UDC 616.132.2-089.843-06-085.816

E. V. Fot[1], V. V. Kuzkov[1], K. M. Gaidukov[1], L. J. Bjertnæs[2], M. Y. Kirov[1, 2]

EFFICACY AND SAFETY OF THREE ALVEOLAR RECRUITMENT MANOEUVRES AFTER OFF-PUMP CORONARY ARTERY BYPASS GRAFTING

[1] Northern State Medical University. Arkhangelsk, Russian Federation,
[2] University of Tromsø, Tromsø, Norway

УДК 616.132.2-089.843-06-085.816

Е. В. Фот, В. В. Кузьков, К. М. Гайдуков, Л. Я. Бьертнес, М. Ю. Киров

ЭФФЕКТИВНОСТЬ И БЕЗОПАСНОСТЬ РАЗЛИЧНЫХ ВАРИАНТОВ МАНЕВРА РЕКРУТМЕНТА АЛЬВЕОЛ ПОСЛЕ АОРТОКОРОНАРНОГО ШУНТИРОВАНИЯ НА РАБОТАЮЩЕМ СЕРДЦЕ

Актуальность. Необходимость проведения маневра рекрутмента альвеол (МРА) после кардиохирургических вмешательств требует дальнейшего изучения.

Целью нашего исследования является оценка эффективности и безопасности различных вариантов МРА после аортокоронарного шунтирования (АКШ) на работающем сердце.

Материалы и методы. В ходе исследования 80 взрослых пациентов, перенесших АКШ на работающем сердце, были рандомизированы в одну из четырех групп: группу CPAP-40, где МРА осуществлялся за счет подъема положительного давления в конце выдоха до 40 см вод. ст. в течение 40 с; группу Peak-40, в которой рекрутмент выполнялся за счет повышения пикового давления в дыхательных путях до 40 см вод. ст. на период 40 с; группу PEEP-15, где МРА осуществлялся за счет подъема положительного давления в конце выдоха до 15 см вод. ст. на период 5 мин; и контрольную группу, где МРА не выполнялся. Всем пациентам осуществлялся мониторинг показателей гемодинамики и газообмена при поступлении в реанимацию, во время выполнения маневра, а также через 10 мин после его окончания и через 1, 6, 12 ч после экстубации трахеи.

Результаты. Артериальная оксигенация и динамический комплайнс легких улучшились во всех группах, получивших МРА ($p<0,017$). Проведение маневра в группе CPAP-40 сопровождалось достоверным снижением среднего артериального давления ($p=0,01$). Длительность послеоперационной искусственной вентиляции легких была достоверно корче в группе PEEP-15 по сравнению с контрольной группой ($p=0,012$).

Выводы. Проведение МРА в раннем послеоперационном периоде после АКШ на работающем сердце в группах Peak-40 и PEEP-15 сопровождалось улучшением оксигенации, не оказывая при этом отрицательного влияния на показатели гемодинамики. Подъем положительного давления в конце выдоха до 15 см вод. ст. на период 5 мин способствовал сокращению продолжительности послеоперационной респираторной поддержки.

Ключевые слова: маневр рекрутмента альвеол, искусственная вентиляция легких, аортокоронарное шунтирование.

UDC 616.132.2-089.843-06-085.816

E. V. Fot, V. V. Kuzkov, K. M. Gaidukov, L. J. Bjertnæs, M. Yu. Kirov

EFFICACY AND SAFETY OF THREE ALVEOLAR RECRUITMENT MANOEUVRES AFTER OFF-PUMP CORONARY ARTERY BYPASS GRAFTING

Background. The significance of alveolar recruitment manoeuvre (RM) after coronary artery surgery is still unsettled.

Objective. The aim of this study was to compare three methods of RM after off-pump coronary artery bypass grafting (OPCAB).

Materials and methods. 80 adult patients undergoing OPCAB were enrolled into a prospective randomized trial. Six patients were excluded from the analysis due to deviation from the study protocol. Four groups: CPAP-40 group was exposed to RM by changing the ventilator mode to continuous positive airway pressure of 40 cm H_2O for 40 sec (n=19); in a Peak-40 group (n=20), RM was achieved by inflating the lungs at constant flow until a peak inspiratory pressure of 40 cm H_2O was reached and held for 40 sec; the PEEP-15 (n=19) group received RM by raising the positive end-expiratory pressure to 15 cm H_2O for 5 min; the control group (n=16) received no RM. PEEP level was defined as 5 cm H_2O in all groups. The primary end-point of the study was the decrease in duration of postoperative respiratory support. Blood gases, respiratory and haemodynamic parameters were registered before RM, 10 min after RM, after a spontaneous breathing trial, at 1, 6, and 12 hrs after tracheal extubation.

Results. Arterial oxygenation and dynamic compliance increased in all groups receiving RM ($P<0.017$). In the CPAP-40 group, mean arterial pressure decreased significantly during RM ($P=0.01$). In the PEEP-15 group, the duration of respiratory support was shortened by 1 hr as compared with the control group ($P=0.012$).

Conclusion. Alveolar RM Peak-40 and PEEP-15 after OPCAB improved the oxygenation without negative influence on the haemodynamics, whereas CPAP-40 was accompanied by arterial hypotension. Application of a PEEP of 15 cm H_2O for five minutes reduced the time to tracheal extubation.

Key words: alveolar recruitment, mechanical ventilation, coronary artery bypass grafting.

Introduction

The formation of atelectases is a common complication of mechanical ventilation during general anaesthesia [1–3]. Chest radiograms display crest-shaped changes of increased density in dependent lung regions within minutes after induction of anaesthesia and neuromuscular blockade. These changes are concerted by a fall in functional residual capacity and a cranial displacement of the diaphragm [2; 3]. Following cardiac surgery, collapse of pulmonary parenchyma can persist postoperatively and contribute to increased morbidity and additional health care costs [1]. Notably, the incidence of atelectases is particularly high after cardio-surgical interventions because the patients are exposed to multiple promoting factors. Attention also has been paid to the sternotomy *per se* and to lung compression by mediastinal structures. Moreover, the use of retractors during the surgery, manipulations in the pleural cavities and mechanical ventilation with high inspiratory oxygen fractions might all add to the de-aeration of lung tissue [4; 5].

