

Efficacy of Continuous Positive Airway Pressure (CPAP) 5 cmH₂O during Cardiopulmonary Bypass (CPB) on Partial Pressure of Oxygen in Elderly Patients Undergoing Cardiac Surgery

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Abstract

The number of elderly patients undergoing open-heart surgery is rising due to increase in life expectancy. Despite advances in surgical techniques and perioperative care, postoperative pulmonary complications (PPCs) remain common, often indicated by reduced arterial oxygen levels influencing ventilator weaning. Oxygenation decline may result from pulmonary collapse during Cardiopulmonary Bypass (CPB), ischemia-reperfusion injury, inflammation, and impaired alveolar-capillary function. Continuous Positive Airway Pressure (CPAP) 5 cmH₂O during CPB on arterial oxygenation and postoperative pulmonary complications (PPCs) in elderly patients. This single-center randomized controlled study included 110 elderly patients undergoing open-heart surgery with CPB. Patients were assigned to one of two intraoperative ventilation strategies: (1) no mechanical ventilation and no oxygen supplied during CPB (control group) or (2) CPAP at 5 cmH₂O during CPB (CPAP group). Arterial blood gas samples were collected at multiple consecutive stages throughout the surgery. Postoperative outcomes included mechanical ventilation duration, intensive care unit (ICU) stay, and PPCs incidence.

The CPAP group showed significantly higher PaO₂/FiO₂ ratios and PaO₂ at 5 minutes post-CPB (403.53±104.43 mmHg and 403.5±104.42 mmHg in control group vs. 445.20±85.31 mmHg and 445.19±85.30 mmHg in CPAP group,

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$p = .024$) and after sternal closure (361.90 ± 139.48 mmHg and 353.33 ± 149.30 mmHg in control group vs. 417.42 ± 117.90 mmHg and 413.07 ± 125.87 mmHg in CPAP group, $P=0.026$ and $P=0.025$ respectively), but not after ICU admission. No differences were found in PPCs incidence (42% control versus 31% CPAP), ICU stay ($p = .78$) and extubating time ($p = .26$).

Applying CPAP 5 cmH₂O during CPB was associated with better oxygenation in early stage and did not reduce the incidence of PPCs in elderly patients undergoing cardiac surgery.

Keyword: CPAP, Cardiopulmonary bypass, Cardiac surgery, Elderly

Introduction

Despite much improvement in perioperative management of cardiac surgery, postoperative respiratory dysfunction remains a widely reported complication in among many countries. According to the Society of Thoracic Surgeons (STS), prolonged intubation (>24 hours) resulting from cardiopulmonary bypass (CPB) occurs in up to 2.2% (Seese L et al., 2020) of patients and can lead to mortality and increased length of stay in the intensive care unit (ICU) (Curiel-Balsera E et al., 2013 ; Ball L et al., 2016) Although stopping ventilation during CPB is standard in order to provide a more stable surgical field, free from interference caused by lung movement, it may contribute to postoperative respiratory problems such as micro-atelectasis, hydrostatic pulmonary edema, and decreases in both lung compliance and surfactant diffusion. An absent of blood flow to the lung during cardiac bypass is a major cause of these complications. (Apostolakis E et al., 2010) During this period, oxygenation is maintained by an extracorporeal gas exchanger. Some newer strategies involve applying low tidal volume ventilation or continuous positive airway pressure (CPAP) during CPB is studied to prevent these effects. (Chi D et al., 2017 ; Schreiber JU et al., 2012 ; Berry CB et al., 1993) Using hypoventilation during CPB demonstrates better PaO₂ early after surgery, duration of ICU admission and Postoperative pulmonary complications (PPCs) are still a matter of debate.4 However, the administration of positive respiratory support during CPB can present challenges for the surgical team, as ventilation-induced lung motion may compromise the stability of the surgical field and obstruct the surgeon's view, thereby complicating the procedure. On the other hand, CPAP is mentioned in many studies in abdominal surgery to prevent Postoperative pulmonary complications (PPCs) (Ferreya GP et al., 2018) but in cardiac surgery the results are unclear.

