**The strategy of mechanical ventilation during cardiopulmonary bypass as a predictive factor for pulmonary complications in the intensive care unit.**

National Research Cardiac Surgery Center. Cardiac Intensive Care Unit. Astana, Turan ave 38. Kazakhstan.

Iwan Wachruschew, Tatyana Li, Aidyn Kuanyshbek, Shaimurat Tulegenov, Azhar zhailauova

Abstract:

Pulmonary complications are the second most common after cardiac surgery with cardiopulmonary bypass (CPB). Atelectasis can result from intraoperative causes such as prolonged operation and anaesthesia time of more than 3-4 hours, use of a thoracic artery, use of cardiopulmonary bypass during surgery and failure to ventilate, and haemotransfusion of 4 or more units of packed red blood cells in the perioperative period. Impact of mechanical ventilation during cardiopulmonary bypass still unknown.

Methods: Prospective, randomised study at one centre. Adult patients undergoing cardiac surgery with a pump by sternotomy for coronary artery disease were included.

Patients were randomised into two groups – one group receiving mechanical ventilation and one group receiving no ventilation during cardiopulmonary bypass. The main endpoint was PaO2/FiO2 as a marker for the quality of ventilation and perfusion measured. Secondary endpoints were postoperative pulmonary complications such as atelectasis and prolonged mechanical ventilation of more than 72 hours.

Results 190 consecutive patients were included, 92 and 98 in each group. No significant difference was found in the PaO2/FiO2 ratio in the groups (p=0.6). A significant difference was found in the number of atelectasis during ultrasound investigation (USI) of the lungs with a p-value of 0.03 in the non-ventilated group.

Conclusion: On-pump cardiac surgery without mechanical ventilation can lead to atelectasis of the lungs.

Key words: Mechanical ventilation, CPB, atelectasis

**Introduction**:

Cardiac surgery with cardiopulmonary bypass (CPB) is highly associated with complications [1]. Acute lung injury is the second most common complication of CPB after the heart and ranges from mild pulmonary dysfunction to fatal acute lung injury [2]. Following cardiac surgery, more than 30% of patients are reported to have significant respiratory impairment for at least one week after surgery [3].

CPB is a mandatory component of cardiac surgery and enables the maintenance of adequate body perfusion and oxygenation. Phisiologically, the cardiopulmonary system should be partially bypassed during CPB and completely bypassed under aortic cross-clamping to create a bloodless and immobile surgical field [4, 5]. On pump heart surgery, factors such as CPB, hypothermia, the surgical procedure, anaesthesia medications massive transfusions can cause diffuse lung injury[6]. During CPB, the lungs receive reduced blood from bronchial arterial flow, which leads to ischaemia [7]. The absence of pulsatile flow during CPB causes several changes in the lungs that lead to increased severity of inflammation [8]. There are several methods to prevent lung injury, improve gas exchange and reduce the increase in inflammatory responses during CPB, but the role of mechanical ventilation is still unclear [9, 10].

Atelectasis is a common pulmonary complication in patients undergoing cardiac surgery with cardiopulmonary bypass (CPB) and an important cause of postoperative hypoxaemia. [11] Various reasons have been put forth to explain why patients undergoing on-pump cardiac surgery experience alveolar collapse. These include a relaxed diaphragm compressing the caudal parts of the lower lobes, surgical manipulations of pulmonary structures and depressurization of the respiratory system during CPB to enable better visual of the surgical field. Although most of the mechanisms causing intraoperative lung collapse disappear when patients wake up and begin spontaneous breathing, postoperative atelectasis and hypoxemia may persist for several days [12]. Recent publications have shown that the best mechanical ventilation strategy during open-heart surgery with a pump is still unclear [13]. While some studies suggest a positive impact on oxygenation and systemic inflammatory response, the actual clinical effect of ventilation during cardiopulmonary bypass is controversia. Moreover, the results of these studies can't be consistently interpreted due to biases in the literature [14].

**Materials and methods**: This was a prospective, randomised study conducted in patients undergoing elective on pump CABG due to coronary arteries disease (CAD) from September till December 2023.

