COMPARISON OF THE EFFECT OF PRESSURE CONTROLLED VENTILATION AND VOLUME CONTROLLED VENTILATION ON THE DEGREE OF PERIOPERATIVE ATELECTASIS IN ADULTS UNDERGOING LAPAROSCOPIC SURGERY WITH GENERAL ANAESTHESIA USING MODIFIED LUNG ULTRASOUND SCORE – A COMPARATIVE RANDOMISED PROSPECTIVE OBSERVATIONAL TRIAL

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Abstract

Introduction: Perioperative atelectasis, a common complication of general anesthesia, particularly in laparoscopic surgeries, was investigated in this study. This research aimed to assess the impact of Volume Controlled Ventilation (VCV) and Pressure Controlled Ventilation (PCV) on perioperative atelectasis in individuals undergoing elective laparoscopic surgery under general anesthesia (GA). **Methodology:** In this comparative randomized prospective observational trial, thirty participants were assigned to each of the two groups. Patients undergoing elective laparoscopic surgery under GA were randomly assigned to either the VCV or PCV group. The evaluation of perioperative atelectasis was conducted using the Modified Lung Ultrasound Score (LUS) **Result:** Significant differences were observed between the PCV and VCV groups in preventing the development of atelectasis. Notably, the mean difference in total lung ultrasonography scores at different time points was significant: PCV had a mean difference of 0.333 ($p = 0.001$), whereas VCV had a mean difference of 0.3333 ($p = 0.001$). Moreover, both PCV and VCV showed statistically significant variations across different time periods in the comparison of the median values of LUS in dependent lung quadrants. In the PCV group, significant improvements in lung function were evident ($p < 0.05$). **Conclusion:** In the context of reducing perioperative atelectasis during laparoscopic surgery performed under general anesthesia as evaluated by modified lung ultrasound scores, PCV emerges as the superior option compared to VCV.

Keywords: Atelectasis, Laparoscopic Surgery, Ventilation Strategies, Lung Ultrasound Score.

INTRODUCTION

A major problem in the field of surgical interventions is perioperative atelectasis, which is the partial or total collapse of lung tissue, especially in elective laparoscopic operations performed under general anaesthesia (GA) [1]. Even with improvements in anaesthesia care and surgical methods, atelectasis is still a common side effect that can result in poor gas exchange, lung problems after surgery, and extended hospital stays [2]. In addressing this challenge, mechanical ventilation strategies play a pivotal role in optimizing respiratory function and mitigating the risk of atelectasis formation.

The two most common mechanical ventilation modalities used in surgical settings are Volume Controlled Ventilation (VCV) and the other is Pressure Controlled Ventilation (PCV)[3]. PCV delivers breaths at a constant pressure, adjusting tidal volume based on lung compliance and airway resistance, while VCV administers breaths at a set tidal volume, modulating pressure to maintain this volume [4]. Both ventilation modes aim to provide adequate oxygenation and ventilation while minimizing the risk of complications associated with atelectasis.

Compared to open procedures, elective laparoscopic surgeries have become more popular because they need less recovery time and require less surgical trauma. They also require fewer hospital admissions. Nevertheless, in spite of these benefits, there are particular difficulties with gas exchange and ventilation during laparoscopic surgery. Pneumoperitoneum establishment, which is necessary for laparoscopic visualisation and manipulation, can put patients at risk for developing atelectasis by raising intra-abdominal pressure, reducing diaphragmatic excursion, and impairing lung mechanics [5-6].

Given the clinical significance of perioperative atelectasis and the prevalence of laparoscopic procedures, it is imperative to evaluate the comparative efficacy of mechanical ventilation strategies in mitigating atelectasis during elective laparoscopic surgery under GA. By utilizing the Modified Lung Ultrasound Score (LUS) as an objective evaluation tool, this study compares the effects of PCV and VCV upon perioperative atelectasis in an attempt to close this knowledge gap.The Modified LUS offers a comprehensive and non-invasive method for assessing lung aeration and detecting atelectasis [7]. LUS assessment, analyzing parameters like lung sliding, B-lines, consolidation, and pleural effusion, offers real-time insights into atelectasis during the perioperative period.

