Section: Anesthesia

Original Research Article

EFFECT OF LOW TIDAL VOLUME VENTILATION VERSUS NO VENTILATION DURING CARDIOPULMONARY BYPASS IN ADULT CARDIAC SURGICAL PATIENTS ON POST-OPERATIVE RESPIRATORY OUTCOMES

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ABSTRACT

Background: Postoperative pulmonary dysfunction is a common complication following cardiac surgery with cardiopulmonary bypass (CPB), often leading to impaired gas exchange, atelectasis, and reduced lung compliance. Various ventilation strategies, including continuous positive airway pressure (CPAP) and high-frequency ventilation, have been investigated to minimize these adverse effects, but their clinical benefits remain uncertain. Atelectasis during CPB is considered a major factor contributing to postoperative pulmonary impairment and intrapulmonary shunting. Continuous low tidal volume ventilation during CPB may help maintain alveolar recruitment and preserve lung function. Therefore, this study aimed to evaluate the effect of continuous low tidal volume ventilation during CPB on postoperative pulmonary function, gas exchange, and lung mechanics in patients undergoing cardiac surgery. The aim is to evaluate and compare the effect of LTVV techniques versus no ventilation during CPB on post operative respiratory outcomes.

Materials and Methods: This prospective single-blind randomized controlled clinical study was conducted in the Department of Anaesthesiology, Geetanjali Medical College & Hospital, Udaipur over 24 months from September 2022 to June 2024 after institutional ethical committee approval. 80 patients were enrolled after accounting for a 10% dropout rate and were randomly allocated into two groups: a ventilation group (n = 36) and a non-ventilation group (n = 36). During cardiopulmonary bypass (CPB), Group A received low tidal volume ventilation (3 mL/kg, respiratory rate 12/min, PEEP 5 cm H_2O), while ventilation was discontinued in Group B until aortic cross-clamp removal. Arterial blood gases, SpO_2, chest radiographs, extubation time, ICU stay, and hospital stay were recorded and compared between the groups.

Results: The demographic characteristics were comparable between the two groups, with most patients belonging to the 51–60 years age group and a similar gender distribution. Oxygen saturation (SpO_2) values were similar preoperatively and intraoperatively; however, postoperative SpO_2 was significantly higher in the LTVV group compared to the No Ventilation group (96.78 ± 1.12% vs. 93.13 ± 1.9%, $p < 0.0001$). No statistically significant differences were observed between the groups in arterial blood gas parameters (PaO_2 and $PaCO_2$) at any measured time point ($p > 0.05$). Although the LTVV group showed shorter extubation times and ICU stays than the No Ventilation group, these differences were not statistically significant. The duration of hospital stay was significantly shorter in the LTVV group (8.6 ± 1.86 days) compared to the No Ventilation group (10.38 ± 2.02 days, $p = 0.0001$).

Furthermore, postoperative pulmonary complications, including basal atelectasis (10% vs. 25%) and pneumonia (5% vs. 12.5%), were less frequent in the LTVV group, suggesting a beneficial effect of low tidal volume ventilation during cardiopulmonary bypass. Discussion is Despite these encouraging findings, this study has certain limitations, including its single-center design and relatively small sample size, which may limit the generalizability of the results. Additionally, only short-term postoperative outcomes were assessed, and long-term respiratory outcomes were not evaluated. Further large-scale multicenter studies are needed to confirm these findings and determine the optimal ventilation strategy during cardiopulmonary bypass.

Conclusion: This study demonstrates that low tidal volume ventilation (LTVV) during cardiopulmonary bypass improves postoperative respiratory outcomes in adult cardiac surgical patients, including better oxygen saturation, reduced extubation time, and fewer pulmonary complications. It is also associated with shorter ICU and hospital stays, indicating faster overall recovery, although no significant differences were observed in PaO_2 and $PaCO_2$ levels. These findings support the use of LTVV during CPB, with further large-scale studies needed to confirm long-term benefits.

Keywords: Low Tidal Volume Ventilation; Cardiopulmonary Bypass; Postoperative Respiratory Outcomes; Pulmonary Complications.