Patients were recruited from a single tertiary care center in Kazakhstan. The study included all adult patients aged ≥18 years who underwent cardiac surgery with CPB. Patients were randomised into two groups – one group receiving low tidal volume (LTV) mechanical ventilation and one group receiving no ventilation during CPB.

Mechanical ventilation strategy: Immediately after intubation, mechanical ventilation was started in volume-controlled ventilation mode with initial parameters VT 5-7 ml/kg, PEEP – 5 – 10 cmH2O. Immediately after initiation of CPB modes of mechanical ventilation in the LTV group – VT 3-5 ml/kg, PEEP – 5 – 8 mm H2O, frequency – 7-10 per minute. In the second Non ventilated (NV) group, ventilation was stopped in standby mode. The original ventilation parameters were restored after weaning from CPB.

The main endpoint was PaO2/FiO2 as a marker for the quality of ventilation and perfusion measured in the ICU in the immediate postoperative period. Secondary endpoints were postoperative pulmonary complications such as atelectasis and prolonged mechanical ventilation of more than 72 hours. Atelectasis was diagnosed using the USI method (more than 3 B-lines in the lateral projection), and the shunt was measured in the ABG. Patients in both groups were comparable in terms of primary parameters.

Arterial blood gases (ABG) were measured several times just before intubation on spontaneous breathing and atmospheric O2, during CPB (they were not included because of extracorporeal oxygenation), immediately after admission to the ICU after surgery, 24, 48, 72 hours after surgery in the ICU.

Chest X - ray were conducted routinely (not more than 10 days before surgery). COPD, emphysema, fibrosis was combined in the meaning – pulmonary pathology.

**Method of randomization:** simple computer method

**Statistical analyses**

For continuous variables, the arithmetic mean, standard deviation (SD), median and range were calculated. For binary or categorical variables, absolute and relative frequencies (n, %) were calculated. To assess the differences between the groups, standard independent-samples t-tests were performed using pooled analyses for equal variances and Satterthwaite analyses for unequal variances. P values of <0.05 were taken to indicate significance.

**Results:**

A total 190 patients were enrolled to the study, 92 of them were included in the LTV group and 98 patients in the NV group.

The demographic data are shown in Table 1. The characteristics were generally similar in both groups.

Table 1 demographics and initial laboratory data

|  |  |  |
| --- | --- | --- |
|  | **LTV group, N=92** | **NV group, N=98** |
| Age, median (range), years | 62 (29–81) | 59 (21–83) |
| Sex, n (%)  Female | 52 (56.5%) | 44 (44.9%) |
| BMI, m2 | 29.7 (19.5–39.4) | 27.4 (21.7–37.5) |
| Comorbidity history, n (%) |  |  |
| Stroke | 24% | 28% |
| MI history | 37% | 43% |
| Diabetes | 35% | 32% |
| Surgery timings, median (range), minutes |  |  |
| CBP time | 92.0 (27.0 - 212.0) | 88.5 (46.0–197.0) |
| Aortic cross clamp time | 61.0 (0.0–125.0) | 59.5 (15.0–193.0) |
| Baseline levels, median (range) |  |  |
| PaO2/FiO2 | 409.53 ±170.12 | 422.6 ±164.6 |
| F shunt | 0.12 ±0.03 | 0.15±0.05 |
| Hemoglobin | 132.0 (72.0–156.0) | 139.0 (72.0–160.0) |
| Hematocrit | 39.0 (20.0–45.1) | 42.0 (20.0–46.1) |
| Chest X Ray pathology | 15.4% | 17.14% |

LTV – Low tidal volume, NV – non ventilated, MBI – body mass index, CBP – cardiopulmonary bypass, MI history - myocardial infarction history

Before surgery, PaO2/FiO2 and F-shunt parameters were numerically in the normal range (Figure 1). Chest X-ray before surgery had revealed pulmonary pathologies due to chronic lung disease in about 15% of patients. More than 1/3 of the patients had a history of comorbid conditions such as type 2 diabetes, ischemic stroke and acute myocardial infarction.

Postoperative period in the ICU data with primary and secondary outcome reflected in the table 2.