METHODOLOGY

The study employed a comparative randomized prospective observational design to evaluate the impact of VCV and PCV on perioperative atelectasis in individuals undergoing elective laparoscopic surgery under GA. This study was performed in a teritiary care institute in kancheepuram district, Tamilnadu, India from July 2023 to February 2024. Randomization was used to reduce bias. The observational component made it easier to evaluate actual clinical procedures and results. The primary material required was ultrasound equipment for lung ultrasound assessments. This non-invasive method allowed for evaluating lung aeration and detecting atelectasis during laparoscopic surgery under GA, providing clinicians with valuable insights into respiratory function.

The study's outcome measure was the utilization of Modified Lung Ultrasound score to evaluate the incidence of perioperative lung atelectasis in comparison between PCV and VCV. The secondary outcomes were Lung ultrasound assessments, conducted at multiple time points, served as a tool for detecting changes in lung aeration and identifying atelectasis areas. Lung Ultrasound Score (LUS) quantified atelectasis degree and assessed its impact on perioperative respiratory function.

Inclusion criteria were adults aged 18-60, classified under ASA classifications I and II, of both genders, undergoing elective lower abdominal and gynecologic laparoscopic surgery under GA. Exclusions were hepatic disease, renal insufficiency, history of thoracic surgery, BMI >35kg/m2, severe COPD, and diaphragmatic paralysis.

Sixty individuals undergoing elective laparoscopic surgery under general anesthesia (GA) were randomly divided into two groups: thirty assigned to the Pressure Controlled Ventilation group and thirty to the Volume Controlled Ventilation group. Participants were randomly assigned to groups using computer-generated randomization. Allocation was concealed until after anesthesia induction. Anesthesiologists managed anesthesia and conducted lung ultrasound assessments, while a radiologist scored ultrasounds. Blinding was maintained as only the anesthesiologist overseeing anesthesia induction and pulmonary ultrasound was informed about the group assignments.

The hemithorax was divided into the upper and lower zones with two vertical lines drawn on the anterior axillary line and posterior axillary line, and one horizontal line drawn at mid mammary line across the nipples as depicted in Figure 1A. The ultrasonic probe was positioned perpendicular to the ribs to demonstrate the "bat sign view," and subsequently and was rotated parallel to the ribs to obtain a wider pulmonary view as displayed in Figure 1B. The image with the greatest loss of ventilation was captured after scanning each intercostal space in the area for investigation. The final lung ultrasound image, as depicted in Figure 1C, was obtained and used to evaluate any aeration loss. Each area's score for the lack of ventilation was recorded, and each patient's overall score was calculated. According to the degree of atelectasis, each location was given a score between 0 and 3, as presented in Figure 2. The overall score for the 12 areas ranged from 0 (no loss of aeration) to 36 (complete loss of aeration).

Comprehensive data collection gathered baseline demographic data and Modified Lung Ultrasound Score (LUS) assessments at three time points: pre-induction (T1), after intubation (T2), Before extubation (T3) and One hour after extubation (T4) postoperatively in recovery. Trained personnel conducted assessments following standardized protocols for consistency.