Over the last years, different strategies have been used to re-expand collapsed lung areas, both intra- and postoperatively [6–8]. Several studies have shown that the application of an alveolar recruitment manoeuvre (RM) can improve respiratory function by re-opening atelectatic regions after cardiac surgery. It is widely accepted that RM reduces intrapulmonary shunt and ventilation-perfusion mismatch and subsequently improves arterial oxygenation [1; 9]. However, some effects of the RM might be deleterious since it might affect the cardiovascular system adversely; besides this it might induce barotrauma, volutrauma and biotrauma [5; 10; 11].

Currently, there is a wide variety of methods for recruitment manoeuvres in clinical practice, including different levels of continuous positive airway pressure (CPAP), positive

end-expiratory pressure (PEEP), increased tidal volume and peak or plateau pressures for different periods of time [5–8]. However, to date there is no general agreement on which mode of RM is most advantageous postoperatively for the individual patient [12]. Correspondingly, the significance of RM after coronary surgery is also still unsettled [13].

Thus, the aim of our study was to assess the efficacy and safety of three different modes of RM and to evaluate their influence on the postoperative ventilation time and early postoperative period after off-pump coronary artery bypass grafting (OPCAB).

Methods

The study design and the informed consent form were approved by the Ethical Committee of Northern State Medical University, Troitsky av. 51, 163001 Arkhangelsk, Russian Federation, on 1 February 2011 (No 2; Chairperson Professor A. Gudkov). Written informed consent was obtained from every patient.

The study was performed in a 900-bed university hospital (City Hospital №1 of Arkhangelsk, Russia). During the period from March 2011 to January 2012, 80 adult patients undergoing OPCAB were enrolled into a prospective randomized study. Exclusion criteria were age>75 years, morbid obesity with body mass index (BMI)>35 kg/m^2, history of acute myocardial infarction within the preceding month, pre-existing COPD at the stage of decompensation, lung surgery, pregnancy, signs of acute lung injury after the surgery and unstable haemodynamics defined as requirement for dobutamine/dopamine>10 mcg/kg/min, or epinephrine/norepinephrine>0.1 mcg/kg/min to maintain the mean arterial pressure (MAP) within 60–80 mm Hg.

All the patients received a standard anaesthesia using propofol (Diprivan, AstraZeneca, UK) 3 mg/kg/hr and fentanyl (Moscow Endocrine Factory, Russia) 2–4 mcg/kg/hr.

Mechanical ventilation in the operating room was performed by means of a semi-closed anaesthetic circuit (Fabius GS, Dräger, Germany) with FiO_2 0.5 to obtain SpO_2 values above 95%, tidal volume (V_T) 8 mL/kg of predicted body weight (PBW), respiratory rate 12–14/min aiming at $PaCO_2$ of 35–45 mm Hg, PEEP was set to 5 cm H_2O and fresh gas flow of 1 L/min. Nobody received RM during the surgery.

At the end of surgery and transfer to the cardiosurgical ICU, all the patients were randomized by using the envelope method into the following groups:

1) The CPAP-40 group (n=19) where RM was achieved by changing the ventilator mode to CPAP of 40 cm H_2O for 40 sec.

2) The Peak-40 group (n=20) where RM was performed by increasing inspiratory pressure in constant flow rate to achieve peak inspiratory pressure of 40 cm H_2O during 40 sec.

3) The PEEP-15 group (n=19) where alveolar RM was achieved by raising positive end-expiratory pressure to 15 cm H_2O for 5 min.

4) The Control group (n=16) received no RM during conventional assist-control ventilation.

Six patients were excluded from the analysis: one because of protocol violation (inability to follow the protocol of ventilation for technical reasons), one due to deviation from the inclusion criteria (emphysematous changes in the lung diagnosed intraoperatively) and four due to problems with data sampling.

During RM, all groups were sedated with continuous infusion of propofol 1–2 mg/kg to suppress spontaneous breathing. All patients received epidural analgesia at the Th_{2-4} level with a continuous infusion of ropivacaine 0.2% (Naropin, AstraZeneca, UK) at rate 3–8 ml/hr aiming at a visual analogue scale (VAS) score <30 mm at rest. All the patients received respiratory support using pressure controlled ventilation (PCV) (Avea, Viasys, USA). Inspiratory pressure was adjusted to deliver a V_T of 8 mL/kg predicted body weight, PEEP was set to 5 cm H_2O, FiO_2 to 0.5 or higher to obtain SpO_2 above 95%. Respiratory rate (RR) was adjusted to provide $EtCO_2$ of 30–35 mm Hg. Haemodynamic parameters were optimized according to the goal-directed therapy protocol [14].

After stabilization of haemodynamic and ventilation variables following transfer from the operation room, the RM was performed according to the group allocation, or the patients received ventilation without any RM (control group). The RM was discontinued if hypotension (MAP<50 mm Hg) and/or bradycardia below 35/min occurred during the procedure.

Within 10 min after RM, the ventilation mode was changed, if possible, to pressure support ventilation (PSV) with inspiratory pressure increasing gradually from 6 cm H_2O to a level sufficient for obtaining a spontaneous V_T of 6 mL/kg PBW. The ventilatory parameters were assessed every 30 min and adjusted, if necessary, aiming at a stepwise decreasing pressure support of by 2–4 cm H_2O each time. In case of dyspnoea or reduction of V_T, inspiratory pressure was increased to the previous level. After decrease of pressure support to 6 cm H_2O (8 cm H_2O in case of BMI>30 kg/m^2), the spontaneous breathing trial (SBT) was started.

The SBT was considered to be passed if the patient displayed no episodes of tachypnoea (RR>30 /min), had V_T>6 mL/kg PBW, PaO_2/FiO_2>250 mm Hg, f/V_T<105 breaths/(min·mL) and HR<100/min during the last 30 min. After passing the SBT all the patients were immediately extubated. After the extubation, the patients received a supplementary oxygen flow of 4 L/min via a nasal catheter.

The measurements included ventilatory parameters (Ppeak (peak inspiratory pressure), V_T, RR, dynamic compliance), blood gases (ABL800Flex, Radiometer, Denmark), $EtCO_2$ and SpO_2 (Capnostream-20, Oridion, Israel), and haemodynamics including HR, MAP and CVP assessed by electrocardiogram and invasive monitoring of arterial and central venous pressure, respectively. All these parameters were registered before and at 10 min after RM, after SBT, as well as at 1, 6, and 12 hrs after extubation. After tracheal extubation, all the values were measured after 3 min without supplemental oxygen (FiO_2 0.21). $EtCO_2$ at 1, 6 and 12 hrs after extubation was measured using $EtCO_2$ breath sampling lines for non-intubated patients (Smart CapnoLine® Plus, Oridion, Israel). In addition, we recorded the perioperative fluid balance and length of postoperative ICU stay. Chest radiographs were taken on postoperative day one. Atelectases were graded as 0: no atelectasis and 1: partial or total atelectasis. The treating staff in the ICU was blinded to the patient's randomization. The primary end-point of the study assessing the efficacy of RM was the decrease in duration of postoperative respiratory support. The secondary endpoint was an increment in PaO_2/FiO_2 ratio by at a least 10 mm Hg at 10 min after RM.

