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Choice of Respiratory Support During Cardiac Bypass in Cardiac Surgical Patients (Pilot Study)

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Выбор тактики респираторной поддержки в период искусственного кровообращения у кардиохирургических пациентов (пилотное исследование)

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Summary

Currently, there is no uniform respiratory support strategy during cardiopulmonary bypass (CPB) in cardiac anesthesiology.

The aim of the study was to examine possible variants of respiratory support during CPB and determine the most effective technique capable to reduce the incidence of postoperative pulmonary complications.

Material and methods. Ninety cardiac surgery patients were enrolled in the pilot study and divided into groups (CPAP, VC, and apnea). In the CPAP group, positive airway pressure of + 5 cm H_2O was maintained during CPB. The VC group patients underwent mechanical ventilation during CPB with a reduced tidal volume of 3 mL/kg, respiratory rate of 6/min, and REER of + 5 cm H_2O. In the apnea group, patients received no respiratory support (non-rebreathing system).

Results. In both the apnea and CPAP (constant positive airway pressure) group, there was a decrease in oxygenation index (OI) at the end of the CPB compared with baseline values. In the apnea group, the OI dropped from 316.31±81.76 to 230.10±102.48, while in the CPAP group it decreased from 319.37±80.01 to 223.17±152.36 (P<0.001). No significant changes in this parameter were observed in the VC group. The frequency of recruitment maneuvers after CPB to correct the impaired respiratory oxygenation was maximal in patients from apnea group (22 cases (73%) versus 13 cases (43%) in the CPAP group and 5 cases (16%) in the VC group) (P<0.001). Frequency of pulmonary atelectasis on chest radiology in postoperative period was 47, 37, 10% in apnea, CPAP, and VC groups, respectively, and the difference was also significant (P=0.006).

Conclusion. Low-volume ventilation is the preferable method of respiratory support in cardiac surgery patients during CPB.

Keywords: respiratory support; cardiopulmonary bypass; mechanical lung ventilation; pulmonary complications; cardiac surgery; prevention of complications

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

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Introduction

According to clinical research results, the search for an optimal respiratory strategy is currently relevant when developing organ protective techniques in cardiac anesthesiology, particularly those aimed at protecting the lung during cardiopulmonary bypass (CPB).

However, a unified concept of respiratory support has not yet been developed. This is corroborated by surveys of anesthesiologists world-wide showing that in most centers (75%) ventilation during CPB is discontinued [1, 2], while in the remaining centers the main types of respiratory support during CPB include CPAP with various pressure levels (from 5 to 15 cm H_2O) and low-frequency low-volume ventilation [1–4].

Previously, we reported the results of two strategies of respiratory management of patients during CPB [5]. Here, based on previous and novel data, we present and compare the results of three possible strategies.

The aim of this pilot study was to examine possible strategies of respiratory support during CPB for identifying the most effective technique capable of reducing the incidence of postoperative pulmonary complications.

Material and Methods

Study design.

It was a prospective pilot study with parallel groups approved by the Local Ethical Committee of Sechenov University.

Inclusion/exclusion criteria.

Patients who met the following criteria were included in the study:

- 18 years of age or older;
- signed informed consent;
- elective primary cardiac surgery with cardioplegia and CPB.

Patients were excluded from the study if they refused to participate for any reason at any stage of the study.

The non-inclusion criteria were:

- elective thoracotomy with single-lung ventilation
- mechanical ventilation prior to surgery
- history of lung resection or pneumonectomy
- pregnancy.

The study endpoints.

The primary endpoint of respiratory support efficacy during CPB was the oxygenation index (OI, calculated as PaO_2/FiO_2) at different stages of surgery:

T1 — after tracheal intubation and the start of ventilation

T2 — before the start of CPB

T3 — after the CPB completion

T4 — the end of surgery

T5 — immediately after the admission to ICU

T6 — 6 hours after the admission to ICU

T7 — 12 hours after the admission to ICU.

Secondary endpoints included frequency of postoperative respiratory complications (atelectasis, pneumonia, etc.), the need and number of recruiting lung maneuvers during surgery and in ICU, duration of postoperative ventilation, frequency of noninvasive ventilation after tracheal extubation, cases of tracheal reintubation, length of stay in ICU, length of stay in the hospital, and mortality.

