularization (N = 14, including 4 surgeries performed in combination with valve replacement), and combined ascending aorta reconstruction and aortic valve replacement (N = 2). Surgery was performed under cardiopulmonary bypass at room temperature or moderate hypothermia in 48 patients. Postoperative analgesia for VAS greater than 3 was administered with drugs that do not affect respiratory function (intravenous acetaminophen at a dose of 1 g; or tramadol, 50–100 mg; or intramuscular ketoprofen, 100 mg; or oral tapentadol, 50 mg).

During surgery, balanced multicomponent anesthesia (intravenous propofol, midazolam, ketamine, fentanyl, inhalational sevoflurane) was used. Muscle relaxation was maintained by intermittent intravenous boluses of pipecuronium bromide. Del Nido (or blood or Custodiol) cardioplegia was used for myocardial protection.

Spirometry was performed with a Spiro Scout portable ultrasonic spirometer (Schiller, Switzerland) according to the device manual and the Russian Respiratory Society guidelines for spirometry [12, 13]. Before the study, the patient was instructed on the correct examination technique. The investigator explained and demonstrated the correct grip of the mouthpiece and the breathing maneuver (at least four cycles of quiet inhalation and exhalation, followed by maximal deep inhalation and maximal deep exhalation, performed strictly at the request of the investigator, with the completion of the breathing maneuver after the subject's return to normal breathing). The measurements were performed three times, the criterion for a successful performance was the value of the vital lung capacity (VLC) within 150 ml of the maximum value obtained during the given test session. Several parameters were measured, but for the purpose of the study we used maximal inspiratory capacity (MIC), which is the sum of tidal volume (V_t) in ml and inspiratory reserve volume (IRV) in ml.

The studies were performed 10–12 hours after tracheal extubation, 3 times a day for the next 72 hours, before and after the use of different vibration techniques, such as vibroacoustic lung massage with the BARK VibroLUNG device, oscillating PEP therapy with the Acapella Duet Green, mechanical cough stimulation with the Comfort Cough Plus mechanical aspirator, and classical therapeutic manual chest massage with percussion and verbal cough stimulation together with chest compressions. A detailed description of each method is given in our previous publications [14–17].

During these phases of the study, we performed an incentive spirometry session (Coach-2 spirometer by SmithsMedical, USA). The following procedure was used. After instruction and under the control of the intensive care physician, the patient inhales through the spirometer mouthpiece and exhales into the ambient air. The tidal volume (V_t) value is recorded. The patient then places the mouthpiece in his/her mouth and slowly inhales as deeply as possible. The value of maximum inspiratory capacity (MIC), which is the sum of tidal volume and inspiratory reserve volume, is recorded. The measurement was performed three times and then the average value of this parameter was calculated. In this study, we analyzed 812 MIC and spirometric MIC (SMIC) measurements (406 each). Any adverse events and discomfort during these procedures were also recorded. The tests were performed by 6 specially trained physicians.

Statistical analysis was performed using Statistica 10.0 software (StatSoft, Inc.). The results obtained during the study were evaluated for normality of distribution using the Shapiro–Wilk criterion. Parametric and nonparametric methods of analysis were used. Arithmetic means (M) and standard de-

Table 1. The results of the measurement of the inspiratory capacity before and after respiratory physiotherapy sessions (median, 10 and 90 percentiles or *M*±*SD*).

№	Parameter (ml)	Before the therapy	*P-value*	After the therapy	*P-value*	Average △	*P-value*
1	MIC	1000 [500–2500]	0.01	1250 [600–3000]	0.04	200 [0–750]	0.38
	SMIC	1555±616		1735±666		180±270	
2	MIC	1200 [500–2750]	0.53	1694±893	0.88	203±280	0.35
	SMIC	1473±593		1587±591		95 [–225–510]	
3	MIC	1400 [750–3000]	1.00	1500 [750–3100]	0.46	125 [–100–300]	0.06
	SMIC	1519±578		1594±578		90 [–260–440]	
4	MIC	1500 [600–3100]	0.92	1843±878	0.004	100 [–250–300]	1.00
	SMIC	1510±605		1598±655		105 [–215–350]	
5	MIC	1880±937	0.02	1922±853	0.03	10 [–200–350]	0.65
	SMIC	1640±617		1727±599		87±330	
6	MIC	1906±920	<0.001	2025±971	<0.001	50 [–100–500]	0.17
	SMIC	1588±499		1670±635		82±291	
7	MIC	2160±976	<0.001	2261±1042	<0.001	25 [–250–300]	0.77
	SMIC	1845±641		1855±675		10 [–250–300]	
8	MIC	2255±965	<0.001	2500 [1000–4000]	<0.001	50 [–100–400]	0.17
	SMIC	1893±653		1878±648		5 [–380–390]	
9	MIC	2321±961	<0.001	2443±1004	<0.001	50 [–100–500]	0.88
	SMIC	1970±628		2036±674		85 [–185–330]	

