THE STRATEGY OF MECHANICAL VENTILATION DURING CARDIOPULMONARY BYPASS AS A PREDICTIVE FACTOR FOR PULMONARY COMPLICATIONS IN THE INTENSIVE CARE UNIT

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The authors declare no conflict of interests

Key words:
Mechanical ventilation, Cardiopulmonary bypass, Atelectasis

Annotation

Background. Pulmonary complications are the second most common complication after cardiac surgery with cardiopulmonary bypass. Pulmonary atelectasis can occur from various intraoperative causes such as prolonged operation, time of anaesthesia more than 3-4 hours, use of a thoracic artery, use of cardiopulmonary bypass during surgery, lack of ventilation, haemotransfusion of 4 or more units of packed red blood cells in the perioperative period. Impact of mechanical venatilation 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, $p=0.591$. A significant difference was found in the number of atelectasis during ultrasound investigation of the lungs in the non-ventilated group, $p = 0.0001$.

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

Қанның жасанды айналымы кезіндегі жүрек-өкпе ауа айналымының механикалық желдету жоспарының стратегиясы реанимация бөліміндегі өкпе асқынуларының болжамды факторы ретінде

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Түіндеме

Өзектідігі. Түйі нжасанды қан айналым кезіндегі қолданылатын кардиохирургиялық процедуралардан кейін өкпе асқынулары екінші орында тұр. Өкпе ателектазы операция себептерінен туындауы мүмкін, мысалы, ұзақ операция және анестезия уақыты 3-4 сағаттан асатын жағдайда, кеуде артериясын қолдану, операция кезінде жасанды қан айналымын қолдану және механикалық желдетудің мүмкін еместігі, сондай-ақ периоперативті кезеңде 4 немесе одан да көп құты эритроциттерінен қан құюы. Жүрек-өкпе айналымы кезінде механикалық желдетудің әсері әлі белгісіз.

Әдістері. бір орталықта перспективалық рандомизацияланған сынақ. Зерттеуге жүректің ишемиялық ауруы үшін стернотомия арқылы сорғыны пайдаланып жүрекке операция жасаған ересек пациенттер енгізілді.

Пациенттер екі топқа бөлінді яғни рандомизацияланды бірінші топқа механикалық желдету қолданылды да, ал екінші топқа жасанды қан айналымы кезінде механикалық желдету берілмеді. Негізгі соңғы көрсеткіш желдету және перфузия сапасының көрсеткіші ретінде PaO2/FiO2 болды. Екінші соңғы көрсеткіште операциядан кейінгі өкпе асқынулары болды, мысалы, ателектаз және 72 сағаттан астам уақыт бойы механикалық желдету кезіндегі асқынулар.

Нәтижелері. қатарынан 190 пациентті, әр топта 92 және 98 науқас қатысты. Топтарда PaO2/FiO2 қатынасында айтарлықтай айырмашылық табылған жоқ p=0.591. Өкпенің ультрадыбыстық зерттеуінен кейін механикалық желдетусіз өткен топтағы p = 0.0001 көрсетіп ателектаздар саныайтарлықтай жоғары болды.

Қорытынды. жасанды қан айналым кезіндегі операция, өкпенің механикалық желдетуінсіз өткен жағдайда өкпе ателектазының жиілігі едәуір жоғары болады.

Түйінді сөздер:
механикалық желдету, жасанды қан айналымы, ателектаз

Стратегия механической вентиляции легких во время искусственного кровообращения как прогностический фактор легочных осложнений в отделении интенсивной терапии

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Ключевые слова:
Искусственная вентиляция легких, искусственное кровообращение, ателектаз.

Аннотация

Введение. Легочные осложнения занимают второе место по распространенностипосле кардиохирургических операций с применением искусственного кровообращения. Ателектаз легочной ткани может возникнуть в результате различных причин, таких как длительная операция и анестезия, более 3-4 часов, выделение грудной артерии, искусственного кровообращенияи отсутствие искусственной вентиляции легких, а также массивные гемотрансфузии более 4 единиц эритроцитарной взвеси в периоперационном периоде. Влияние искусственной вентиляции легких во время искусственного кровообращения на осложнения послеоперационного периода до сих пор неясно.