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Notably, this study differs from previous research in that the study population comprised elderly patients, who are more likely to experience age-related declines in pulmonary function. Based on this consideration, the investigators hypothesized that the application of CPAP could improve postoperative arterial oxygenation in this high-risk group, which may in turn reduce the incidence of postoperative complications and shorten the length of hospital stay. The goal of this randomized controlled trial was to compare the effects of applying CPAP at 5 cmH₂O during cardiopulmonary bypass on arterial oxygenation at specific time points, duration of postoperative ventilation, ICU length of stay, and postoperative complications in elderly patients undergoing open cardiac surgery

Materials and Methods

The single-center, patient-blinded, nonpharmacologic, randomized, parallel-group study. The study population consisted of patients aged 65 years or older who underwent open-heart surgery at Rajavithi Hospital between October 2023 and September 2025. Data were collected by a single attending anesthesiologist and three cardiac surgeons who were members of the research team.

Ethical Approval and Clinical Trial Authorization

After obtaining Rajavithi Ethics Committee approval and written, informed consent, we studied 110 patients with coronary, valvular and aorta disease listed for open cardiac surgery using cardiopulmonary bypass. Aortic surgery which needed one lung ventilation was excluded from the study. Patients were randomly assigned to two groups, one group received CPAP at 5 cmH₂O during CPB, whereas in the other group, the lungs were not ventilated.

The study endpoints

The primary endpoint of respiratory support efficacy during CPB was the PaO₂/fraction of inspired oxygen (F_iO₂) ratio (PF ratio) and PaO₂ at different stages of surgery:

- T1 — before tracheal intubation with oxygen supplement
- T2 — 5 minutes after weaning from CPB or Modified Ultrafiltration
- T3 — 10 minutes after sternal closure
- T4 — 1 hour after admit in ICU

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Intervention

After patients were in operating room, vital signs were monitored according to the American Society of Anesthesiology guidelines prior to administration of anxiolytics and prior to administration of oxygen supplement. A continuous blood pressure monitor was then inserted into the radial artery (arterial line) in one arm, arterial blood gas was collected and a central venous catheter was inserted. Then, preoxygenation for at least 3 min, anesthesia was induced by using Propofol 1.5-2.5 mg/kg or Etomidate 0.15-0.3 mg/kg fentanyl 1-2 mcg/kg, and Cisatracurium 0.15 mg/kg or rocuronium bromide 0.6-1 mg/kg. This was followed by manual ventilation at a fraction of inspired oxygen (F_{iO_2}) of 1.0 for 3-5 minutes and subsequent tracheal intubation. Lungs were ventilated by using 6-10 mL/kg tidal volume at 10-16 breaths/min respiratory rate, and the F_{iO_2} was adjusted between 0.4-1. Anesthesia was maintained with 1-2% sevoflurane, 1-to-2 mcg/ kg/min of Cisatracurium infusion, and 5-10 mcg/kg of fentanyl until the time of CPB. Both patient groups received the same ventilatory support and anesthesia up to the initiation of cardiopulmonary bypass (CPB). During the CPB period, the study group received continuous positive airway pressure (CPAP) set at 5 cmH₂O, while the control group did not receive any respiratory support and oxygen supplement. After weaning off CPB, all patients were administered protamine to reverse the anticoagulation effects of heparin. After surgery, patients were transferred to the cardiac surgical intensive care unit for postoperative care. In the initial ventilator setting in ICU, tidal volume was 6-10mL/kg respiratory rate 10-16 breaths/min, PEEP 3-5 cmH₂O and the F_{iO_2} was 1. Continuous monitoring was maintained in the form of invasive blood pressure, oxygen saturation, heart rate, electrocardiogram, central venous pressure and urine output. Once the arterial blood gas was collected 1 hour after admit to ICU and criteria for extubating were met, patients were extubated and oxygen supplement was administered.