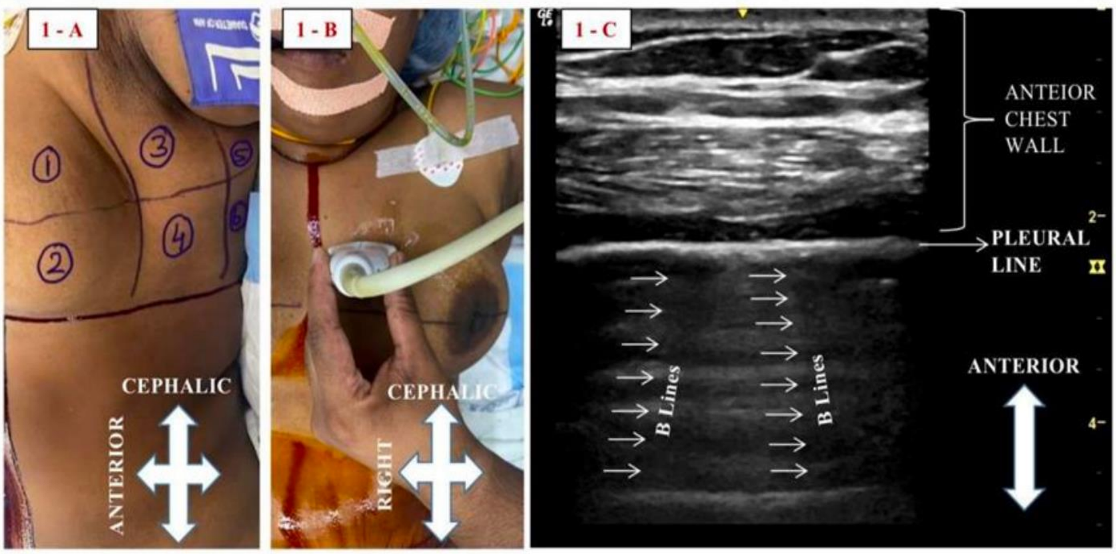

Figure 1: A) Six areas for scanning in patient's hemithorax, B) Final Ultrasound probe position, and C) Lung Ultrasound images obtained for LUS assessment (white arrows depicts the vertical B lines)

Score	Aeration	Findings
0	Normal aeration	0-2 B lines
1	Small loss of aeration	B lines > 3 or 1 or more multiple subpleural consolidations separated by a normal pleural line
2	Moderate loss of aeration	Multiple coalescent B lines or multiple small subpleural consolidations separated by a thickened or irregular pleural line
3	Severe loss of aeration	Consolidation or small subpleural consolidations of > 1*2 cm in diameter

Figure 2: Modified lung ultrasound scoring system

Data analysis was done using SPSS software, data analysis used descriptive statistics to compare mean LUS scores across PCV and VCV groups to summarize demographic information. Statistical significance was determined using t-tests and Mann-Whitney U tests to compare continuous variables between groups. A significance level of $p < 0.05$ was applied to assess the results.

RESULTS

In this study, a total of 60 adult patients undergoing elective laparoscopic surgery under general anesthesia were included, with equal distribution into two ventilation mode groups: Pressure Controlled Ventilation (PCV) and Volume Controlled Ventilation (VCV). Table 1 provides a comprehensive overview of the demographic characteristics of the participants enrolled in the study.

Descriptive statistics including Sex, ASA grading, mean age, height, weight, BMI, and surgery time are provided for both groups. These parameters offer valuable insights into the baseline characteristics of the study population, facilitating comparisons between groups and identifying potential confounding factors.

Table 1: Demographic characteristics

Demographic features	Pressure Controlled Ventilation : Group A	Volume Controlled Ventilation : Group B
Sex		
Female (%)	20 (66.7%)	26 (86.7%)
Male (%)	10 (33.3%)	4 (13.3%)
ASA Classification		
I (%)	20 (66.7%)	13 (43.3%)
II (%)	8 (26.7%)	6 (20.0%)
III (%)	2 (6.7%)	11 (36.7%)
Descriptive Statistics		
Age in years (Mean ± SD)	43.8 ±15.1	49.2 ± 18.5
Height in cm (Mean ± SD)	155.4 ± 7.9	151.4 ± 10.9
Weight in kg (Mean ± SD)	59.3 ± 9.8	60.8 ± 15.4
BMI (Mean ± SD)	24.6 ± 4.5	26.9 ± 7.1
Surgery Time in minutes (Mean ± SD)	65.5 ± 5.9	56.9 ± 5.0

The difference in Median values of LUS was observed only in the dependent lung quadrants (R5, R6, L5 and L6) and rest all of the quadrants were comparable. Hence, only the changes in the dependent quadrants enumerated in both the groups.

Median values of Lung ultrasound scores in the dependent lung quadrants at different time points for the PCV group are summarized in Table 2. Table 2 suggests a significant improvement in lung ultrasound scores from Total T1 to Total T4

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Table 2: Median values of LUS in dependent lung quadrants at different time periods in Group PCV

Time Period	R5		R6		L5		L6	
	Z-value	P-value	Z-value	P-value	Z-value	P-value	Z-value	P-value
T1-T2	-2.408	0.023	-1.000	0.326	2.112	0.043	-2.693	0.012
T1-T3	-14.617	0.000	-7.077	0.000	-4.709	0.000	-7.616	0.000
T1-T4	-8.968	0.000	-7.077	0.000	-2.971	0.006	-5.757	0.000
T2-T3	-10.500	0.000	-4.287	0.000	-6.158	0.000	-5.037	0.000
T2-T4	-8.449	0.000	-7.077	0.000	-2.971	0.006	-5.757	0.000
T3-T4	3.500	0.002	0.194	0.739	2.112	0.043	3.808	0.001

The statistical parameters in Table 3—mean difference, standard error, Z-value, and p-value—highlight the significance of changes in lung ultrasound scores over time within the PCV group. Table 2 and 3 suggests reduced severity of atelectasis over time following pressure-controlled ventilation.