Note. Here and in Tables 1, 2 and Fig. 1, 2. MIC — maximum inspiratory capacity; SMIC — spirometric maximum inspiratory capacity.

viations (*SD*) were calculated for numerical parameters with normal distribution. Sets of numerical parameters with non-normal distribution were described using median (*Me*) and 10th and 90th percentile values. The frequency of events in the group was determined by Fisher's exact criterion. Differences were considered significant when $P < 0.05$. The Pearson correlation coefficient (*r*) was calculated to assess the correlation between the same parameters from two different devices. The Bland–Altman method was used to determine bias and outliers, as well as the agreement between all results and between the results of individual patients [18, 19]. Sensitivity and specificity of the methods were determined by ROC analysis [20, 21].

Results and Discussion

Spirometry-based assessment of ventilatory lung function plays an essential role in the diagnosis and management of respiratory diseases and is used to evaluate the effectiveness of various therapies and the results of clinical trials [22–24].

Spirometry is a rather complex test that includes training of participants, acceptability and reproducibility of maneuvers (appropriate patient performance), training of specialists, calibration of equipment, and processing of results. Performing spirometric studies in the early period after cardiac surgery is difficult for patients due to the complexity of their training, the severity of their condition, general weakness, residual effects of general anesthesia and pain. In this context, only resting spirometry, i. e., measurement of volumetric parameters, is used because most of these patients are unable to perform effort-related testing. According to the literature, portable or stationary spirometers measuring forced vital capacity (FVC), forced expiratory volume in 1 second (FEV_1), FEV_1/FVC ratio, total lung capacity (TLC), peak expiratory flow, mean forced expiratory flow in the middle half of the FVC and other parameters have been used in most research studies to evaluate the effectiveness of respiratory physiotherapy [25, 26]. However, these studies were conducted in non-surgical patients who were in significantly better condition compared to cardiac surgery patients, and they did not have pain and fatigue.

Based on the results of previous studies [14–17], we proposed that to evaluate the efficiency of respiratory physiotherapy methods in cardiac surgery patients in the immediate postoperative period, we could use the measurement of MIC changes using an incentive spirometer, which were compared with the data obtained using a portable ultrasound spirometer. The values of the studied parameters before and after physiotherapy sessions are presented in Table 1.

As it is evident from the data, the mean absolute values of MIC and SMIC were different in most cases. The difference in the absolute values of the volumetric parameters of the compared methods can be explained by the different measurement conditions and characteristics of the devices. Unlike the ultrasonic spirometer, the incentive spirometer has considerable resistance and inertia. In addition, nasal leakage is possible during its use because the nose is not clamped during the measurement. However, according to our data, the MIC changes measured with an incentive spirometer can be used in the respiratory rehabilitation of patients. The mean changes of these parameters before and after rehabilitation (mean △) did not show significant differences. The error in measuring the maximum inspiratory capacity with the incentive spirometer in

Table 2. Results of △MIC and △SMIC measurement in relation to the direction of their change after respiratory physiotherapy sessions (*N*=406 for each method).

Direction of changes	Number of measurements	△MIC (ml)	△SMIC (ml)	*P-value*
△ ⩾ 0	341/256	200 [0–500]	175 [25–−510]	0.32
△ < 0	65/150	–200 [–500—100]	–117[–480–−20]	0.23

comparison with the «gold standard» data (conventional spirometry) before and after the sessions was 5.35% and 9.24%, respectively. Regarding the general changes in the measured inspiratory volumes, we observed a significant increase in the first 4 sessions, while in the 5th session the increase was less than 100 ml according to both methods (Fig. 1). This was due to the fact that by this time the respiratory function of the lungs had been restored and the maximum possible values for a particular patient had been reached. Depending on the direction of change of the evaluated parameters, we distinguished two groups: with decreased (△ < 0) and with increased or the same (△ ⩾ 0) respiratory volumes.