Statistical Analysis

For data collection and analysis, we used SPSS software (version 16.0; SPSS Inc., IL, USA). All the variables were expressed as median (25th–75th interquartile interval).

Calculation of sample size was based on initial observations (5 cases in each group) and the hypothesis that RM would shorten the duration of postoperative respiratory support by 60 min compared with the control group. In order to find a statistically significant difference with α of 0.05 and β of 0.2, a sample size of 16 patients in each group proved to be sufficient.

The groups were compared using Kruscal–Wallis and *post hoc* Mann–Whitney tests with Bonferroni correction. The intragroup comparisons with baseline (before RM) were performed by Friedman and *post hoc* Wilcoxon tests with Bonferroni correction. Discrete data were compared using Fisher's exact test and expressed as patient number. For *post hoc* intragroup comparisons, p value<0.01 was considered as statistically significant. In case of *post hoc* intergroup comparisons, p<0.017 was regarded as statistically significant.

Results

We found no statistically significant intergroup differences with regard to sex, age, BMI, PBW, ejection fraction determined by echocardiographic, EuroSCORE assessment, duration of surgery and postoperative fluid balance (Table 1).

Table 1

Key Clinical Characteristics of the Patients

Parameter	Groups			
	CPAP-40 (n=19)	PEEP-15 (n=19)	Peak-40 (n=20)	Control (n=16)
Gender, (male / female)	16/3	11/8	16/4	11/5
Age, yrs	57 (54–65)	60 (58–62)	62 (55–65)	61 (54–70)
Body mass index, kg /m^2	27 (24–31)	25 (23–31)	26 (24–28)	25 (24–29)
Predicted body weight, kg	69 (62–72)	62 (47–68)	66 (56 –71)	66 (55–72)
Ejection fraction, %	59 (53–61)	61 (59–66)	59 (57–62)	60 (54–66)
EuroSCORE, points	2 (1–4)	3 (3–5)	2 (2–4)	3 (1–5)
Duration of surgery, min	185 (155–205)	185 (175–195)	178 (155–194)	188 (168–205)
Postoperative fluid balance, mL	1550 (1350–1900)	1725 (1400–2000)	1475 (1237–1725)	1425 (1175–1912)
Postoperative time to tracheal extubation, min	150 (107–190)	115 (83–148)*	120 (115–180)	175 (115–180)
Intensive care unit time, hrs	45 (24–63)	44 (24–50)	46 (24–48)	46 (24–48)
Atelectases	2	3	3	4

Note. * — p<0.017 between groups compared with the control, data represented as median (25th–75th interquartile interval) or number.

During the RM peak inspiratory pressure in groups CPAP-40 and Peak-40 was 40 cm H_2O; in PEEP-15 group it was 29 (28–31) cm H_2O.

The Efficacy of the Recruitment Manoeuvres

After RM, we observed an increase in PaO_2/FiO_2 in comparison with intragroup baseline by 17, 18 and 16% in the PEEP-15, Peak-40 and CPAP-40 groups, respectively, (P<0.01; Table 2). The difference between PaO_2/FiO_2 before and 10 min after RM (delta PaO_2/FiO_2) in the PEEP-15 and the Peak-40 groups was significantly higher as compared to delta PaO_2/FiO_2 in the Control group (P<0.017, Fig. 1). The increment in PaO_2/FiO_2 following RM persisted during the post-extubation period. In the Control group, we observed a transient increase in PaO_2/FiO_2 at 1 and 6 hrs after tracheal extubation (P<0.013). In parallel with the increase in arterial oxygenation, dynamic respiratory compliance increased significantly in all the three groups of RM (P<0.03). $EtCO_2$ and $PaCO_2$ registered 5 and 10 min after the RM did not differ significantly between or within the groups. However, in the RM groups, $EtCO_2$ increased after tracheal extubation compared with baseline (P<0.01) and with the Control group (P<0.017). Respiratory rate rose in all the groups after the discontinuation of mechanical ventilation (see Table 2).

Safety of Recruitment Manoeuvres

In the CPAP-40 group, 30 sec after the start of RM, MAP decreased by 33% compared with baseline (P=0 001) and by 36% compared with the Control group (P=0.0001; Fig. 2). Severe hypotension (MAP below 50 mm Hg) developed in one patient of the PEEP-15 group and in two patients of the CPAP-40 group. The data obtained from these patients during the post-extubation period were excluded from further analysis.

Table 2

Changes of the studied parameters during the recruitment manoeuvres and after extubation