Материалы и методы. Рандомизированное одноцентровое исследование. В исследование были включены взрослые пациенты, перенесшие открытую операцию на сердце с проведением искусственного кровообращения.

Пациенты были рандомизированы в две группы – одна группа с искусственной вентиляцией легких во время искусственного кровообращения, вторая без вентиляции во время искусственного кровообращения. Основной точкой измерения был индекс PaO2/FiO2 как показатель качества вентиляции и перфузии в легких. Вторичными показателями оценки были послеоперационные легочные осложнения, такие как ателектаз и длительная искусственная вентиляция легких более 72 часов.

Результаты. В исследование были включены 190 последовательных пациентов, 92 и 98 в каждой группе. Не было обнаружено существенной разницы в отношении PaO2/

FiO2 индекса в группах, p=0.591. При ультразвуковом исследовании легких была выявлена достоверная разница в количестве ателектазов, большев группе без искусственной вентиляции легких, p = 0.0001.

Заключение. Операция на открытом сердце с применением искусственного кровообращения, без длительной вентиляции легких может привести к ателектазу легких.

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 injury 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. Physiologically, 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 intervention, anaesthesia, medications, massive transfusions can cause diffuse lung injury.[6] During CPB, the lungs receive less 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 and an important cause of postoperative hypoxaemia.[11] Various reasons have been put forward 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 depressurisation of the respiratory system during CPB to enable better visualisation 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.[6] Recent publications have shown that the best mechanical ventilation strategy during open-heart surgery with a pump is still unclear.[12] While some studies suggest a positive impact on oxygenation and systemic inflammatory response, the actual clinical effect of ventilation during cardiopulmonary bypass is controversial. Moreover, the results of these studies can't be consistently interpreted due to literature biases.[13]

Materials and methods

This is a prospective, randomised study conducted in patients undergoing elective on-pump CABG due to coronary arteries disease (CAD) from September till December 2023. Method of randomization:simple computer-generated random numbers (odd and even numbers).

Patients were recruited from a single regional healthcare centre in Kazakhstan. The study included all adult patients aged ≥18 years that 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 pulmonaryatelectasis and prolonged mechanical ventilation of more than 72 hours. Atelectasis was diagnosed using the US method (more than 3 B-lines in the lateral projection), and the shunt was measured in the arterial blood gases (ABG). Patients in both groups were comparable in terms of primary parameters.

ABG were measured several times just before intubation on spontaneous breathing with atmospheric O2, during CPB (they were not included because of extracorporeal oxygenation), immediately after admission to the ICU after surgery and 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.

Ethicalapproval.

This study was conducted in strict accordance with the principles outlined in the Helsinki Declaration. Before commencing the research, approval was obtained from the Local Bioethics Committee of the Corporate Fund "University Medical Center."

Statistical analysis

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. To determine whether the means of two datasets are different from each other the Z test was used. The Z score is used to assess the significance of an individual data point within a distribution, while the Odds Ratio and the Chi-Square test are used to analyse the association between variables in different contexts.

Results

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

Table 1. Demographics and initial laboratory characteristics

	NV group, N=98	LTV group, N=92	Chi-squared	z-statistic	P value
Age, (years)	59±11.40	62±9.63	-	1.953	0.052*
Gender, n (%)					
Female	44 (44.9%)	52 (56.5%)	1.270	-	0.260
Male	54 (55.10%)	40 (43.48%)	1.228	-	0.268
BMI, m^2	27.4±3.56	29.7± 4.12	-	4.125	0.0001*
Comorbidity, n (%)					
Stroke	27 (27.55%)	22 (23.91%)	0.082	-	0.775
MI history	42 (42.86%)	34 (36.96%)	0.268	-	0.604
Diabetes	31 (31.63%)	32 (34.78%)	0.069	-	0.792
Surgery timings, median (range), minutes					
CBP time	88.5±38.2	92.0±27.56	-	0.38	0.56
Aortic cross clamp time	59.5±25.92	61.0±27.44	-	0.50	0.54
Baseline levels, median (range)					
PaO2/FiO2	422.6 ±164.6	409.53±170.12	-	0.538	0.591
F shunt	0.15±0.05	0.12 ±0.03	-	4.975	0.0001*
Haemoglobin	139.0±11.6	132.0±8.54	-	0.632	0.09
Haematocrit	42.0±6.71	39.0±5.12	-	0.174	0.32
Chest X Ray pathology	17 (17.36%)	14 (15.21%)	0.025	-	0.874