No significant differences were found when comparing the two methods (Table 2).

In order to assess the relationship between the measured parameters, we performed a correlation analysis by calculating Pearson's correlation coefficient, which showed a strong positive significant correlation (R = 0.74 before the session, R = 0.79 after the session, whole sample R = 0.77, P < 0.001).

Taking into account the fact that the Pearson correlation coefficient can only assess the linear dependence between the results obtained, the level of agreement between the two measurement methods was assessed using the Bland–Altman method (Fig. 2). This showed a mean difference of 216.9 mL between the measurement pairs (limits of agreement: –1021.3; 1455) with an outlier of 4.06% (33/812). Thus, more than 95% of the values were within ± 1.96 SD of the mean difference, indicating good agreement between the two methods.

To determine the diagnostic efficacy of incentive spirometry in measuring inspiratory capacity, its diagnostic sensitivity and specificity relative to the spirography method (reference standard) were evaluated. The ROC curve is a graph of the frequency of true positives (sensitivity) versus the frequency of false positives (100 — specificity). The area under the ROC curve (AUC) was 0.8 (95% CI: [0.76; 0.83]), sensitivity was 87% and specificity was 85%, P < 0.001.

Thus, the incentive spirometry method showed a good diagnostic accuracy compared to the reference method, which, in our opinion, allows its use in assessing changes in maximal inspiratory capacity in the postoperative period in cardiac surgical patients in the intensive care unit.

We performed a comparative analysis of the side effects, tolerability and comfort of the incentive spirometer and the bedside spirometer when performing measurements in cardiac surgical patients. The results of this analysis are shown in Table 3.

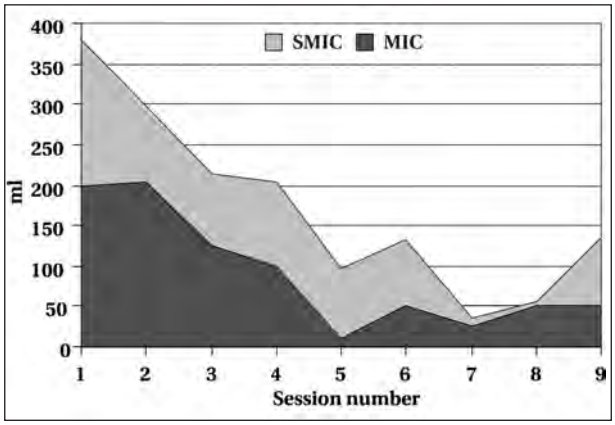

Fig. 1. Changes in the increase of the average values of the inspiratory capacity (△ MIC and △ SMIC) before and after respiratory rehabilitation sessions in ml.

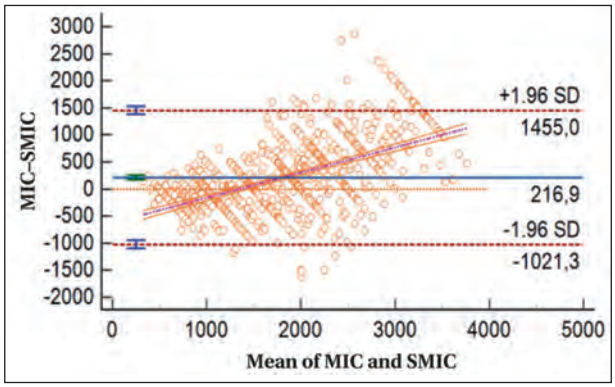

Fig. 2. Comparison of maximum inspiratory capacity and spirometric maximum inspiratory capacity values using the Bland–Altman method.
Note. X-axis shows the average value for two methods in one test (MIC and SMIC in ml), Y-axis shows the difference of values in one test, «mean» is the average value (shown by continuous middle line), upper and lower limits of agreement are represented by upper and lower dashed lines, respectively.

As can be seen from the Table 3, when performing measurements on a bedside spirograph (mainly in the first two days of the postoperative period), various complaints appeared (a total of 18 events in 8 patients, which is 16%), which made it impossible to perform further spirography, while using an incentive spirometer in the same patients did not cause such sensations [27, 28].