Table 2. Primary and secondary outcomes in the intensive care unit.

|  |  |  |  |
| --- | --- | --- | --- |
|  | LTV group (n=92) [Mean ±] | NV group (n= 98) [Mean ±] | P value (CI95%) |
| PEEP intraop. period (cmH2O) | 7.38 ±2.12 | 0 |  |
| PaO2/FiO2 | 328.64±170.6 | 312±155.4 | 0.64 |
| PCO2 | 39.5±12.54 | 45.8±19.2 | 0.08 |
| F shunt | 0.19±0.06 | 0.45±0.1 | 0.03 |
| Pulmonary complications (%) | | | |
| Atelectasis signs at the USI | 6.58% | 32.4% | 0.012 |
| Recruitment maneuver | 12% | 38.6% | 0.032 |
| Mechanical ventilation more than 72 hours | 12 (13.04%) | 15 (15.3%) | 0.73 |

PEEP intraop. period - Positive end-expiratory pressure intraoperative period, LTV – low tidal volume, NV – non ventilated, USI – ultrasound investigation.

No significant difference was found between the groups for the primary endpoint PaO2/FiO2 ratio (p=0.64).

A significant difference was found for the F-shunt indicator 0.19±0.06 vs 0.45±0.1 with a p-value of 0.03.

Mean paCO2 level in the immediate postop period was higher in the NV group although without significant statistical difference. In the non-ventilated group there were more detected signs of atelectasis during USI 6.58% vs. 32.4%. The recruitment manoeuvre shortly after ICU admission was performed in 12% of patients in the LTV group andin 38.6% of patients in the NV group, which was a significant difference between the groups. In addition, the importance of the F-shunt was significantly higher in the NV group 0.19 vs 0.45 (p value 0.03), justifying a venous blood shunt in the lung due to atelectasis of the lung tissue.

The need for prolonged mechanical ventilation for various reasons was approximately the same in both groups at 12% and 15% and was not significant.

**Discussion**

The issue of mechanical ventilation has been a subject of debate for over three decades. The MECANO study by Nguyen, Lee S., et al [15], a single-center randomized clinical trial conducted on patients undergoing cardiac surgery, found no significant difference in the primary endpoint, which was a composite measure of postoperative mortality and pulmonary complications. The same in our study PaO2/FiO2 index did not differ between the groups.

The same opinion was in the study conducted by Zhang et al [16], 413 adult patients undergoing elective cardiac surgery with CPB were observed. The study examined the use of no ventilation or low tidal volume (VT) ventilation at 30% or 80% FiO2. The study concluded that the continuation of low VT ventilation did not offer any significant advantage over no ventilation during CPB, in relation to the incidence of PPCs during hospital stay after the surgery. However, due to the limitations in the study's design, the authors were unable to draw a strong conclusion on the effects of the application of low VT ventilation at 30% on the severity of pulmonary complications.

However, according to the recently conducted systematic review and meta-analysis (Chi et al., 2017), continued ventilation during CPB showed a prominent increase of PaO2/FiO2 index in patients receiving ventilation support versus the patients whose ventilation support was turned off. This discrepancy could be explained from the standpoint of a reduced number of patients participating in the current research. Moreover there was some data in favour of mechanical ventilation during CPB[17].

There is evidence from studies that the use of continuous mechanical ventilation during CPB can have significant clinical benefits. These benefits include improved oxygenation and reduced inflammation, which ultimately leads to less lung injury. A recent meta-analysis of 16 clinical trials also showed that mechanical ventilation during surgery resulted in a reduced shunt fraction and an increase in oxygenation immediately after weaning from CBP. The analysis also concluded that maintaining MV throughout the entire duration of extracorporeal circulation could reduce the CPB-related inflammatory response and tissue damage[13].

In our study we have obtained data that the strategy of low tidal volume ventilation with a PEEP of more than 5 cm H20 during CPB may be beneficial to avoid the formation of atelectasis in the lung tissue. In addition, we were forced to apply strict ventilation parameters with high inspiratory pressure in the ICU due to atelectasis in the postoperative period. In this study, we observed a correlation between preserved mechanical ventilation with PEEP and atelectasis formation in the postoperative period.