INTRODUCTION

Cardiopulmonary bypass (CPB) is a technique used in cardiac surgery to allow operations on a non-beating heart while maintaining systemic circulation, oxygenation, and temperature control. The non-physiological circulation produced during CPB can contribute to postoperative pulmonary dysfunction, which remains a significant complication after open-heart surgery, ranging from mild functional impairment to acute respiratory distress syndrome (ARDS).[1–3]

Reduced pulmonary function following CPB [Figure 1], commonly referred to as “post-bypass lung,” is frequently observed and is characterized by increased intrapulmonary shunt, atelectasis, elevated alveolar–arterial oxygen gradient ($AaDO_2$), increased extravascular lung water, and decreased lung compliance.[4–8] CPB is also known to trigger a systemic inflammatory response that increases pulmonary capillary permeability and leads to injury of the lung parenchyma.[9] Among these changes, postoperative atelectasis is considered the primary contributor to intrapulmonary shunting and impaired arterial oxygenation.[10]

Various strategies have been explored to reduce CPB-associated lung dysfunction, including continuous positive airway pressure (CPAP) and low-volume, high-frequency ventilation.[11–13] Reported CPAP levels range from 5 to 15 cmH_2O, while high-frequency ventilation protocols have used rates up to 100 breaths per minute, with varying inspired oxygen concentrations from room air to 100%. Some approaches have also included bilateral extracorporeal circulation to facilitate oxygenation during bypass. Although CPAP at around 10 cmH_2O has shown limited and transient benefits, no ventilatory strategy has yet demonstrated consistent or significant clinical improvement.[14]

Cardiopulmonary bypass (CPB) cannulation [Figure 1] diverts venous blood from the pulmonary circulation into the CPB circuit, allowing systemic perfusion with oxygenated blood. The ascending aorta is the preferred site for arterial cannulation due to its accessibility and visibility, and the procedure is usually performed under direct visualization using a surgical cut-down technique.[15]

Figure 1: Aortic cannulation

Blood pumps in the cardiopulmonary bypass (CPB) circuit are divided into main arterial pumps (Fig 2), which circulate blood through the oxygenator and back to the body, and auxiliary pumps used for suction and cardioplegia delivery. Arterial blood pumps are classified into two types: roller (displacement) pumps and centrifugal pumps. Roller pumps provide fixed flow by compressing tubing, whereas centrifugal pumps use centrifugal force to generate blood flow and are associated with less blood trauma.[16]

Figure 2: Blood centrifugal pump with stacked cones.[20]

Aim: To evaluate and compare the effect of low tidal volume ventilation (LTVV) versus no ventilation during cardiopulmonary bypass (CPB) on postoperative respiratory outcomes.

Objectives

Primary Objective

- Oxygen saturation (SpO_2)
- Arterial blood gas (ABG) parameters
- Time to extubation

Secondary Objectives

- Duration of ICU stay and total hospital stay
- Incidence of postoperative pulmonary complications, including:
    - Basal atelectasis
    - Pneumonia

MATERIALS AND METHODS

This prospective, single-blind, randomized controlled clinical study was conducted in the Department of Anaesthesiology, Geetanjali Medical College & Hospital, Udaipur, over a period of 24 months from September 2022 to June 2024, after obtaining approval from the Institutional Ethics Committee. A total of 80 patients fulfilling the inclusion and exclusion criteria were enrolled in the study.

Inclusion Criteria

- Patients aged more than 18 years of either sex.
- Patients with preoperative pulmonary function test showing FEV1/FVC ratio > 75%.
- Adult patients undergoing surgical procedures under anaesthesia without significant respiratory comorbidities as defined in the exclusion criteria.

Exclusion Criteria

- Refusal to participate in the study.
- Patients with left ventricular ejection fraction (LVEF) < 30%.
- Obese patients with a history of obstructive sleep apnea.
- Patients undergoing redo or emergency surgeries.
- Patients with renal or hepatic failure.
- Patients with chronic obstructive pulmonary disease (COPD) or other significant lung diseases.
- Patients with systemic inflammatory diseases.

Sample Size Calculation: The study included patients undergoing cardiopulmonary bypass (CPB) surgery in the cardiac operating theatre.

