

## Original Research

# Perioperative Detection of Atelectasis Using Lung Ultrasound in Laparoscopic Surgeries: A Comparative Evaluation of PCV and VCV Modes

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## Abstract

**Background:** Perioperative atelectasis represents a common complication in patients undergoing laparoscopic surgeries under general anaesthesia (GA), potentially leading to decreased lung compliance, impaired gas exchange, and increased postoperative pulmonary complications. **Material and Methods:** This prospective single-blinded observational study enrolled 60 ASA I-II patients aged 18-60 years undergoing elective laparoscopic surgeries, allocated alternately into two groups of 30 each: Group 0 on volume-controlled ventilation (VCV) mode and Group 1 on pressure-controlled ventilation (PCV) mode intraoperatively. The primary objective was to determine significant lung atelectasis production in laparoscopic surgeries under GA, while the secondary objective compared PCV versus VCV effects on atelectasis extent. Lung ultrasound (LUS) scoring assessed aeration loss using a 0-3 scale per each of 6 quadrants (total LUS score 0-18), performed at three time points: preoperative (T1, pre-induction), five minutes post-induction (T2, post-intubation), and one-hour post-extubation (T3) in the postoperative room. A single anesthesiologist conducted all LUS examinations using a curvilinear probe (3-5 MHz) following a standardized 3-point protocol per hemithorax (upper anterior, lower anterior, posterolateral basal). **Results:** Baseline demographics were comparable: age (PCV 41.8±13 years vs VCV 43.4±12.4 years, p=0.620), gender (females 76.7% both, p=1.000), ASA class (p=0.791), BMI (24.8±2.2 vs 25.3±2.6 kg/m<sup>2</sup>, p=0.483), anesthesia duration (151.7±19.5 vs 156.7±22.9 min, p=0.366). Total LUS scores increased significantly within both groups from T1 to T3 (PCV Friedman  $\chi^2=48.274$ , p<0.001; VCV  $\chi^2=51.529$ , p<0.001), with mean ranks rising (PCV: T1 1.27 to T3 2.85; VCV: T1 1.2 to T3 2.9), confirming GA-induced atelectasis, predominantly basal. No intergroup LUS differences (T1 p=0.756; T2 p=0.784; T3 p=0.236, Mann-Whitney U). Vitals showed higher pulse rates in VCV early (T1 p=0.019; T2 p=0.003), normalizing at T3 (p=0.798); SBP, DBP, SpO<sub>2</sub> comparable. Post-extubation atelectasis incidence higher in VCV (26.7% vs 6.7%). **Conclusion:** LUS proved feasible, non-invasive, and reliable for real-time perioperative atelectasis tracking, correlating GA and pneumoperitoneum with aeration loss but revealing no PCV superiority over VCV. These findings emphasize LUS as a point-of-care tool for early detection and intervention guidance (e.g., recruitment maneuvers), particularly in pneumoperitoneum surgeries where basal collapse predominates. Study limitations include single-center design and exclusion of high-risk patients. Future research should evaluate PEEP optimization and long-term outcomes.

**Keywords:** Lung Ultrasound (LUS); Perioperative Atelectasis; General Anaesthesia; Pressure-Controlled Ventilation (PCV); Volume-Controlled Ventilation (VCV); Laparoscopic Surgery; Pneumoperitoneum; Ventilation Modes; Pulmonary Aeration; Point-of-Care Ultrasound (POCUS)

## Introduction

Perioperative atelectasis frequently complicates pneumoperitoneum surgeries under general anaesthesia (GA), driven by mechanical lung compression, intra-abdominal pressure elevations (12-15 mmHg), muscle relaxants, and diaphragmatic cephalad displacement, reducing functional residual capacity and promoting basal collapse.<sup>1</sup> This leads to ventilation-perfusion mismatch, hypoxemia, and heightened postoperative pulmonary risks, with incidence up to 90% in GA patients. Lung ultrasonography (LUS) has emerged as a non-invasive, radiation-free, bedside tool superior to chest X-ray for atelectasis assessment, detecting aeration loss via absent A-lines, B-lines, subpleural consolidations, and reduced lung sliding.