Parameter	Group	Stage					
		Before RM	10 min after RM	After SBT	1 hrs after extubation	6 hrs after extubation	12 hrs after extubation
PaO_2/FiO_2, mm Hg	CPAP-40	240 (195–301)	285 (238–348)*	300 (246–384)*	318 (292–360)*	358 (299–430)*	328 (290–383)*
	PEEP-15	292 (199–370)	352 (220–394)*	322 (210–372)*	312 (292–386)*	322 (302–392)*	343 (306–391)*
	Peak-40	257 (210–350)	311 (260–433)*	298 (236–336)*	352 (279–385)*	357 (290–411)*	314 (270–413)*
	Control	254 (208–354)	260 (224–370)	228 (226–334)	348 (303–384)*	330 (308–464)*	301 (291–356)
Compliance, mL/cm H_2O	CPAP-40	34 (30–41)	39 (34–51)*	—	—	—	—
	PEEP-15	34 (29–45)	36 (34–46)*	—	—	—	—
	Peak-40	39 (34–45)	44 (36–53)*	—	—	—	—
	Control	35 (31–41)	36 (32–46)	—	—	—	—
$EtCO_2$, mm Hg	CPAP-40	32 (29– 36)	32 (29–35)	39 (35–41)*	36 (35–38)*	36 (35–39)**	35 (32–41)**
	PEEP-15	31 (28–37)	33 (29–36)	38 (35–40)*	38 (34–41)*	35 (31–38)	35 (30–39)**
	Peak-40	32 (28–35)	33 (29–35)	38 (35–43)*	38 (31–41)*	35 (34–38)*, **	33 (31–35)
	Control	31 (28–33)	32 (28–32)	38 (35–39)*	35 (33–38)	33 (28–36)	31 (24–32)
$PaCO_2$, mm Hg	CPAP-40	37 (34–41)	37 (35–43)	38,7 (36,7–42,1)	36 (34–40)	36 (33–39)	37 (33–41)
	PEEP-15	39 (36–41)	39 (36–41)	39,3 (38,3–42,8)	39 (38–42)	37 (35–39)	37 (35–38)
	Peak-40	38 (36–41)	37 (34–43)	39,9 (37,9–42)	39 (36–42)	37 (35–39)	35 (32–38)
	Control	38 (34–41)	39 (35–41)	40 (37–43)	38 (37–41)	37 (34–38)	36 (34–40)
Respiratory rate/min	CPAP-40	14 (12–15)	14 (12–15)	19 (14–22)*	23 (17–24)*	20 (18–21)*	23 (19–24)*
	PEEP-15	14 (12–14)	13 (11–14)	18 (16–21)*	20 (15–22)*	20 (16–24)*	20 (16–23)*
	Peak-40	12 (12–14)	12 (12–14)	18 (16–22)*	18 (15–23)*	19 (17–21)*	20 (18–22)*
	Control	12 (12–14)	12 (12–14)	20 (17–25)*	20 (18–24)*	21 (19–25)*	21 (18–24)*
Heart rate/min	CPAP-40	68 (52–78)	66 (51–82)	89 (78–98)*	95 (72–100)*	83 (74–90)*	78 (75–86)*
	PEEP-15	65 (55–73)	66 (56–72)	77 (70–96)*	89 (81–97)*	84 (73–90)*	81 (69–83)*
	Peak-40	67 (57–72)	69 (54–76)	86 (78 –90)*	86 (77–94)*	82 (78–88)*	78 (71–89)*
	Control	61 (54–77)	67 (54–76)	77 (67–92)*	83 (71–97)*	78 (61–91)*	76 (66 –88)*

Note. Data represented as median (25th–75th interquartile interval) * — $p<0.01$ within group compared with baseline (before recruitment manoeuvre), $p<0.03$ within group compared with baseline (before recruitment manoeuvre) in case of compliance measurements, ** — $p<0.017$ as compared with the control group. $EtCO_2$ — end-tidal CO_2, SBT — spontaneous breathing trial

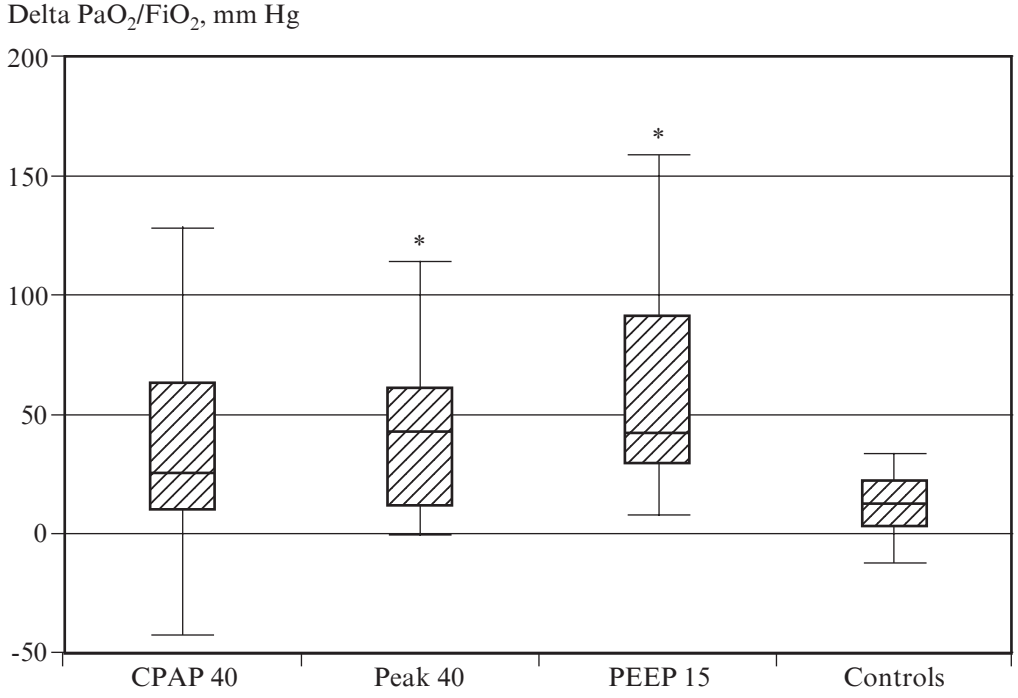

Fig. 1. Delta PaO_2/FiO_2 ratio by 10 minutes after the recruitment manoeuvre in comparison with the control group: * — p<0.017 compared with the Control group. Data represented as median, 25th–75th interquartile interval

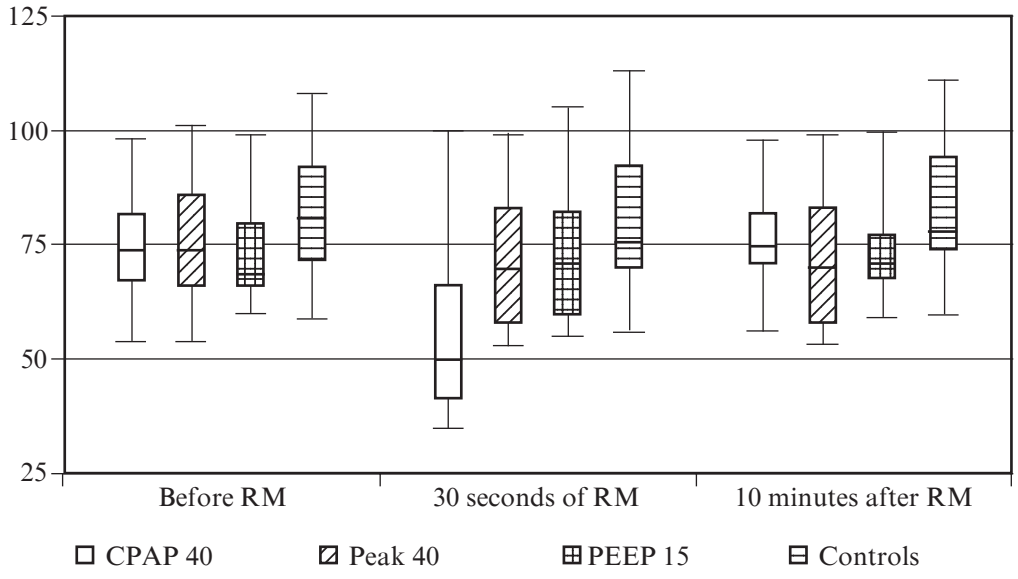

Fig. 2. Changes in mean arterial pressure during and after recruitment manoeuvres: * — p<0.017 compared with the Control group. Data represented as median, 25th–75th interquartile interval

In these patients, RM was cancelled prematurely. After RM, MAP returned to the baseline values. There were no significant intergroup differences in HR postoperatively (see Table 2).