The sample size was calculated using the formula:

$$n = \frac{(r+1)}{r} \times \frac{Z_\alpha^2 \, P(1-P)}{E^2}$$

Where:
n = sample size per group
Zα = 1.96 at 95% confidence level
P = expected proportion (assumed prevalence)
E = absolute error = 10% (0.10)
r = ratio of sample size between groups = 1

Based on the calculation, the required sample size was 36 patients per group. Considering potential dropouts, 40 patients were included in each group, resulting in a total sample size of 80 patients.

Statistical Analysis: The data were entered into Microsoft Excel and analyzed using SPSS version 21. Continuous variables are presented as mean ± standard deviation, while categorical variables were analyzed using the chi-square test. A p-value of <0.05 was considered statistically significant.

RESULTS

Age Distribution: In the LTVV group, 30% of participants were aged 31–40 years, and another 30% were aged 41–50 years. The largest proportion (32.5%) fell within the 51–60 year age group, while 7.5% were older than 60 years.

A similar pattern was observed in the No Ventilation group, where 27.5% of participants were aged 31–40 years and another 27.5% were aged 41–50 years. A slightly higher proportion (35%) belonged to the 51–60 year age group, and 10% were above 60 years of age.

Overall, both groups demonstrated comparable age distributions, with a predominance of participants in the 51–60 year age category. The detailed age-wise distribution is presented in [Figure 3].

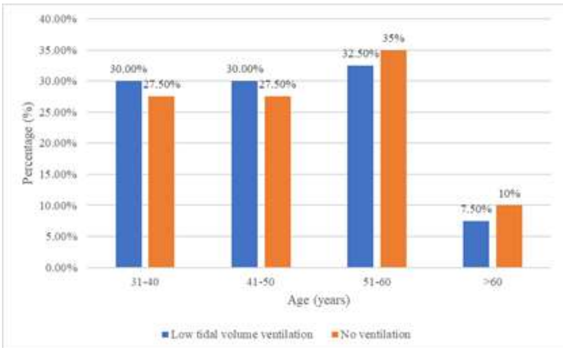

Figure 3: Distribution of age.

Distribution of Group with Gender: In the LTVV group, there were 22 females (55%) and 18 males (45%). In the No Ventilation group, the distribution was evenly balanced, with 20 females (50%) and 20 males (50%) shown in [Figure 4].

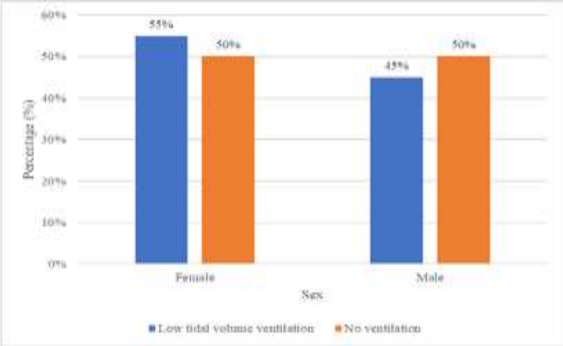

Figure 4: Distribution of Group with Gender.

Comparison of oxygen saturation between groups
In the LTVV group, mean SpO_2 decreased from 98.89 ± 1.5% preoperatively to 97.78 ± 1.14% intraoperatively and 96.78 ± 1.12% postoperatively. In the No Ventilation group, SpO_2 decreased from 99.10 ± 1.2% preoperatively to 97.85 ± 1.20% intraoperatively and 93.13 ± 1.9% postoperatively. There were no significant differences between groups preoperatively or intraoperatively ($p > 0.05$), but postoperative SpO_2 was significantly lower in the No Ventilation group ($p < 0.0001$), indicating a greater decline after surgery are shown in [Table 1].

Table 1: Comparison of oxygen saturation between groups

Group	SpO2 (mean±SD)		
	Preoperative	Intraoperative	Postoperative
LTVV	98.89±1.5	97.78±1.14	96.78±1.12
No ventilation	99.10±1.2	97.85±1.20	93.13±1.9
P-Value	>0.05	>0.05	<0.0001

Arterial Blood Gas Analysis (PaO_2)
Baseline preoperative PaO_2 values were comparable between the two groups. In the low tidal volume ventilation (LTVV) group, mean PaO_2 was 94.4 ± 3.54 mmHg, which showed a slight increase intraoperatively to 95.5 ± 4.13 mmHg, followed by a mild decline postoperatively to 93 ± 4.53 mmHg. In the no ventilation group, mean PaO_2 was 95 ± 4.7 mmHg preoperatively, decreased intraoperatively to 93.7 ± 4.2 mmHg, and further decreased postoperatively to 91.28 ± 4.73 mmHg.
Intergroup comparisons at all three time points (preoperative, intraoperative, and postoperative) revealed no statistically significant differences in PaO_2 values ($p > 0.05$). Overall, both ventilation strategies demonstrated similar oxygenation profiles throughout the perioperative period, with only minor within-group fluctuations observed. Detailed comparisons are presented in [Table 2].