* z test statistical significance P⩽0.05. LTV – Low tidal volume, NV – non ventilated, MBI – body mass index, CBP – cardiopulmonary bypass, MI history - myocardial infarction history

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

Before surgery, PaO2/FiO2 and F-shunt parameters were numerically in the normal range. Chest X-ray before surgery had revealed pulmonary pathologies due to chronic lung disease in 14 (15.21%) of patients. More than 1/3 of the patients had a history of comorbidity conditions such as type 2 diabetes, ischemic stroke and acute myocardial infarction.The postoperative ICU data with primary and secondary outcomes are shown in Table 2.

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

	NV group (n= 98)	LTV group (n=92)	OR	z-statistic	P value
PEEP intraop. period (cmH2O)	0	7.38 ±2.12	-	-	-
PaO2/FiO2	312±155.4	328.64±170.6	-	0.704	0.482
PCO2	45.8±19.2	39.5±12.54	-	2.659	0.008*
F shunt	0.45±0.1	0.19±0.06	-	21.558	0.0001*
Pulmonary complications (%)					
Atelectasis signs (US)	30 (32.61%)	6 (6.52%)	6.32[a]	3.877	0.0001*
Recruitment manoeuvre	35 (38.04%)	11 (11.96%)	4.09[a]	3.667	0.0002*
Mechanical ventilation more than 72 hours	15 (15.3%)	12 (13.04%)	1.20	0.446	0.655

* z test statistical significance P≤0.05
[a] OR - Odds ratio; OR>1 means that the event is directly related and has a chance of occurring in the first group
PEEP intraoperative period - Positive end-expiratory pressure intraoperative period, LTV – low tidal volume, NV – non-ventilated, US – ultrasound.

No significant difference was found between the groups for the primary endpoint PaO2/FiO2 ratio (p=0.482).

A significant difference was found for the F-shunt indicator 0.19±0.06 vs 0.45±0.1 with a p-value < 0.0001.

Mean paCO2 level in the immediate postoperative period was higher in the NV group although without significant statistical difference. In the non-ventilated group, there were more detected signs of pulmonary atelectasis during US30 (32.61%) vs.6 (6.52%), OR=6.32, 95%CI [2.49;16.07], z-statistic 3.877, P value <0.0001. The recruitment manoeuvre shortly after ICU admission was performed in 11 (11.96%) of patients in the LTV group and in35 (38.04%) of patients in the NV group, which was a significant difference between the groups, OR=4.09, 95%CI [1.92;8.68], z-statistic 3.667, P value 0.0002. In addition, the importance of the F-shunt was significantly higher in the NV group 0.45±0.1 vs 0.19±0.06 (p value <0.0001), substantiating the presence of venous blood shunt in the lung due to pulmonary atelectasis.

The need for prolonged mechanical ventilation for various reasons was approximately the same in both groups at 12 (13.04%) and 15 (15.3%) and was not significant, P value 0.655.

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*, a single-center randomised 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. In our study, the PaO2/FiO2 index also did not differ between groups.[14]

The same opinion was in the study conducted by *Zhang et al.*, 413 adult patients undergoing elective cardiac surgery with CPB were observed. The study examined non- 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.[15]

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.[16]

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.[12]

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 pulmonary 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.

Limitations.

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.

What is already known on this topic: After cardiopulmonary bypass, patients are at risk of developing pulmonary complications such as pulmonary atelectasis and edema. Atelectasis, the collapse of alveoli, can occur due to the reabsorption of air from the alveoli during periods of reduced lung volume. Pulmonary edema may develop as a result of increased capillary permeability and fluid retention.

What this study adds: Determination of the effect of mechanical ventilation with positive PEEP to pulmonary atelectasisformation in the postoperative period still unknown and the benefit for cardiac surgery patients is to preserve mechanical ventilation during cardiopulmonary bypass.

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