Recruitment Manoeuvres and the Postoperative Period

All the patients passed the SBT-test successfully. As shown in Table 1, we observed a decrease by 1 hr in the length of postoperative mechanical ventilation in the PEEP-15 group compared with the control group (P=0.012). The duration of ICU stay (P>0.017) and the incidence of atelectases (P>0.017) did not differ significantly between the groups. All the patients survived beyond Day 28 after the surgery.

Discussion

In the present study, all the three different recruitment manoeuvres resulted in increased dynamic respiratory compliance and improved oxygenation compared with the baseline values. These findings are consistent with those reported by other authors [5; 7; 15]. Thus, Claxton et al. [15] studied recruitment manoeuvres with PEEP increments to 15 cm H_2O after cardiac surgery and found a significant increase in the PaO_2/FiO_2 ratio in the recruitment group at 30 min and one hour after the manoeuvre as compared with groups of zero PEEP and 5 cmH_2O PEEP. In 40 hypoxemic cardiosurgical patients, the investigators also [5] noticed significant improvement in arterial oxygenation during the postoperative period after recruitment manoeuvres (CPAP of 20, 30 and 40 cmH_2O for 30 sec). Tusman and co-workers also demonstrated improvement of arterial oxygenation 40 min after RM, which included repeated increments in inspiratory pressure to 40 cm H_2O over 10 breathing cycles [7]. However, neither the latter studies nor our own investigation aimed at a detection of differences between the recruitment groups; a comparison was made only with the group in which RM was not performed.

One of the major reasons for hypoxemia after OPCAB is the formation of atelectasis [1–3]. On the other hand, in ARDS, reduced generation of surfactant, lung consolidation, lung oedema and impairment of hypoxic pulmonary vasoconstriction, all contribute to derangement of oxygenation [16]. However, to counteract hypoxemia after cardiac surgery, as opposed to ARDS, requires a less vigorous RM to open up collapsed airways. Thus, in adults with healthy lungs, inflations of up to 40 cm H_2O for 7–8 sec may expand the collapsed lung tissue [17]. In contrast, a sustained inflation of up to 45 cm H_2O for 20 sec might be required to improve oxygenation in patients with ARDS [18]. Furthermore, to maintain the beneficial effects of RM, it should be combined with an adequate PEEP level as a part of the open lung concept. Therefore, in coronary surgery patients we used different strategies of RM, including CPAP-40 and Peak-40 that are widely used in ARDS, and a more "gentle" approach including PEEP-15. It has been shown that the open lung concept results in significantly improved lung aeration and oxygenation, both in ARDS and during the perioperative period [1, 19–23]. Meanwhile, it was also shown in a number of studies that the PEEP level of 5 cm H_2O after the manoeuvre is also followed by the oxygenation improvement [24, 25]. In addition, in our study the effect of RM was also stimulated by rapid restoration of spontaneous breathing activity of the patients. However, the effects of RM are not always reproducible in different settings and depend on a number of perioperative factors, including pneumoperitoneum in laparoscopic surgery, increased intraabdominal pressure after laparotomy, or heart failure in cardiac patients [1; 10; 22; 23].

According to recent investigations, the effect of RM persists from 10 min to several hours [15]. In our study, we assessed the initial effect of RM on dynamic compliance and oxygenation within the first 10 min, because the patients restored their spontaneous respiratory activity within 30–60 min followed by tracheal extubation within one-two hours after RM. The improved arterial oxygenation observed after RM and during the post-extubation period was accompanied by an increase in $EtCO_2$ after tracheal extubation.

This may be explained by a reduction of venous admixture and physiological dead space due to restoration of spontaneous breathing, which is consistent with the findings of previous investigators [27–29]. It is well known that a spontaneous breathing pattern favours alveolar recruitment and is associated with increased oxygenation and improved ventilation in dependent lung areas [26; 27]. During spontaneous breathing, the dorsal muscular part of the diaphragm moves more vigorously compared with the tendon plate and promotes the aeration of the dependent lung regions, thereby counteracting the formation of atelectases [27]. Therefore, it is important to preserve spontaneous breathing during postoperative ventilation both after cardiac and non-cardiac interventions.

In our study, RM applying a CPAP of 40 cm H_2O was complicated by arterial hypotension. Consistently, hemodynamic collapse has been described as the most common adverse effect of RM [30]. We interpret the hemodynamic instability during RM as a result of increased intrapleural pressure and reduced venous return and preload [29]. In parallel, increased alveolar pressure can compress the pulmonary vasculature increasing the pulmonary vascular resistance and, consequently, reduce the right ventricle afterload [31–33]. The decrease in cardiac output and the arterial hypotension after RM may compromise coronary and cerebral blood flow postoperatively in the OPCAB patients. Therefore, the benefits for the respiratory system of postoperative RM should be weighed against the risk of compromising the haemodynamics during the procedure.

In addition, it is important to decide, which type of RM is optimal for the different clinical situations. Despite an ability to open up the lungs, a CPAP of 40 cm H_2O is associated with hemodynamic instability in both ARDS [34] and postoperative patients [35]. In addition to arterial hypotension, investigators recently showed a significant decrease in cardiac index during recruitment with CPAP of 40 H_2O in ARDS patients [36]. By contrast, van den Berg et al. demonstrated that increasing PEEP up to 20 cm H_2O during the postoperative period was associated with minimal deterioration of MAP and cardiac output [31]. Thus, as this study is concerned, we decided to evaluate the mode of RM by increasing PEEP up to 15 cm H_2O, which was not accompanied by significant changes in haemodynamics.