Table 2: Comparison of ABG (PaO2) between groups.

Group	ABG (PaO2) (mean±SD)		
	Preoperative	Intraoperative	Postoperative
LTVV	94.4±3.54	95.5±4.13	93±4.53
No ventilation	95±4.7	93.7±4.2	91.28±4.73
P-Value	>0.05	>0.05	>0.05

Comparison of ABG (PaCO2) between groups: In the LTVV group, mean $PaCO_2$ was 39.84 ± 4.56 mmHg before the procedure, showed a slight increase to 40.2 ± 2.30 mmHg intraoperatively, and further rose to 40.7 ± 6.62 mmHg postoperatively. In the No Ventilation group, mean $PaCO_2$ was 40.12 ± 5.13 mmHg preoperatively, increased slightly to 40.81 ± 4.21 mmHg during surgery, and reached 41.38 ± 3.36 mmHg after surgery. At all measured time points, intergroup comparisons showed p-values > 0.05, indicating no statistically significant differences in $PaCO_2$ between the two groups are represented in [Table 3].

Table 3: Comparison of ABG (PaCO2) between groups.

Group	ABG (PaCO2) (mean±SD)		
	Preoperative	Intraoperative	Postoperative
LTVV	39.84±4.56	40.2±2.30	40.7±6.62
No ventilation	40.12±5.13	40.81±4.21	41.38±3.36
P-Value	>0.05	>0.05	>0.05

Comparison of extubation time: The mean extubation time in the LTVV group was 150 minutes (SD = 36.86), which was shorter than that of the no ventilation group (160 minutes, SD = 42.15). However, this difference was not statistically significant ($p = 0.1894$). A comparison of extubation times between the two groups is presented in [Table 4].

Table 4: Comparison of extubation time between groups.

Group	Extubation Time (Min)		P-Value
	Mean	SD	
LTVV	150	36.86	0.1894
No ventilation	160	42.15	

Comparison of Duration of ICU Stay: The mean duration of ICU stay was lower in the LTVV group (60.0 ± 20.22 hours) compared with the non-ventilated group (70.9 ± 43.46 hours). However, the difference did not reach statistical significance (P = 0.1544). The comparison is shown in [Table 5].

Table 5: Comparison of ICU stay between groups.

Group	ICU Stay (Hr)		P-Value
	Mean	SD	
LTVV	60	20.22	0.1544
No ventilation	70.9	43.46	

Comparison of duration of hospital stay: The mean duration of hospital stay was 8.6 ± 1.86 days in the LTVV group and 10.38 ± 2.02 days in the non-ventilated group. Patients in the LTVV group experienced a significantly shorter hospital stay compared with those in the non-ventilated group (P = 0.0001) [Table 6].

Table 6: Comparison of duration of hospital stay

Group	Hospital Stay (Day)		P-Value
	Mean	SD	
LTVV	8.6	1.86	0.0001
No ventilation	10.38	2.02	

Distribution of Group with Postoperative Basal Atelectasis: Postoperative basal atelectasis was observed in 4 participants (10%) in the LTVV group and 10 participants (25%) in the No Ventilation group. The majority of participants remained free from basal atelectasis in both groups, accounting for 36 (90%) and 30 (75%) participants in the LTVV and No Ventilation groups, respectively. Figure 3 illustrate the distribution of postoperative basal atelectasis between the two study groups. [Figure 5]

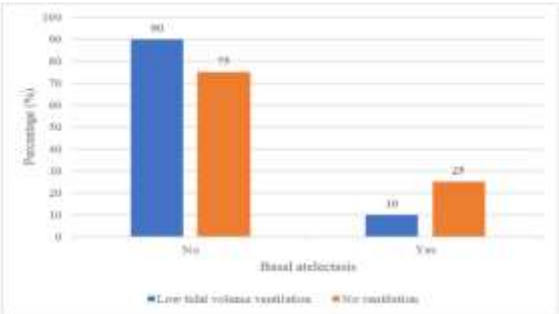

Figure 5: Distribution of Group with Postoperative Basal Atelectasis.