Table 3. Side effects during spirometry in cardiac surgery patients.

Side effects	Incentive Spirometer	Bedside Ultrasonic Spirometer	*P-value*
Nausea	0	3	0.08
Dizziness	0	3	0.08
Weakness	0	8	< 0.001
Palpitations	0	4	0.05
Total	0	18	< 0.001

The vast majority of cardiac surgery patients (44 out of 50 patients, 88%), despite performing all the tests, reported discomfort and difficulties in spirography due to the use of mouthpiece, nasal clip, incomplete understanding of the test itself, which required repeated instructions from the physician-researcher and prolonged the measurement process. Thus, we conclude that the use of the incentive spirometer is perceived by the patients as a simpler and easier procedure to perform.

Conclusion

Comparative evaluation of changes in inspiratory capacity using the incentive spirometer showed good agreement with the method of ultrasound spirography.

The incentive spirometer can be used to assess the increase in respiratory capacity parameters during rehabilitation of cardiac surgery patients in the early postoperative period.

The majority of postoperative cardiac surgery patients rated incentive spirometry as a more comfortable procedure compared with conventional spirography.

References

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: 19–26. *[Bautin A.E., Kasherininov I.Yu., Latetin D.A., Mazurok V.A., Rubinchik V.E., Naymushin A.V., Marichev A.O., Gordeev M.L.* Prevalence and causes of the postoperative acute respiratory failure in cardiac surgery. *Ann Crit Care /Vestnik Intensivnoy Terapii.* 2016; 4: 19–26. (In Russ.).].
2. *Faker A. A., Damag A., Norman T.* Incidence and outcome of pulmonary complications after open cardiac surgery. *Egypt J Chest Dis Tuberc* 2013; 62 (4): 775–780. DOI: 10.1016/j.ejcdt. 2013.08.008.
3. *Mathis M.R., Duggal N. M., Likosky D.S., Haft J. W., Douville N.J., Vaughn M.T., Maile M.D., Blank R.S., Colquhoun D.A., Strobel R.J., Janda A.M., Zhang M., Kheterpal S., Engoren M.S.* Intraoperative mechanical ventilation and postoperative pulmonary complications after cardiac surgery. *Anesthesiology*. 2019; 131 (3): 1046–1062. DOI: 10.1097/ALN.0000000 000002909. PMID: 31403976.
4. *Saffari N,H.N., Nasiri E, Mousavinasab S.N., Ghafari R., Soleimani A., Esmaeili R.* Frequency rate of atelectasis in patients following coronary artery bypass graft and its associated factors at Mazandaran Heart Center in 2013–2014. *Glob J Health Sci.* 2015; 7 (7 Spec No): 97–105. DOI: 10.5539/gjhs. v7n7p97. PMID: 26153209.
5. *Салухов В.В., Харитонов М.А., Макаревич А.М., Богомолов А.Б., Казанцев В.А., Иванов В.В., Чугунов А.А., Морозов М.А.* Опыт применения аппарата Bark Vibrolung в комплексном лечении внебольничной пневмонии. *Вестник Российской Военно-медицинской академии.* 2021; 23 (1): 51–58. DOI: 10.17816/brmma63576. [*Salukhov V.V., Kharitonov M.A., Makarevich A.M., Bogomolov A.B., Kazantsev V.A., Ivanov V.V., Chugunov A.A., Morozov M.A.* Experience of using the «Bark Vibrolung» device in comprehensive treatment of community-acquired pneumonia. *Bulletin of the Russian Military Medical Academy/ Vestnik Rossiyskoy Voenno- Meditsinskoy Akademii.* 2021; 23 (1): 51–58. (in Russ.). DOI: 10.17816/brmma63576].