In addition, the volume of pulmonary extravascular fluid (PEVF) was assessed in selected patients of each group using the transpulmonary thermodilution technique. For this purpose, the right internal jugular vein was catheterized, a catheter with a PICCO 5F 20 cm thermistor was inserted into the femoral artery, and then during T2 and T3 stages of surgery the PEVF was measured using PICCOplus (PULSION Medical Systems, Germany) device.

Study groups and methods.

All patients recruited for the study were assigned to one of the three study groups using the envelope method. The patients, their attending physicians (in case they were not members of the surgical team), and intensive care unit physicians were «blinded» in this study.

In group 1 the constant positive airway pressure (CPAP, *n*=30) of +5 cm H_2O was maintained during CPB using the GE Avance CS2 anesthesia machine (USA).

In group 2 (volume control [VC], *n*=30), the patients received low-volume lung ventilation (up to 3 ml/kg of ideal body weight) during CPB, with RR of 6/min, PEEP + 5 cm H_2O using the GE Avance CS2 (USA) anesthesia machine.

In group 3 (apnea, *n*=30), the patients did not receive respiratory support.

In the respiratory support groups, oxygen-air mixture with FiO_2 21% was used during CPB.

During the surgery (except for CPB), all patients underwent protective ventilation with volume control using the GE Avance CS2 (USA) anesthesia machine. The target parameters were Vt = 6–8 ml/kg of ideal body weight, I/E = 1:2, RR = 12–16/min, PEEP = 4–8 cm H_2O, FiO_2 of breathing mixture = 50%, $EtCO_2$ = 34–36 mmHg. Peak airway pressure did not exceed 30 cm H_2O.

Protective ventilation was performed in ICU using Puritan Bennett 840 (Medtronic, USA), Dräger Savina 300 (Dräger, Germany) machines with Vt = 6–8 ml/kg of ideal body weight, I:E = 1:2, RR (respiratory rate) and MV (minute ventilation) were chosen depending on the results of arterial blood gases on admission, PEEP was 6–8 cm H_2O, FiO_2 of

breathing mixture was 50%. Peak airway pressure did not exceed 30 cm H_2O.

Cardiopulmonary bypass was performed with S-3 machine with integrated CDI500 real-time gas analyzer and Dideco 703 oxygenator. Blood cardioplegia according to Calafiore was used to protect myocardium during aortic clamping. Volumetric perfusion rate was chosen depending on patient's body surface area and its values ranged from 4.3 to 5.3 L/min. Perfusion was performed in normothermia mode (body temperature at least 35.3°C). When performing surgery on the aortic arch, hypothermia was applied; when the temperature reached 25°C, circulatory arrest was initiated and antegrade cerebral perfusion of 10 ml/kg/min was performed under the control of cerebral oximetry.

Statistical analysis.

The statistical analysis of the data was done using the Statistica 10 and jamovi 2.2.5 software. Data distribution was tested using the Shapiro–Wilk criterion. The results were presented using median and interquartile range or mean and standard deviation, where appropriate. When testing statistical hypotheses, the critical level of significance was set at P=0.05. For comparison of the obtained results, we used analysis of variance (Student test with Bonferroni correction), Kruskal–Wallis test, Friedman test with Durbin–Conover paired comparison test, depending on the type of data distribution and the type of analysis. Pearson correlation test or Spearman rank correlation coefficient were used to evaluate linear relationship between the variables. Fisher exact test was used to compare the frequency of complications between the groups.

Results

The characteristics of the three study groups are summarized in Table 1.

Data from the Table 1 shows that the groups do not differ in the specified parameters.

The changes in oxygenation index (OI) in groups according to the stage of the surgery are shown in Table 2.

The intragroup analysis of each group, has demonstrated no significant decrease of the OI compared with the VC group (331.43±55.07 at T1) at all study stages.

On the contrary, decrease in OI values was found in the CPAP group compared with the outcome at stages T3 and T4 (P<0.001) (Table 2).

The largest negative changes in OI was recorded in the apnea group where it dropped significantly vs the baseline values at all stages after the end of CPB (T3) (P<0.001), except for T7 (P=0.21) (Table 2).

On intergroup analysis of OI values, no significant differences were noted until the T3 stage. In turn, at the T3 stage (after CPB), we found a significant difference (P=0.02), with the maximum OI values found in the VC group (289.60±100.32), while in the CPAP and apnea group they were significantly (223.17±152.36 and 230.10±102.48, respectively). Similar differences persisted at all further stages of the study (T4–T7), see Table 2.