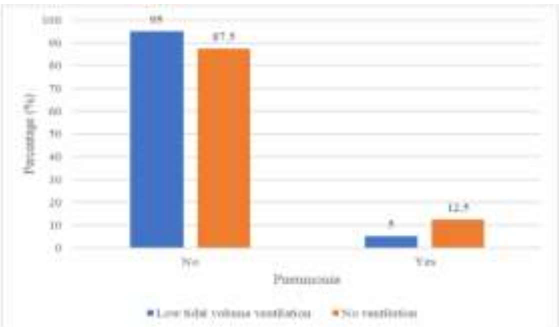

Figure 6: Distribution of Group with postoperative pneumonia

Distribution of Group with postoperative pneumonia: In the LTVV group, 38 participants (95.0%) did not develop postoperative pneumonia, while 2 participants (5.0%) developed pneumonia. In comparison, 35 participants (87.5%) in the No Ventilation group remained free of pneumonia, whereas 5 participants (12.5%) developed the condition. The distribution of postoperative pneumonia among study participants is presented in [Figure 6].

DISCUSSION

The present study demonstrates the beneficial effects of low tidal volume ventilation (LTVV) during cardiopulmonary bypass (CPB) on postoperative respiratory outcomes in adult cardiac surgical patients. Since both groups were comparable in terms of age and gender distribution, the observed differences can be attributed to the ventilation strategy employed during CPB.

A key finding was the significantly higher postoperative oxygen saturation in the LTVV group, indicating better preservation of pulmonary function and oxygenation following surgery. Although arterial blood gas parameters (PaO_2 and $PaCO_2$) did not differ significantly between groups, the improved oxygen saturation suggests enhanced overall respiratory performance in patients receiving LTVV. These findings are consistent with previous studies that reported improved pulmonary perfusion and oxygenation with ventilation during CPB.[20,21]

Patients in the LTVV group also showed trends toward earlier extubation and shorter ICU stay, along with a significantly reduced hospital stay. These findings suggest faster postoperative recovery and more efficient utilization of healthcare resources. Similar observations have been reported in previous studies.[17,19–22]

Importantly, the incidence of postoperative pulmonary complications, particularly basal atelectasis and pneumonia, was lower in the LTVV group. This supports the lung-protective effect of maintaining ventilation during CPB and highlights its role in reducing postoperative respiratory morbidity.

Comparable findings have been reported by Zhang et al., although some studies have shown conflicting results, possibly due to differences in ventilation protocols and oxygen concentrations used during CPB.[23–24]

Overall, the findings of this study emphasize that LTVV during CPB is associated with improved postoperative oxygenation, fewer pulmonary complications, and enhanced recovery. These results support the use of LTVV as a simple and effective lung-protective strategy in adult cardiac surgery.

CONCLUSION

This study evaluated the effects of low tidal volume ventilation (LTVV) compared with no ventilation during cardiopulmonary bypass (CPB) on postoperative respiratory outcomes in adult cardiac surgery patients. The findings showed that LTVV significantly improved postoperative oxygen saturation (SpO_2) and reduced extubation time. Patients receiving LTVV also had a lower incidence of postoperative pulmonary complications, including basal atelectasis and pneumonia. In addition, the LTVV group experienced shorter ICU and hospital stays, indicating enhanced recovery and potential cost savings. Arterial blood gas analysis showed no significant differences in PaO_2 and $PaCO_2$ levels between the two groups. Despite this, LTVV was associated with better overall postoperative respiratory function and clinical outcomes. These results support the use of LTVV during CPB as an effective strategy to improve postoperative recovery in cardiac surgical patients. The implementation of this ventilation approach may contribute to improved patient care and more efficient use of healthcare resources. Further multicenter studies with larger sample sizes are needed to confirm these findings and assess the long-term benefits of LTVV.

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