6. *Tse J., Wada K., Wang Y., Coppolo D., Kushnarev V., Suggett J.* Impact of oscillating positive expiratory pressure device use on post-discharge hospitalizations: a retrospective cohort study comparing patients with COPD or chronic bronchitis using the aerobika and acapella devices. *Int J Chron Obstruct Pulmon Dis.* 2020; 15: 2527–2538. DOI: 10.2147/COPD. S256866. PMID: 33116469.
7. *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. DOI: 10.1186/1471-2466-13-21. PMID: 23556995.
8. *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 (9): CD011699. DOI: 10.1002/14651858.CD011699.pub2. PMID: 28952156.
9. *Cho Y. J., Ryu H., Lee J., Park I.K., Kim Y.T., Lee Y.H., Lee H, Hong D.M., Seo J.H., Bahk J.H., Y Jeon.* A randomised controlled trial comparing incentive spirometry with the Acapella® device for physiotherapy after thoracoscopic lung resection surgery. *Anaesthesia.*2014; 69 (8): 891–898. DOI: 10.1111/anae.12750. PMID: 24845198.
10. *Wheatley C.M., Baker S.E., Daines C.M., Phan H., Martinez M.G., Morgan W.J., Snyder E.M.* Influence of the Vibralung Acoustical Percussor on pulmonary function and sputum expectoration in individuals with cystic fibrosis. *Ther Adv Respir Dis.* 2018; 12: 1753466618770997. DOI: 10.1177/1753 466618770997. PMID: 29697011.
11. *Козлов И.А., Дзыбинская Е.В., Романов А.А., Баландюк А.Е.* Коррекция нарушения оксигенирующей функции легких при ранней активизации кардиохирургических больных. *Общая реаниматология.* 2009; 2: 37–43. DOI: 10.15360/1813-9779-2009-2-37. [*Kozlov I.A., Dzybinskaya Y.V., Romanov A. A., Balandyuk A.Y.* Correction of pulmonary oxygenizing dysfunction in the early activation of cardiosurgical patients. *General Reanimatology / Obshchaya Reanimatologiya.*2009; 2: 37–43. (In Russ.). DOI: 10.15360/1813-9779-2009-2-37].
12. *Moore V.C.* Spirometry: step by step. *Breathe.* 2012; 8 (3): 232–240. DOI: 10.1183/20734735. 0021711.
13. *Graham B.L, Steenbruggen I., Miller M.R., Barjaktarevic I.Z., Cooper B.G., Hall G.L., Hallstrand T.S., Kaminsky D.A., McCarthy K., McCormack M.C., Oropez C.E., Rosenfeld M., Stanojevic S., Swanney M.P., Thompson B.R.* Standardization of spirometry 2019 update. An official American Thoracic Society and European Respiratory Society technical statement. *Am J Respir Crit Care Med.* 2019; 200 (8): e70–e88. DOI: 10.1164/rccm.201908-1590ST. PMID: 31613151.
14. *Еременко А.А., Зюляева Т.П., Калинина А.А., Розина Н.А.* Оценка эффективности виброакустического массажа легких при самостоятельном дыхании у пациентов после