The mean values of dynamic compliance in the patients of the study groups are presented in Table 3.

A decrease in compliance was observed in the apnea group (P<0.001), and a significant difference was also found between all three studied groups at the end of surgery (P=0.005 as per univariate analysis of variance for independent groups).

Regardless of the study group, all patients in the postoperative period were found to have fluid in the pleural cavity according to chest radiography or ultrasound. However, the necessity of pleural puncture was not always obvious and depended on the volume of the fluid. Thus, pleural puncture was necessary in 13 patients (43%) in the apnea group, 12 (40%) in the CPAP group, and 8 (26%) in the VC group (P=0.37 according to χ^2-test for three groups. The Fischer exact pair test was used to check the significance of differences between the studied groups and yielded the following results: for apnea-VC comparison P=0.27, for CPAP-VC comparison P=0.41, and for apnea-CPAP comparison P=1.

According to chest radiography, the proportion of patients with postoperative atelectasis in the apnea, CPAP, and VC groups was 47%, 36.6%, and 10%, respectively (P=0.006 according to χ^2-test for three groups), while the Fisher exact test yielded P=0.003 for apnea-VC, P=0.03 for CPAP-VC, and P=0.6 for apnea-CPAP comparisons.

The recruitment maneuvers after CPB completion (T3) for correction of impaired oxygenation function were most frequently used in patients of apnea group (n=22, 73%), CPR group (n=13, 43%), and VC group (n=5, 16%) (P<0.001 according to χ^2-test for three groups), while Fisher's exact test yielded P<0.001 for apnea-VC, P=0.47 for CPAP-VC, and P=0.03 for apnea-CPAP paired comparisons.

Similar results were obtained in the postoperative period: the frequency of the «lung opening» technique in the apnea group was 66%, in the CPAP group, 26%, and in the VC group, 7% (P<0.001 according to the χ^2-test for three groups). The Fisher exact test results were as following: P<0.001 for apnea-VC, P=0.07 for CPAP-VC, and P=0.004 for apnea-CPAP paired comparison.

Noninvasive lung ventilation (NILV) sessions after the cessation of mechanical ventilation were required in two patients in the CPAP group, whereas there were no such patients in the VC group and 9

Table 1. Demographic and clinical characteristics of the studied patients (*M*±σ).

Characteristic	Values in groups			*P*
	CPAP (*n*=30)	VC (*n*=30)	Apnea (*n*=30)	
Sex	70% male (*n*=21), 30% female (*n*=9)	60% male (*n*=18), 40% female (*n*=12)	63% male (*n*=19), 37% female (*n*=11)	0.71
Mean age (years)	53.33±13.59	55.77±16.90	55.20±14.67	0.57
Obstructive lung function impairment, *n* (%)	12 (40%)	11 (36%)	13 (43%)	0.25
History of diabetes mellitus, *n* (%)	3 (10%)	3 (10%)	4 (13%)	0.89
Duration of CPB, min	141.83±56.18	157.10±49.17	144.26±46.30	0.25
History of hypertension	12 (40%)	15 (50%)	14 (47%)	0.87
History of coronary heart disease, *n* (%)	12 (40%)	15 (50%)	13 (43%)	0.73
History of COPD, *n* (%)	3 (10%)	3 (10%)	2 (7%)	0.87
History of MI, *n* (%)	6 (20%)	5 (17%)	5 (17%)	0.92
Surgery, *n* (%):				
• AVR	12 (40%)	15 (50%)	11 (37%)	
• MVR	6 (20%)	3 (10%)	4 (13%)	
• CABG	3 (10%)	9 (30%)	8 (27%)	
• ITAG	9 (30%)	3 (10%)	5 (17%)	
• Bentall-De Bono procedure	7 (23%)	5 (16%)	5 (16%)	
• Aortic arch replacement	2 (6%)	2 (6%)	1 (3%)	
• David procedure	1 (3%)	2 (6%)	1 (3%)	

Table 2. Changes in the oxygenation index at different stages of surgery in the studied groups (*M*±σ).