Study Population

The study was performed on elderly patients with undergoing coronary, valvular and aorta surgery using cardiopulmonary bypass, aged equal or more than 65 years, and with American Society of Anesthesiologist class III or IV. Exclusion criteria were: patients with pulmonary disease, patients with history of lung surgeries. Aortic surgeries or transthoracic approach which needed one lung ventilation were also excluded from the study.

The sample size calculation in this study was based on the study by Elhaddad AM et al. (2022) which reported that the oxygen index (OI) 5 minutes after weaning from cardiopulmonary bypass was

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3.0 ± 0.76 in the CPAP group and 3.45 ± 0.84 in the non-CPAP group. Therefore, the required sample size for this study was calculated using the formula

$$n = \frac{(1.96+0.842)^2 \times (0.76^2 + 0.84^2)}{(3.0-3.45)^2}$$

$$n = 50 \text{ for each group}$$

Randomization and Blinding

According to a computer-generated randomization list, all patients were allocated in a 1:1 ratio to one of two groups: (1) the non-ventilated group (control), or (2) the CPAP group. Due to the nature of the intervention, the attending anesthesiologists were not blinded. However, the patients, evaluators, and intensive care unit physicians were all blinded to group allocation and intervention details.

Statistical analysis

Data were coded and entered using the Statistical Package for the Social Sciences (SPSS), version 17 (IBM SPSS Inc.). Results were presented as median and interquartile range (IQR) or mean and standard deviation (SD), as appropriate. A significance level of $p = .05$ was considered statistically significant.

The Chi-square test is used for categorical data to test for associations between two groups. For comparisons between groups, the student-T test was used for normally distributed continuous variables. Mann-Whitney tests were used for nonnormally distributed quantitative variables. ANOVA test is used to compare the difference of the means of PF ratio and PaO_2 between two groups

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Results

The characteristics of the two study groups are summarized in Table 1. which shows that the groups do not differ in the specified parameters. Intraoperative variables including operation time, anesthetic time, and on-pump (CPB) time, did not differ between two groups (Table 2).

Table 1 Demographic data of patients before surgery in two groups (mean $\pm$ SD)

Demographic Data	Control group (n=55)	CPAP group (n =55)	p-value
Age (years)	71.42 $\pm$ 5	71.65 $\pm$ 4.6	.730
BMI (kg/m ²)	22.82 $\pm$ 4	23.4 $\pm$ 4.3	.936
Gender (M/F)	34/21	35/20	1.0
Underlying disease			
Hypertension	50	45	.27
Diabetes mellitus	20	17	.69
Dyslipidemia	34	32	.85
Chronic kidney disease	8	9	.91
Stroke	6	3	.49
Smoking	17	19	.84
Diagnosis			
Coronary artery disease	40	40	1.00
Ascending Aortic aneurysm	3	3	1.00
Mitral stenosis	2	4	.68
Mitral regurgitation	9	8	1.00
Aortic valve stenosis	11	9	.81
Aortic valve regurgitation	6	7	1.00
Tricuspid valve regurgitation	4	5	1.00

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Table 2 Type of procedure, operation time, anesthetic time, and on-pump time in two groups (mean $\pm$ SD)

	Control group (n=55)	CPAP group (n =55)	p-value
<i>Type of procedure</i>			
CABG	40	40	1.00
Mitral valve replacement and repair	8	7	1.00
Aortic valve replacement	17	11	.27
Tricuspid valve surgery	2	1	1.00
Ascending Aorta surgery	4	5	1.00
Total arch replacement	2	1	1.00
Anesthetic time	355.73 $\pm$ 97.56	351.55 $\pm$ 84.97	.865
Operation time	301.87 $\pm$ 94.56	292.09 $\pm$ 83.30	.560
On-pump time	137.06 $\pm$ 67.77	126.85 $\pm$ 47.84	.396

(CABG: Coronary Artery Bypass Graft)

The changes in PaO₂/fraction of inspired oxygen (PF ratio) and PaO₂ in groups according to the stage of the surgery are shown in Table 3.