Table 3: Mean difference in Lung ultrasound scores in comparison with different time periods in Group PCV

Time Period	Mean Difference	Std. Error	Time Period Z	p-value
Total T2 – Total T1	0.333	0.1938	1.720	0.096
Total T3 – Total T1	1.900	0.1300	14.617	0.000
Total T4 – Total T1	1.400	0.1561	8.968	0.000
Total T3 – Total T2	1.5667	0.1492	10.500	0.000
Total T4 – Total T2	1.0667	0.1262	8.449	0.000
Total T4 – Total T3	0.4667	0.1333	3.500	0.002

Table 4 and Table 5 presents the Median values of lung ultrasound scores and total lung ultrasound scores respectively, for the VCV group. Comparisons between different time periods demonstrate the impact of VCV on severity of perioperative lung atelectasis.

It depicts the limited efficacy of VCV in reducing perioperative atelectasis severity compared to PCV. However, despite these improvements, VCV consistently yielded inferior outcomes compared to PCV, as evidenced by higher total lung ultrasound scores and median values of lung ultrasound scores in the VCV group.

Table 4: Median values of LUS in dependent lung quadrants at different time periods (VCV)

Time Period	R5		R6		L5		L6	
	Z-value	P-value	Z-value	P-value	Z-value	P-value	Z-value	P-value
T1-T2	-3.808	0.001	-16.16	0	-0.333	0.009	-13.73	0
T1-T3	-3.808	0.001	-6.158	0	-8.7640	0	-16.16	0
T1-T4	-6.158	0.000	-16.16	0	-10.77	0	-13.73	0
T2-T3	-3.808	0.001	-9.932	0	-6.595	0	-16.16	0
T2-T4	-6.158	0.000	-16.16	0	-5.037	0	-13.73	0
T3-T4	3.808	0.001	6.158	0	8.764	0	16.155	0

Table 5: Total lung ultrasound scores in comparison with different time periods (VCV)

Time Period	Mean Difference	Standard Error	Time Period Z	p-value
TotalT2 - TotalT1	0.3333	0.0875	3.808	0.001
TotalT3 - TotalT1	3.7000	0.1282	28.860	0.000
TotalT4 - TotalT1	3.2333	0.1413	22.885	0.000
TotalT3 - TotalT2	3.3667	0.0895	37.622	0.000
TotalT4 - TotalT2	2.9000	0.1385	20.931	0.000
TotalT4 - TotalT3	-0.4667	0.1333	-3.500	0.002

The statistical analyses revealed significant improvements in lung ultrasound scores following pressure-controlled ventilation, as evidenced by lower mean differences, higher Z-values, and smaller p-values compared to VCV. These findings suggest that PCV effectively reduces the severity of perioperative atelectasis and enhances lung function during the intraoperative and postoperative periods.

DISCUSSION

The superior efficacy of PCV in mitigating perioperative atelectasis can be attributed to several underlying mechanisms inherent to this ventilation mode. PCV allows for precise control over inspiratory pressure, tidal volume, and respiratory rate, thereby optimizing lung recruitment and ventilation-perfusion matching. During PCV, the ventilator delivers a preset inspiratory pressure, ensuring consistent tidal volumes regardless of changes in lung compliance or airway resistance. This constant pressure helps maintain adequate alveolar ventilation and prevents alveolar collapse, thereby reducing the risk of atelectasis formation. Moreover, the decelerating flow pattern characteristic of PCV promotes more uniform distribution of ventilation throughout the lungs, minimizing the occurrence of regional hypoventilation and improving gas exchange efficiency. Additionally, the pressure-controlled nature of ventilation minimizes the risk of barotrauma and volutrauma, making PCV a safer option, particularly in patients with compromised pulmonary function.

The findings of this study have significant clinical implications for anesthesia management and perioperative care. Given the demonstrated superiority of PCV in mitigating perioperative atelectasis, anesthesiologists and perioperative teams should consider prioritizing PCV over VCV, particularly in patients undergoing laparoscopic surgery. Optimal ventilation strategies play a crucial role in preventing postoperative pulmonary complications, such as atelectasis, pneumonia, and respiratory failure, which can significantly impact patient outcomes and length of hospital stay. By selecting ventilation modes that optimize lung recruitment and minimize atelectasis formation, clinicians can reduce the incidence of postoperative respiratory complications and enhance patient recovery.