Group	Stage of surgery						
	T1	T2	T3	T4	T5	T6	T7
CPAP	319.37±80.01	319.43±56.48	223.17±152.36	275.27±90.03	324.03±115.81	319.67±61.18	326.77±60.44
VC	331.43±55.07	333.13±64.93	289.60±100.32	318.70±73.81	321.90±68.91	330.47±62.12	337.77±70.13
Apnea	316.31±81.76	338.53±71.55	230.10±102.48	199.20±73.22	242.70±59.82	237.03±24.88	283.04±40.26
P-value	0.98	0.32	0.02	<0.001	<0.001	<0.001	<0.001

Table 3. Dynamic compliance at various stages of surgery in patients of the study groups (*M*±σ).

Group	Compliance		*P*-value
	At the beginning of the surgery	At the end of the surgery	
CPAP	42.8±9.37 ml/mm H_2O	41.3±12.5 ml/mm H_2O	0.26
VC	40.1±9.1 ml/mm H_2O	39.7±8.07 ml/mm H_2O	0.35
Apnea	40.9±7.2 ml/mm H_2O	32.6±11.3 ml/mm H_2O	<0.001
P-value	0.66	0.005	

Table 4. Changes in pulmonary extravascular fluid (PEVF) volume (*M*±σ).

Group	PEVF volume	
	before CPB	after CPB
CPAP	3.07±0.29 ml/kg	5.60±0.94 ml/kg
VC	2.32±0.30 ml/kg	4.27±0.70 ml/kg
Apnea	2.58±0.49 ml/kg	6.25±0.86 ml/kg

(30%) of them in the apnea group. Tracheal reintubation and reinitiation of mechanical ventilation due to respiratory failure were required only in one patient in the CPAP group and two patients in the apnea group.

There were no differences in the duration of postoperative ventilation between the study groups.

Total pulmonary extravascular fluid was measured in 7 patients per each study group (Table 4).

According to the data obtained, during CPB, the PEVF volume increased compared to the baseline values in all study groups. The largest increase of PEVF volume (by 152%) was recorded in the apnea group, with the mean value of 6.25±0.86 ml/kg after CPB. In the VC and CPAP group, the increase in PEVF volume was much less dramatic (by 86.6% and 85.6%, respectively). The mean values of this parameter were 4.27±0.70 ml/kg and 5.6±0.94 ml/kg, respectively, at the T3 stage.

The length of stay in the ICU for all groups was almost the same (31.76±12.68 h in the apnea group, 31.93±14.25 h in the CPAP group, and 30.70±11.59 h in the VC group).

The mean length of hospitalization after surgery was 15.86±5.12 days in the apnea group, 16.53±6.48 days in the CPAP group, and 13.57±5.38 days in the VC group and did not differ between the groups.

Discussion

Lung atelectasis is known to be one of the factors affecting pulmonary oxygenation function in the postoperative period in cardiac surgery patients who have undergone cardiac bypass. Accumulation of extravascular lung fluid during CPB is another factor influencing venous blood oxygenation [6–10].

Obviously, there are also other causes of postoperative atelectasis such as inadequate ventilation parameters, severe pain syndrome due to sternum retraction, mediastinal and pleural drains [11, 12]. Immobilization, pain increase on deep inspiration and cough also negatively affects the breathing act [13] by making it superficial thus reducing the alveolar ventilation and the number of non-ventilated lung segments and further increasing the high risk of postoperative pulmonary complications [12]. The type of surgical access can also influence the incidence of postoperative respiratory complications. Thus, according to the study of V. Shmyrev et al., respiratory failure during mitral valve correction using minimally invasive access was found in 7.4% of patients, whereas respiratory failure did not develop when sternotomy access was chosen. According to the authors, atelectasis (even total) of the right lung was one of the most frequent causes of this complication in minimally invasive access group [14].

In this study such factors were minimized, as all patients in the ICU received protective ventilation until tracheal extubation, and, if necessary, non-invasive assisted ventilation after extubation. In addition, postoperative pain was continuously controlled in the ICU and multimodal analgesia was modified depending on its severity (target values < 4 points according to the visual analogue scale or < 2 points according to visual scale). Multimodal analgesia allowed achieving necessary level of analgesia with minimal side effects [15]. For postoperative analgesia, intravenous ketorolac 30 mg 2–3 times daily and paracetamol 1 g continuously for 15 min up to 4 times daily were used in combination with the opioid analgesics such as intravenous promedol 20 mg or tramadol 100 mg depending on severity.