The RM using PEEP-15 for 5 min represents a "gentle" but prolonged type of alveolar recruitment that might impair the pattern of spontaneous breathing to a less extent compared with the CPAP-40 and Peak-40 variants. This effect may explain the shorter time in this group until the restoration of spontaneous ventilation and discontinuation of respiratory support. Our results are consistent with the findings of investigators who observed that an increase in PEEP up to 30 cm H_2O to recruit the lungs was associated with shortened duration of postoperative respiratory support in cardiosurgical patients [25]. However, a PEEP of 30 cm H_2O can be associated with derangement of haemodynamics, whereas RM employing a PEEP of 15 cm H_2O, as used in our study, provides stable cardiovascular parameters.

Limitations of the study

We were unable to demonstrate an effect of RM on the length of the ICU or the hospital stay, but our investigation was not powered for that purpose. Moreover, the duration of the ICU or the hospital stay depends on a variety of confounding factors that are difficult to take into account. Another limitation of our study was the impossibility to make quantitative assessments of atelectatic areas. However, other authors evaluating the effects of RM after CABG using a semi-quantitative assessment, have shown a decreased atelectasis score [15].

Conclusions

After off-pump coronary surgery, alveolar recruitment manoeuvres improved arterial oxygenation and dynamic compliance. The method using a 40 sec period of CPAP of 40 cm H_2O was accompanied by arterial hypotension whereas a PEEP of 15 cm H_2O for 5 min reduced the duration of respiratory support compared with the control group.

Acknowledgements

Assistance with the study: The authors highly appreciate the assistance of the personnel of the cardiosurgical ICU of City Hospital №1 of Arkhangelsk. We are especially grateful for the assistance of Marina S. Neverova, MD and Julia A. Sysoeva, MD.

Financial support and sponsorship: none

Conflict of interest: none

ЛИТЕРАТУРА

1. *Intraoperative* ventilatory strategies for prevention of pulmonary atelectasis in obese patients undergoing laparoscopic bariatric surgery / H. F. Talab, I. A. Zabani, H. S. Abdelrahman // Anesth. Analg. – 2009. – Vol. 109, № 5. – P. 1511–1516.

2. *Atelectases* during anaesthesia and in the postoperative period / A. Strandberg, L. Tokics, B. Brismar [et al.] // Acta Anaesthesiol. Scand. – 1986. – Vol. 30, № 2. – P. 154–158.

3. *Pulmonary* densities during anesthesia with muscular relaxation — a proposal of atelectasis / B. Brismar, G. Hedenstierna, H. Lundquist [et al.] // Anesthesiology. – 1985. – Vol. 62, № 4. – P. 422–430.

4. *Effects* of off-pump coronary surgery on the mechanics of the respiratory system, lung, and chest wall: comparison with extracorporeal circulation / C. Roosens, J. Heerman, F. De Somer [et al.] // Crit. Care Med. – 2002. – Vol. 30, № 11. – P. 2430–2437.

5. *Padovani C.* Alveolar recruitment in the immediate postoperative period of cardiac surgery / C. Padovani, O. M. Cavenaqhi // Rev. Bras. Cir. Cardiovasc. – 2011. – Vol. 26, № 1. – P. 116–121.

6. *Hedenstierna G.* Atelectasis formation during anesthesia: causes and measures to prevent it / G. Hedenstierna, H. U. Rothen // J. Clin. Monit. Comput. – 2000. – Vol. 16. – P. 329–335.

7. *Tusman G.* How to open the Lung? The unsolved question / G. Tusman, E. Turchetto, A. Rodriguez // Anesthesiology. – 2000. – Vol. 93, № 4. – P. 1154–1159.

8. *Hess D. R.* Lung recruitment: the role of recruitment maneuvers / D. R. Hess, L. M. Bigatello // Respir. Care. – 2002. – Vol. 47, № 3. – P. 308–317.

9. *Effects* of alveolar recruitment on arterial oxygenation in patients after cardiac surgery: a prospective, randomized, controlled clinical trial / L. Minkovich, G. Djaiani, R. Katznelson [et al.] // J. Cardiothorac. Vasc. Anesth. – 2007. – Vol. 21, № 3. – P. 375–383.

10. *Lung* recruitment maneuver depresses central hemodynamics in patients following cardiac surgery / J. Nielsen, M. Østergaard, J. Kjaergaard [et al.] // Intensive Care Med. – 2005. – Vol. 31, № 9. – P. 1189–1194.

11. *Clinical* review: The implication of experimental and clinical studies of recruitment maneuvers in acute lung injury / E. Piacentini, A. Villagra, J. Lopez-Aguilar, L. Blanch // Crit. Care. – 2004. – Vol. 8, № 2. – P. 115–121.

12. *Rama-Maceiras P.* Peri-operative atelectasis and alveolar recruitment manoeuvres / P. Rama-Maceiras // Arch. Bronconeumonal. – 2010. – Vol. 46, № 6. – P. 317–324.

13. *Alveolar* recruitment strategy during cardiopulmonary bypass does not improve postoperative gas exchange and lung function / M. Scherer, S. Dettmer, D. Meininger [et al.] // Cardiovasc. Eng. – 2009. – Vol. 9, № 1. – P. 1–5.

14. *Single* transpulmonary thermodilution and continuous monitoring of central venous oxygen saturation during off-pump coronary surgery / A. A. Smetkin, M. Y. Kirov, V. V. Kuzkov [et al.] // Acta Anaesthesiol Scand. – 2009. – Vol. 53. – P. 506–514.

15. *Alveolar* recruitment strategy improves arterial oxygenation after cardiopulmonary bypass / B. A. Claxton, P. Morgan, H. McKeague [et al.] // Anaesthesia. – 2003. – Vol. 58, № 2. – P. 111–117.

16. *Matthay M. A.* The acute respiratory distress syndrome: pathogenesis and treatment / M. A. Matthay, R. L. Zemans // Ann. Rev. Pathology. – 2011. – № 6. – P. 147–163.

17. *Effects* of periodic lung recruitment maneuvers on gas exchange and respiratory mechanics in mechanically ventilated acute respiratory distress syndrome (ARDS) patients / G. Foti,

M. Cereda, M. E. Sparacino [et al.] // Intensive Care Med. – 2000. – Vol. 26, № 5. – P. 501–507.

18. *Dynamic* of re-expansion of atelectasis during general anaesthesia / H. U. Rothen, P. Neumann, J. E. Berglund // Br. J. Anaesth. – 1999. – Vol. 82, № 4. – P. 551–556.