кардиохирургических операций. *Клиническая и экспериментальная хирургия. Журнал имени академика Б.В. Петровского*. 2020; 8 (4): 126–134. DOI: 10.33029/2308-1198-2020-8-4-126-134. [*Eremenko A.A., Zyulyaeva T.P., Kalinina A.A., Rozina N.A.* Evaluation of vibroacoustic lung massage effectiveness in self-breathing patients after cardiosurgical operations. *Clinical and Experimental Sursery. Petrovsky Journal/ Klinicheskaya i Eksperimentalnaya Khirurgiya. Zhurnal im. Akademika B.V. Petrovskogo*. 2020; 8 (4): 126–134. (In Russ.). DOI: 10.33029/2308-1198-2020-8-4-126-134].

15. *Еременко А.А., Рябова Д.В., Комнов Р.Д., Червинская А.В.* Оценка эффективности и безопасности аппаратной стимуляции кашля при ранней послеоперационной респираторной реабилитации у кардиохирургических пациентов. *Вопросы курортологии, физиотерапии и лечебной физической культуры*. 2021; 98 (6–2): 17–24. [*Eremenko AA, Ryabova D.V, Komnov R.D, Chervinskaya A.V.* Effectiveness and safety evaluation of a cough stimulation device in early postoperative respiratory rehabilitation in cardiac surgery patients. *Problems of Balneology, Physiotherapy and Exercise Therapy/ Voprosy Kurortologii, Fizioterapii, i Lechebnoi Fizicheskoi Kultury*. 2021; 98 (6–2): 17–24. (In Russ.). DOI: 10.17116/kurort20219806217].
16. *Еременко А.А., Зюляева Т.П., Алферова А.П.* Оценка эффективности осциллирующей PEP-терапии в раннем периоде после кардиохирургических операций. *Кардиология и сердечно-сосудистая хирургия*. 2021; 14 (6): 477–482. DOI: 10.17116/kardio202114061477. [*Eremenko A.A, Zyulyaeva T.P, Alferova A.P.* Effectiveness of oscillating PEP-therapy in early period after cardiac surgery. *Cardiology and Cardiovascular Surgery// Kardiologiya i Serdechno-Sosudistaya Khirurgiya*. 2021; 14 (6): 477–482. (In Russ.)]. DOI: 10.17116/kardio202114061477.
17. *Еременко А.А., Зюляева Т.П., Рябова Д.В., Алферова А.П.* Сравнительная оценка эффективности вибрационных физиотерапевтических методов в ранние сроки после кардиохирургических вмешательств. *Вестник анестезиологии и реаниматологии*. 2021; 18 (6): 80–89. DOI: 10.21292/2078-5658-2021-18-6-80-89. [*Eremenko A.A., Zyulyaeva T.P., Ryabova D.V., Alferova A.P.* Comparative evaluation of vibratory physiotherapy methods in the early period after cardiac surgery. *Messenger of Anesthesiology and Resuscitation/Vestnik Anesthesiologii i Reanimatologii*. 2021; 18 (6): 80–89. (In Russ.). DOI: 10.21292/2078-5658-2021-18-6-80-89].
18. *Giavarina D.* Understanding bland altman analysis. *Biochem Med (Zagreb)*. 2015; 25 (2): 141–151. DOI: 10.11613/BM.2015. 015. PMID: 26110027.
19. *Myles P.S., Cui J.I.* Using the Bland–Altman method to measure agreement with repeated measures. *Br J Anaesth*. 2007; 99 (3): 309–311. DOI: 10.1093/bja/aem214. PMID: 17702826.
20. *Linden A.* Measuring diagnostic and predictive accuracy in disease management: an introduction to receiver operating characteristic (ROC) analysis. *J Eval Clin Pract*. 2006; 12 (2): 132–139. DOI: 10.1111/j.1365-2753.2005.00598.x PMID: 16579821.
21. *Metz C. E.* Basic principles of ROC analysis. *Semin Nucl Med*. 1978; 8 (4): 283–298. DOI: 10.1016/S0001-2998(78)80014-2. PMID: 112681.
22. *Agostini P, Singh S.* Incentive spirometry following thoracic surgery: what should we be doing? *Physiotherapy*. 2009; 95 (2): 76–82. DOI: 10.1016/j.physio.2008.11.003. PMID: 19627688.
23. *Manapunsopee, S., Thanakiatpinyo, T., Wongkornrat, W., Chuaychoo, B., Thirapatarapong, W.* Effectiveness of incentive spirometry on inspiratory muscle strength after coronary artery bypass graft surgery. *Heart, Lung Circ*. 2019; 29 (8): 1180–1186. DOI: 10.1016/j.hlc.2019.09.009. PMID: 31735684.
24. *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: 10.7759/ cureus.6851. PMID: 32181086.
25. *Dempsey T.M, Scanlon P.D.* Pulmonary function tests for the generalist: a brief review. *Mayo Clin Proc*. 2018; 93 (6): 763–771. DOI: 10.1016/j.mayocp.2018.04.009. PMID: 29866281.
26. *Nathan S.D., Wanger J., Zibrak J.D., Wencel M.L., Burg C., Stauffer J.L.* Using forced vital capacity (FVC) in the clinic to monitor patients with idiopathic pulmonary fibrosis (IPF): pros and cons. *Expert Rev Respir Med*. 2021; 15 (2): 175–181. DOI: 10.1080/17476348.2020.1816831. PMID: 32985286.
27. *Beningfield A., Jones A.* Peri-operative chest physiotherapy for paediatric cardiac patients: a systematic review and meta-analysis. *Physiotherapy*. 2018; 104 (3): 251–263. DOI: 10.1016/j.physio.2017.08.011. PMID: 29361296.
28. *Alwekhyan S.A., Alshraideh J.A., Yousef K.M., Hayajneh F.* Nurse-guided incentive spirometry use and postoperative pulmonary complications among cardiac surgery patients: a randomized controlled trial. *Int J Nurs Pract*. 2022; 28 (2): e13023. DOI: 10.1111/ijn.13023. PMID: 34676618.

Received 26.08.2022
Accepted 30.01.2023