For primary outcome, the PaO₂/FiO₂ ratio and PaO₂ were significantly higher in the CPAP group at 5 minutes post-bypass (403.53 $\pm$ 104.43 mmHg and 403.54 $\pm$ 104.42 mmHg in control group versus 445.19 $\pm$ 85.30 mmHg and 445.20 $\pm$ 85.31 mmHg in CPAP group, p = .024 and p = .024 respectively). However, the difference was not considered clinically significant. These values remained significantly higher after chest closure (361.90 $\pm$ 139.48 mmHg and 353.33 $\pm$ 149.30 mmHg in control group versus 417.42 $\pm$ 117.90 mmHg and 413.07 $\pm$ 125.87 mmHg in CPAP group, p = .026 and p = .025 respectively). Upon arrival to the intensive care unit (ICU), no significant differences in PaO₂ or PaO₂/FiO₂ ratio were observed between the groups.

There were no significant differences between groups in predictive indices, including time to extubate and length of ICU stay. Additionally, the incidence of postoperative complications both respiratory and non-respiratory did not differ significantly between groups.

The composite incidence of postoperative pulmonary complications (PPCs) was 42% in the control group and 31% in the CPAP group. No participants developed acute respiratory distress syndrome (ARDS) or phrenic nerve injury. Time to extubate (measured from ICU admission) was not significantly different between the two groups (p = .24) (see Table 4).

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Table 3 The changes in PaO₂/fraction of inspired oxygen (PF ratio) and PaO₂ in groups according to the stage of the surgery

	Control group (n=55)	CPAP group (n =55)	p-value	Eta squared
PaO₂ (mmHg)				
Before intubation, FiO ₂ 0.3-0.4	157.95±62.24	156.82±67.58	.928	0.000
(T1)	403.54±104.42	445.20±85.31	.024	0.046
After CPB completion, FiO ₂	353.33±149.30	413.07±125.87	.025	0.045
1.0(T2)	350.95±126.33	384.55±96.83	.12	0.022
After sternal closure, FiO ₂ 0.8-				
1(T3)				
1hr after admit ICU, FiO ₂ 0.8-1				
(T4)				
PaO₂/FiO₂ ratio (mmHg)				
Before intubation, FiO ₂ 0.3-0.4	473.28±171.14	470.64±183.22	.938	0.000
(T1)	403.53±104.43	445.19±85.30	.024	0.046
After CPB completion, FiO ₂	361.90±139.48	417.42±117.90	.026	0.045
1.0(T2)	350.95±126.33	384.55±96.83	.12	0.022
After sternal closure, FiO ₂ 0.8-				
1(T3)				
1hr after admit ICU, FiO ₂ 0.8-1				
(T4)				

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Table 4 Postoperative Pulmonary and other organs complications, Duration of ventilator, Length of stay in the ICU

	Control group (n=55)	CPAP group (n =55)	p-value
Pulmonary complication			
Composite incidence	23/55	17/55	-
Pneumonia	3/55	3/55	1.00
ARDS	-	-	-
Atelectasis	2/55	1/55	1.00
Pleural effusion	8/55	4/55	.36
Ventilator>48hr	10/55	9/55	1.00
Phrenic n injury	-	-	-
Etc.			
Other complication			
Arrhythmia	13/55	7/55	.22
Cardiac tamponade	0/55	1/55	1.00
Stroke	0/55	1/55	1.00
Acute renal failure (ARF)	1/55	1/55	1.00
Postoperative hemorrhage	-	-	-
Etc. (other)			
Postoperative ventilation (min)	2065.49±377.67	1542.04±232.37	.26
The length of stay in the ICU (min)	5890.25±690.12	5727.07±684.25	.78

(ARDS: Acute respiratory distress syndrome)

There was no statistical difference between two groups in term of length of stay in the ICU. There was one patient failed extubating in the ICU and subsequently required a tracheostomy after underwent a thrombectomy for a lower limb thrombus. Another patient died on the operating table due to aortic dissection during cannulation. Both patients mentioned were excluded from the study.