19. *The effect* of open lung ventilation on right ventricular and left ventricular function in lung-lavaged pigs / D. R. Miranda, L. Klompe, F. Cademartiri [et al.] // Crit Care. – 2006. – Vol. 10, № 3. – P. R86.

20. *Effect* of alveolar recruitment maneuver in early acute respiratory distress syndrome according to anti-derecruitment strategy, etiological category of diffuse lung injury, and body position of the patient / C. M. Lim, H. Jung, Y. Koh [et al.] // Crit. Care Med. – 2003. – Vol. 31, № 2. – P. 411–418.

21. *Intercomparison* of recruitment maneuver efficacy in three models of acute lung injury / S. C. Lim, A. B. Adams, D. Simonson [et al.] // Crit. Care Med. – 2004. – Vol. 32, № 12. – P. 2371–2377.

22. *Comparison* of two ventilatory strategies in elderly patients undergoing major abdominal surgery / T. N. Weingarten, F. X. Whalen, D. O. Warner [et al.] // Br. J. Anaesth. – 2010. – Vol. 104, № 1. – P. 16–22.

23. *Lapinsky S. E.* Bench-to-bedside review: Recruitment and recruiting maneuvers / S. E. Lapinsky, S. Mehta // Crit. Care. – 2005. – Vol. 9, № 1. – P. 60–65.

24. *"Alveolar* recruitment strategy" improves arterial oxygenation during general anaesthesia / G. Tusman, S. H. Bohm, G. F. Vsquez de Anda [et al.] // Br. J. Anaesth. – 1999. – Vol. 82, № 1. – P. 8–13.

25. *Hajjar L.* Effect of alveolar recruitment in patients after cardiac surgery: a prospective, randomized, controlled clinical trial / L. Hajjar, F. Galos, E. Nozawa // Crit. Care. – 2008. – Vol. 12, Suppl. 2. – P. 314.

26. *Pressure* support improves oxygenation and lung protection compared to pressure-controlled ventilation and is further improved by random variation of pressure support / P. M. Spieth, A. R. Carvalho, A. Güldner [et al.] // Crit. Care Med. – 2011. – Vol. 39, № 4. – P. 746–755.

27. *Varelman D.* Cardiorespiratory effects of spontaneous breathing in two different models of experimental lung injury: a randomized controlled trial / D. Varelman, T. Muders, J. Zinserling // Crit. Care. – 2008. – № 12. – R 135.

28. *Haemodynamic* stability and pulmonary shunt during spontaneous breathing and mechanical ventilation in porcine lung collapse / L. Vimláti, A. Larsson, G. Hedenstierna, M. Lichtwarck-Aschoff // Acta Anaesthesiol. Scand. – 2012. – Vol. 56, № 6. – P. 748–754.

29. *Lung* collapse and gas exchange during general anesthesia: effects of spontaneous breathing, muscle paralysis and positive end-expiratory pressure / L. Tokics, G. Hedenstierna, A. Strandberg [et al.] // Anesthesiology. – 1987. – Vol. 66, № 2. – P. 157–167.

30. *Recruitment* maneuvers for acute lung injury: a systematic review / E. Fan, M. E. Wilcox, R. G. Brower [et al.] // Am. J. Respir. Crit. Care Med. – 2008. – Vol. 178, № 11. – P. 1156–1163.

31. *Van den Berg P. C.* Effect of positive pressure on venous return in volume-loaded cardiac surgical patients / P. C. Van den Berg, J. R. Jansen, M. R. Pinsky // J. Appl. Physiol. – 2002. – Vol. 92, № 3. – P. 1223–1231.

32. *Respiratory* and hemodynamic changes during decremental open lung positive end-expiratory pressure titration in patients with acute respiratory distress syndrome / C. Gernoth, G. Wagner, P. Pelosi, T. Luecke // Crit. Care. – 2009. – Vol. 13, № 2. – P. R59.

33. *How* far can we go with positive end-expiratory pressure (PEEP) in liver transplant patients? / F. H. Saner, S. W. Olde Daminik, G. Pavlkovic [et al.] // Clin. Anesth. – 2010. – Vol. 22, № 2. – P. 104–109.

34. *The pulmonary* and hemodynamic effects of two different recruitment maneuvers after cardiac surgery / S. Celebi, O. Köner, F. Menda [et al.] // Anesth. Analg. – 2007. – Vol. 104, № 2. – P. 384–390.

35. *Different* patterns of lung recruitment maneuvers in acute respiratory distress syndrome: effect on oxygenation and central hemodinamics / M. Iannuzzi, A. De Sio, E. De Robertis [et al.] / / Minerva Anestesiol. – 2010. – Vol. 76, № 9. – P. 692–698.

36. *Hemodynamic* and respiratory changes during lung recruitment and descending optimal positive end-expiratory pressure titration in patients with acute respiratory distress syndrome / I. Toth, T. Leiner, A. Mikor [et al.] // Crit Care Med. – 2007. – Vol. 35, № 3. – P. 787–793.

REFERENCES

1. Talab H.F., Zabani I.A., Abdelrahman H.S. Intra-operative ventilatory strategies for prevention of pulmonary atelectasis in obese patients undergoing laparoscopic bariatric surgery. *Anesth Analg* 2009; 109 (5): 1511-1516.

2. Strandberg A., Tokics L., Brismar B., et al. Atelectases during anaesthesia and in the postoperative period. *Acta Anaesthesiol Scand* 1986; 30 (2): 154-158.

3. Brismar B., Hedenstierna G., Lundquist H, et al. Pulmonary densities during anesthesia with muscular relaxation — a proposal of atelectasis. *Anesthesiology* 1985; 62 (4): 422-430.

4. Roosens C., Heerman J., De Somer F., et al. Effects of off-pump coronary surgery on the mechanics of the respiratory system, lung, and chest wall: comparison with extracorporeal circulation. *Crit Care Med* 2002; 30 (11): 2430-2437.

5. Padovani C., Cavenaqhi O.M. Alveolar recruitment in the immediate postoperative period of cardiac surgery. *Rev Bras Cir Cardiovasc* 2011; 26 (1): 116-121.

6. Hedenstierna G., Rothen H.U. Atelectasis formation during anesthesia: causes and measures to prevent it. *J Clin Monit Comput* 2000; 16: 329-335.

7. Tusman G., Turchetto E., Rodriguez A. How to open the Lung? The unsolved question. *Anesthesiol*ogy 2000; 93: 1154-1159.