According to some researchers, the frequency of pulmonary atelectasis development after surgery with CPB can reach 54–92% [4], which agrees with our results. We found postoperative atelectasis in 47% of patients in patients without respiratory support during CPB, which is significantly more frequent than in those who underwent CPAP or low-volume ventilation (36.6% in CPAP and 10% in VC groups). Different severity of atelectasis in the studied groups is an important factor affecting various parameters characterizing the pulmonary system function. Thus, oxygenation index after CPB and surgery was significantly higher in patients who were on continuous low-volume ventilation (VC group) than in CPAP and apnea group. Similar results were reported by J. Gagnon et al. who compared 2 groups of patients, one of them ventilated with Vt = 3 ml/kg and PEEP = 0 cmH_2O during CPB, and the other group was not on ventilator during the CPB. In the group with low-volume ventilation higher OI values and lower length of stay with no difference in the frequency of postoperative complications were found [16]. L. S. Nguyen et al. performed a study with a very similar design which compared groups of patients identical to those participating in the previous one, but aimed at evaluating the rate of atelectasis development. According to the results, the incidence of postoperative pulmonary complications (atelectasis) in these groups did not differ [3]. On the contrary, we revealed differences in the incidence of atelectasis development which was 47% in apnea group, 36.6% in the CPAP group, and 10% in the VC group (P=0.006).

In patients of apnea group compared with the other groups much more corrective measures to achieve normal oxygenation function were taken. They included higher oxygen fraction used immediately after CPB and more frequent recruiting maneuvers. Moreover, decreased oxygenating function of lung in patients of apnea group could not always be corrected in the operating room and later in ICU. In these patients, higher frequency of recruiting maneuvers and assisted ventilation after tracheal extubation was observed.

Another factor impairing the pulmonary oxygenation function, as mentioned above, can be the accumulation of PEVF which depends both on the preoperative infusion therapy and on hemodilution during CPB. The patients of the studied groups did not differ in water balance and hematocrit value during CPB. The only difference was in the respiratory strategy used during CPB.

One more aspect merits mentioning. The use of apnea and CPAP during the CPB led to a greater accumulation of PEVF compared with low-volume ventilation. This, in turn, led to a significant decrease of compliance parameters, and in the apnea group this reduction was significant (P<0.001). In other words, under equal conditions (equal water balance and degree of hemodilution), respiratory strategy during CPB affects the accumulation of pulmonary extravascular fluid. This is supported by the results of correlation analysis between the obtained values of OI and volume of PEVF at the stage after CPB in the studied groups. The analysis showed an intermediate strength negative correlation (R=–0.6512, P<0.05), which proves the importance of PEVF accumulation in decreasing the oxygenation index.

Our data correspond to the results obtained in the study of K.Iha et al. who demonstrated extravascular fluid accumulation in the lungs at different time stages (2, 4, 8, 24 and 48 hours) after CPB surgery [17]. J.Boldt et al. measured the volume of PEVF 15 and 45 min after the end of CPB. According to their report, PEVF values increased after CPB, and PaO_2 values decreased [18].

Unfortunately, accumulation of pulmonary extravascular fluid is inevitable due to CPB, prolonged pulmonary ischemia with underlying limited collateral blood flow, mechanical impact on lung tissue in the operating field, massive transfusions. In this regard, it is crucial to use methods that reduce PEVF. According to our results, this can be improved by low-volume lung ventilation.

Another relevant issue when providing respiratory support during CPB could be uncomfortable conditions for the surgeon's work because lung motions can interfere with the stability of the surgical field. There is a report [3] that in 21.4% of cases, the surgical team requested to stop ventilatory support during the main stage of surgery. In our study, the surgeons reported some discomfort while performing surgery only in 10% when low-volume ventilation was used for respiratory support. Notably, there were no cases of switching from low-volume ventilation to CPAP or apnea during CPB at the surgeons' request.

Conclusion

Low-volume ventilation is the first-choice technique for respiratory support during CPB in cardiac surgery patients. This is demonstrated by:

— lack of significant decrease of oxygenation index in patients from low-volume ventilation group, in contrast to apnea and CPAP groups, at all study stages;

— less frequent development of atelectasis in the VC group (10% vs 36.6% in the CPAP group, and 47% in the apnea group);

— lower frequency of recruiting maneuvers for correction of oxygenation during surgery in the VC group (16% vs 43% in the CPAP group and vs 73% in the apnea group);

— reduced use of recruitment maneuvers for correction of oxygenation function after surgery in the VC group (7% vs 26% in the CPAP group and vs 66% in the apnea group).

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