The target PaO₂ during cardiopulmonary bypass varies among institutions and hospitals but is generally maintained between 150 and 400 mmHg. Following weaning from cardiopulmonary bypass, PaO₂ gradually declines, reflecting the patient's underlying pulmonary physiology and the extent of postoperative lung dysfunction.

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From previous study (Chi D et al., 2017 ; Schreiber JU et al., 2012) the $\text{PaO}_2/\text{FiO}_2$ (PF) ratio and the alveolar-arterial oxygen gradient (A-aDO_2) measured immediately after weaning from cardiopulmonary bypass (CPB) demonstrated that patients receiving either CPAP or positive-pressure ventilation during CPB had significantly better postoperative oxygenation than those who received no ventilatory support. Specifically, the ventilated groups showed significantly higher postoperative $\text{PaO}_2/\text{FiO}_2$ ratios. Subgroup analysis further demonstrated that both CPAP and positive-pressure ventilation were associated with significantly higher postoperative PaO_2 values compared with the control group. These findings suggest that maintaining lung ventilation during CPB improves early postoperative pulmonary oxygenation while CPAP applied at 5–10 cmH_2O does not appear to increase the risk of pulmonary barotrauma.

However, during the pilot phase of the present study, the investigators observed that applying CPAP at pressures of 8–10 cmH_2O interfered with the surgical field by increasing lung inflation, thereby making surgical manipulation more challenging. This effect was particularly evident during coronary artery bypass grafting (CABG), where adequate exposure of the operative field is essential. Consequently, although CPAP within this pressure range appears to be safe with respect to pulmonary barotrauma, its potential to compromise surgical exposure should be carefully considered when selecting the optimal intraoperative ventilation strategy.

Discussion

This study aims to evaluate the effect of CPAP during cardiopulmonary bypass on arterial oxygenation and postoperative pulmonary complications in patients undergoing open-heart surgery. The findings are expected to provide evidence to support the optimization of intraoperative anesthetic management during cardiopulmonary bypass at Rajavithi Hospital. Based on the available evidence, it is hypothesized that patients receiving CPAP will have higher postoperative arterial oxygenation than those who do not receive CPAP, as CPAP helps maintain alveolar recruitment during cardiopulmonary bypass.

According to several studies, the incidence of pulmonary atelectasis following surgery involving cardiopulmonary bypass (CPB) can be remarkably high, with reported rates ranging from 54% to 92%. (Tanner TG & Colvin MO, 2020) This wide range is influenced by multiple factors, including the type and duration of the surgical procedure, patient-specific characteristics (such as age, obesity, and pre-existing pulmonary conditions), and variations in perioperative management protocols.

Elderly patients undergoing open cardiac surgery are more at increased risk of pulmonary dysfunction due to multiple contributing factor (Liu J et al., 2024; Griffith KA et al., 2001) One significant

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factor is atelectasis that leads to inflammation and the increased pulmonary lactate release observed during the first six hours after CPB, (Noguchi S et al., 2016; Yang HH et al., 2020) which parallels a rise in systemic arterial lactate concentration. This suggests the presence of lung ischemia-reperfusion injury, which can intensify the inflammatory response and predispose the pulmonary endothelium to leukocyte-mediated damage.

Postoperative pulmonary complications (PPCs) are common after cardiac surgery and contribute substantially to postoperative morbidity, prolonged hospitalization, and increased healthcare costs. Atelectasis is the most frequent PPC, with a reported incidence of 30%–72%, and is a major cause of impaired pulmonary function and gas exchange. Its development is multifactorial, involving diaphragmatic dysfunction, phrenic nerve injury, and inadequate postoperative analgesia, which promote shallow breathing, ineffective cough, and alveolar collapse.