8. Hess D.R., Bigatello L.M. Lung recruitment: the role of recruitment maneuvers. *Respir Care* 2002; 47: 308-325.

9. Minkovich L., Djaiani G., Katznelson R. et al. Effects of alveolar recruitment on arterial oxygenation in patients after cardiac surgery: a prospective, randomized, controlled clinical trial. *J Cardiothorac Vasc Anesth* 2007; 21: 375-383.

10. Nielsen J., Østergaard M., Kjaergaard J. et al. Lung recruitment maneuver depresses central hemodynamics in patients following cardiac surgery. *Intensive Care Med* 2005; 31:1189-1194.

11. Piacentini E., Villagra A., Lopez-Aguilar J. et al. Clinical review: The implication of experimental and clinical studies of recruitment maneuvers in acute lung injury. *Crit Care* 2004; 8: 115-121.

12. Rama-Maceiras P. Peri-operative atelectasis and alveolar recruitment manoeuvres. *Arch Bronconeu-monal* 2010; 46: 317-324.

13. Scherer M., Dettmer S., Meininger D. et al. Alveolar recruitment strategy during cardiopulmonary by-pass does not improve postoperative gas exchange and lung function. *Cardiovasc Eng* 2009; 9: 1-5.

14. Smetkin A.A., Kirov M.Y., Kuzkov V.V. et al. Single transpulmonary thermodilution and continuous monitoring of central venous oxygen saturation during off-pump coronary surgery. *Acta Anaesthesiol Scand* 2009; 53: 506-514.

15. Claxton BA., Morgan P., McKeague H. et al. Alveolar recruitment strategy improves arterial oxygenation after cardiopulmonary bypass. *Anaesthesia* 2003; 58: 111-117.

16. Matthay M.A., Zemans R.L. The acute respiratory distress syndrome: pathogenesis and treatment. *Annual Review of Pathology* 2011; 6: 147-163.

17. Foti G., Cereda M., Sparacino M.E. et al. Effects of periodic lung recruitment maneuvers on gas exchange and respiratory mechanics in mechanically ventilated acute respiratory distress syndrome (ARDS) patients. *Intensive Care Med* 2000; 25: 501-507.

18. Rothen H.U., Neumann P., Berglund J.E. Dynamics of re-expansion of atelectasis during general anesthesia. *Br J Anaesth* 1999; 82: 5516.

19. Miranda D.R., Klompe L., Cademartiri F. et al. The effect of open lung ventilation on right ventricular and left ventricular function in lung-lavaged pigs. *Crit Care.* 2006; 10: R86.

20. Lim C.M., Jung H., Koh Y. et al. Effect of alveolar recruitment maneuver in early acute respiratory distress syndrome according to anti-derecruitment strategy, etiological category of diffuse lung injury, and body position of the patient. *Crit Care Med* 2003; 31: 411-418.

21. Lim S.C., Adams A.B., Simonson D. et al. Intercomparison of recruitment maneuver efficacy in three models of acute lung injury. *Crit Care Med* 2004; 32: 2371-2377.

22. Weingarten T.N., Whalen F.X., Warner D.O. et al. Comparison of two ventilatory strategies in elderly patients undergoing major abdominal surgery. *Br J Anaesth* 2010; 104: 16-22.

23. Lapinsky S.E., Mehta S. Bench-to-bedside review: Recruitment and recruiting maneuvers. *Crit Care* 2005; 9: 60-65.

24. Tusman G., Bohm S.H., Vsquez de Anda G.F. "Alveolar recruitment strategy" improves oxygenation during general anaesthesia. *Br J Anaesth* 1999; 82: 8-13.

25. Hajjar L., Galos F., Nozawa E. Effect of alveolar recruitment in patients after cardiac surgery: a prospective, randomized, controlled clinical trial. *Crit Care* 2008; 12 (Suppl 2): P314.

26. Spieth P.M., Carvalho A.R., Güldner A. et al. Pressure support improves oxygenation and lung protection compared to pressure-controlled ventilation and is further improved by random variation of pressure support. *Crit Care Med* 2011; 39: 746-755.

27. Varelman D., Muders T., Zinserling J. Cardiorespiratory effects of spontaneous breathing in two different models of experimental lung injury: a randomized controlled trial. *Crit Care* 2008; 12: R 135.

28. Vimláti L., Larsson A., Hedenstierna G. et al. Haemodynamic stability and pulmonary shunt during spontaneous breathing and mechanical ventilation in porcine lung collapse. *Acta Anaesthesiol Scand* 2012; 56: 748-754.

29. Tokics L., Hedenstierna G., Strandberg A. et al. Lung collapse and gas exchange during general anesthesia: effects of spontaneous breathing, muscle paralysis and positive end-expiratory pressure. *Anesthesiology* 1987; 66: 157-167.

30. Fan E., Wilcox ME., Brower RG. et al. Recruitment maneuvers for acute lung injury: a systematic review. *Am J Respir Crit Care Med* 2008; 178: 1156-1163.

31. Van den Berg PC., Jansen JR., Pinsky MR. Effect of positive pressure on venous return in volume-loaded cardiac surgical patients. *J Appl Physiol* 2002; 92: 1223-1231.

32. Gernoth C., Wagner G., Pelosi P. et al. Respiratory and hemodynamic changes during decremental open lung positive end-expiratory pressure titration in patients with acute respiratory distress syndrome. *Crit Care* 2009; 13: R59.

33. Saner F.H., Olde Daminik S.W., Pavlkovic G. et al. How far can we go with positive end-expiratory pressure (PEEP) in liver transplant patients? *J Clin Anesth* 2010; 22: 104-109.

34. Celebi S., Köner O., Menda F. et al. The pulmonary and hemodynamic effects of two different recruitment maneuvers after cardiac surgery. *Anesth Analg* 2007; 104: 384-390.

35. Iannuzzi M., De Sio A., De Robertis E. et al. Different patterns of lung recruitment maneuvers in acute respiratory distress syndrome: effect on oxygenation and central hemodinamics. *Minevra Anestesiol* 2010; 76: 692-698.

36. Toth I., Leiner T., Mikor A. et al. Hemodynamic and respiratory changes during lung recruitment and descending optimal positive end-expiratory pressure titration in patients with acute respiratory distress syndrome. *Crit Care Med* 2007; 35: 787-93.

Submitted 24.02.2016

Reviewer Yu. I. Karpenko, MD, PhD, prof.