Furthermore, these findings underscore the importance of individualized ventilation strategies tailored to patient characteristics, surgical procedures, and intraoperative factors. While PCV may offer advantages in certain patient populations, such as those with reduced lung compliance or at increased risk of atelectasis, the selection of ventilation mode should be guided by a comprehensive assessment of patient physiology and clinical context. The management of atelectasis during general anesthesia, particularly in laparoscopic surgeries, has been extensively investigated in recent years. Various ventilation strategies have been explored to mitigate atelectasis and its associated complications. Here, we discuss the findings of studies focusing on different ventilation approaches and their impact on perioperative atelectasis.

The study conducted by kim et al, examined the effects of low (0.4) versus high (1.0) fraction of inspired oxygen (FIO2) following alveolar recruitment maneuvers (RM) in laparoscopic surgery patients. Their findings revealed that high FIO2 during RM was associated with increased postoperative atelectasis without enhancing oxygenation, indicating a possible advantage of using lower FIO2 to prevent atelectasis[8]. In the study conducted by Liu et al, combining recruitment maneuvers (RM) and positive end-expiratory pressure (PEEP) reduced atelectasis incidence 15 minutes post-admission to the post-anesthesia care unit (PACU). However, this effect dissipated 24 hours post-surgery, indicating the need for further investigation into its long-term implications[9]. In the study conducted by Jeong et al, pressure support ventilation during emergence reduced the incidence of postoperative atelectasis when compared to intermittent manual assistance. Additionally, the pressure support group patients in the PACU had higher PaO2 levels, indicating improved oxygenation[10].

The study conducted by Devaraj et al, investigated the efficacy of compliance-based PEEP optimization in reducing postoperative lung atelectasis in laparoscopic gynaecological procedures. Their findings revealed that tailoring PEEP according to lung compliance substantially decreased surgical atelectasis, leading to improved outcomes by reducing the need for postoperative oxygen supplementation and shortening the duration of oxygen therapy[11].Another study done by Nair et al, explored PEEP's impact on atelectasis in patients undergoing major upper abdominal surgery under general anesthesia. The results indicated that even a minimal PEEP of 5 cm H2O significantly decreased the overall modified lung ultrasonography score after more than two hours of operation, suggesting that PEEP aids in enhancing lung aeration and reducing atelectasis[12].

The study conducted by Xie et al, investigated the viability of utilizing these methods to assess aeration loss and perioperative atelectasis during video-assisted thoracic surgery. Their findings suggest that lung ultrasonography is feasible throughout the perioperative period and aids in early detection of atelectasis. Moreover, evaluating diaphragmatic excursion aligns with changes in lung aeration, providing a comprehensive approach to assessing lung function during surgery[13].

This research sheds light on the management of perioperative atelectasis in laparoscopic surgery, suggesting that Pressure Controlled Ventilation (PCV) may offer advantages over Volume Controlled Ventilation (VCV). While further investigation is needed to establish the optimal ventilation strategy, lung ultrasonography scores prove valuable for early monitoring and intervention, leading to improved outcomes. Specifically, in patients undergoing laparoscopic surgery under general anesthesia, VCV shows superior performance in preventing atelectasis compared to PCV. These findings underscore the importance of selecting the appropriate ventilation technique to enhance perioperative respiratory function and patient outcomes.

This study had some limitations. First, ultrasound is an operator -dependent imaging modality. Hence, findings may vary based on observer. Second, ultrasound was used for diagnosing atelectasis, but it could not be compared with postoperative CT scan since it is not gold standard modality of investigation. Third, we followed up the patient until 1-hour postoperative period and could not evaluate the long-term results of PCV and VCV. Fourth, the criteria for substantial atelectasis were not yet established though many studies have used lung ultrasound as a diagnostic tool for atelectasis. Fifth, blood gases were not evaluated in this study rule out actual failure in oxygenation and ventilation

CONCLUSION

In the context of reducing perioperative atelectasis during laparoscopic surgery performed under general anesthesia as evaluated by modified lung ultrasound scores, PCV emerges as the superior option compared to VCV.

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Conflict of Interest:

The authors declare no conflicts of interest.

Informed Consent:

Informed consent was obtained from patient for the publication of their case details and associated images.

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