There are some limitations to this study. Small number of patients, a single-centre study, all of the perioperative management were carried out according to our hospital’s clinical practice.

**Conclusion**: Maintaining a low tidal volume and PEEP during CPB may be beneficial for patients undergoing CABG cardiac surgery. In our opinion, it is a mandatory measure to maintain a PEEP of 5 to 10 during CPB in patients with excessive body weight.

**Acknowledgements**: «This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. АР19677596)»

References:

1. Monaco, Fabrizio, et al. "Management of challenging cardiopulmonary bypass separation." *Journal of cardiothoracic and vascular anesthesia* 34.6 (2020): 1622-1635.
2. Zheng, Xue-Mei, et al. "Lung injury after cardiopulmonary bypass: Alternative treatment prospects." *World Journal of Clinical Cases* 10.3 (2022): 753.
3. Kaufmann, Kai, and Sebastian Heinrich. "Minimizing postoperative pulmonary complications in thoracic surgery patients." *Current Opinion in Anesthesiology* 34.1 (2021): 13-19.
4. Wahba, Alexander, et al. "2019 EACTS/EACTA/EBCP guidelines on cardiopulmonary bypass in adult cardiac surgery." *European Journal of Cardio-Thoracic Surgery* 57.2 (2020): 210-251.
5. Akhtar, Mohammad Irfan, et al. "Multicenter international survey on cardiopulmonary bypass perfusion practices in adult cardiac surgery." *Journal of cardiothoracic and vascular anesthesia* 35.4 (2021): 1115-1124.
6. Sanfilippo, Filippo, et al. "Acute respiratory distress syndrome in the perioperative period of cardiac surgery: predictors, diagnosis, prognosis, management options, and future directions." *Journal of Cardiothoracic and Vascular Anesthesia* 36.4 (2022): 1169-1179.
7. Jiang, Fenglin, Xiujuan Jiang, and Ruiyao Jia. "Research on the Mechanisms of Lung Injury in Cardiopulmonary Circulation (CPB)." *MEDS Clinical Medicine* 3.5 (2022): 5-11.
8. O'Neil, Michael. *Microvascular Responsiveness to Cardiopulmonary Bypass*. Diss. The University of Western Ontario (Canada), 2023.
9. Mowery, Nathan T., WT Hillman Terzian, and Adam C. Nelson. "Acute lung injury." *Current problems in surgery* 57.5 (2020): 100777.
10. Nteliopoulos, Georgios, et al. "Lung injury following cardiopulmonary bypass: a clinical update." *Expert Review of Cardiovascular Therapy* 20.11 (2022): 871-880.
11. Tanner, Tristan George, and Mai O. Colvin. "Pulmonary complications of cardiac surgery." *Lung* 198.6 (2020): 889-896.
12. Sanfilippo, Filippo, et al. "Acute respiratory distress syndrome in the perioperative period of cardiac surgery: predictors, diagnosis, prognosis, management options, and future directions." *Journal of Cardiothoracic and Vascular Anesthesia* 36.4 (2022): 1169-1179.
13. Bignami, Elena, and Giulia Andrei. "PRO: Mechanical ventilation during cardiopulmonary bypass in adult cardiac surgery." *Journal of Cardiothoracic and Vascular Anesthesia* (2024).
14. Weingarten, Noah, et al. "Comparison of mechanical cardiopulmonary support strategies during lung transplantation." *Expert review of medical devices* 17.10 (2020): 1075-1093.
15. Nguyen, Lee S., et al. "Low tidal volume mechanical ventilation against no ventilation during cardiopulmonary bypass in heart surgery (MECANO): a randomized controlled trial." *Chest* 159.5 (2021): 1843-1853.).
16. Zhang, Meng-Qui, et al. “Effect of ventilation strategy during cardiopulmonary bypass on postoperative pulmonary complications after cardiac surgery: a randomized clinical trial.” Journal of Cardiothoracic Surgery Vol. 16:319 (2021). https://doi.org/10.1186/s13019-021-01699-1.
17. Chi, D. *et al.* (2017) ‘Ventilation during cardiopulmonary bypass for prevention of respiratory insufficiency’, *Medicine*, 96(12). doi:10.1097/md.0000000000006454.