Pleural effusion is the second most common PPC, occurring in approximately 24%–63% of patients. Early pleural effusions (within 15 days after surgery) are typically associated with postoperative bleeding, infection, or surgical tissue injury, whereas late effusions are more commonly related to autoimmune or lymphocyte-predominant inflammatory processes. Pleural effusion is also a frequent cause of hospital readmission after coronary artery bypass grafting and may require therapeutic drainage when accompanied by respiratory compromise or significant fluid accumulation.

Acute respiratory distress syndrome (ARDS), although less common, is the most severe PPC following cardiac surgery. It is characterized by diffuse alveolar inflammation, disruption of the alveolar–capillary membrane, severe hypoxemia, and noncardiogenic pulmonary edema, leading to respiratory failure and increased mortality. Risk factors include advanced age, smoking, chronic obstructive pulmonary disease, previous cardiac surgery, heart failure, liver cirrhosis, multiple blood transfusions, low cardiac output syndrome, valve surgery, and postoperative pulmonary infection.

Additionally, in individuals aged 65 years or older, age-related changes such as increased closing capacity can cause premature airway closure (Janssens JP S et al., 1999; Suraseranivong R., 2022). As noted by Gwen S. Skloot (Skloot GS., 2017), this phenomenon reduces ventilation in the dependent regions of the lungs where the majority of gas exchange occurs and can further impair oxygenation efficiency and ischemic lung injury.

To mitigate these effects, the application of continuous positive airway pressure (CPAP) has been proposed as a strategy to maintain alveolar patency, reduce micro-atelectasis, and improve oxygenation. The findings of this study are consistent with previous research, which demonstrated that arterial oxygen levels (arterial PO_2) and PaO_2/FiO_2 ratio were significantly higher in the intervention group compared to the

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control group during the early phase following discontinuation of CPB but this effect was not sustainable (Magnusson L et al.,1999; Alavi M et al.,1999; Gado AA et al.,2022)

The observed improvement in oxygenation may be attributed to enhanced lung recruitment and the prevention of micro-atelectasis, which together facilitate more effective gas exchange across the alveolar-capillary membrane, and reduction in extravascular lung water. Similarly, previous studies have shown that the use of CPAP at 5 cmH₂O does not lead to significant differences in other outcomes, including extubating time⁶ and the number of postoperative intensive care unit stay days. The incidence of postoperative pulmonary complications (PPCs) also did not significantly differ in most studies (Magnusson L et al.,1999; Alavi M et al.,1999)

Limitations of this study were as follows: First, this was a single-center study, which may limit the generalizability of the type of CPB. Second, there was insufficient evidence to determine the extent of variation in lung function among the patients. Third, the involvement of multiple surgeons with differing techniques and levels of expertise may have introduced variability, potentially affecting the consistency of the outcomes. Additionally, arterial blood gas (ABG) analysis was not performed immediately after endotracheal intubation. The investigators assumed that pulmonary function would not differ significantly before and after intubation, as no surgical intervention or procedure impacting lung function had yet occurred. However, upon further reflection, obtaining arterial blood samples during this early period may have provided valuable insights and allowed for a more comprehensive analysis of oxygenation changes over time.

Conclusions

This study showed that applying CPAP 5 cmH₂O during CPB was associated with better oxygenation in early postoperative period and did not reduce the incidence of postoperative pulmonary complications in elderly patients undergoing open cardiac surgeries compared to the non-ventilated group. Although a difference was not clinically significant, the use of CPAP 5 cmH₂O with 100% FiO₂ during CPB may be a trend to improve postoperative care in term of enhance post-CPB pulmonary gas exchange and attenuate the PPCs in high - risk patients and yet further studies should be investigated to compared the practical pressure of CPAP for better outcomes.

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