Ventilatory modes critically influence atelectasis: Volume-Controlled Ventilation (VCV) delivers fixed tidal volumes (6-8 mL/kg) but risks high peak pressures and barotrauma/volutrauma; Pressure-Controlled Ventilation (PCV) caps inspiratory pressures with decelerating flow for better homogeneity yet variable tidal volumes. Prior thesis-cited studies highlight this: Patel et al. observed LUS score rises post-induction/pneumoperitoneum in laparoscopic cholecystectomies, correlating with anesthesia duration.<sup>2</sup> Lee et al. found no atelectasis reduction with PCV-volume guaranteed versus VCV in Trendelenburg pneumoperitoneum.<sup>1</sup> Hassan et al. reported equivalent postoperative atelectasis in upper abdominal laparotomies.<sup>3</sup> Bansal S et al. confirmed early perioperative atelectasis in cholecystectomies, positively correlating with age/ASA status.<sup>4</sup> Cho et al. showed low tidal volume equivalence to conventional in open abdominal surgeries.<sup>5</sup>

LUS fundamentals underpin its utility: piezoelectric transducers convert electrical to mechanical waves, generating B-mode images of pleural lines, A-lines (normal aeration), B-lines (interstitial fluid), and M-mode seashore signs (lung sliding). Atelectasis manifests as hepatization, shred signs, static bronchograms. Scoring (0=normal; 1= $\geq$ 3 B-lines; 2=consolidation; 3=hepatization) quantifies loss across 6-12 zones. This study fills gaps by directly comparing PCV/VCV in standardized laparoscopic cohorts, aiming to guide mode selection and interventions like recruitment for optimal aeration.

**Materials and Methods**

**Study Design and Setting**

A prospective single-blinded observational study conducted after institutional ethical committee approval. Informed written consent obtained from all participants. Single anesthesiologist performed LUS blinded to ventilator mode.

**Study period:** August 2024 to March 2025

**Inclusion and Exclusion Criteria**

**Inclusion:** Age 18-60 years, ASA I-II, elective laparoscopic surgeries under GA, valid consent. **Exclusion:** ASA III-IV, severe COPD/asthma, diaphragmatic paralysis, pneumothorax history, refusal.

**Sample Size Calculation**

Calculated for mean LUS estimation: prior  $\mu=3.5$ ,  $SD=1.5$ ; 99% confidence, 0.5 margin error  $\rightarrow n=60$  minimum. Analyzed via SPSS v22.

**Patient Allocation and Groups**

60 patients alternately allocated: Group 0 (n=30, VCV: tidal volume 6-8 mL/kg IBW, RR 12-16/min, FiO2 0.4-0.6, PEEP 5 cmH2O); Group 1 (n=30, PCV: pressure targeting same tidal volume, identical RR/FiO2/PEEP).

**Anesthesia Protocol**

Premedication: midazolam 0.02 mg/kg IV. Preoxygenation 3 min. Induction: propofol 2 mg/kg, fentanyl 2 mcg/kg, rocuronium 0.6 mg/kg. Intubation, maintenance: isoflurane 1 MAC. Pneumoperitoneum: 12-15 mmHg CO2. Analgesia: fentanyl boluses. Reversal: neostigmine/glycopyrrolate.

**Lung Ultrasound Protocol**

Curvilinear probe (3-5 MHz). 3-point exam/hemithorax: upper anterior (middle/ring finger base), lower anterior (palm near nipple), posterolateral basal (posterior axillary line). 6 quadrants total, scored 0-3: 0=A-lines/lung sliding; 1= $\geq$ 3 B-lines; 2=subpleural consolidation; 3=hepatization/diaphragm abolition. Total LUS=sum (0-18). Time points: T1 pre-induction; T2 5 min post-intubation; T3 1h post-extubation.

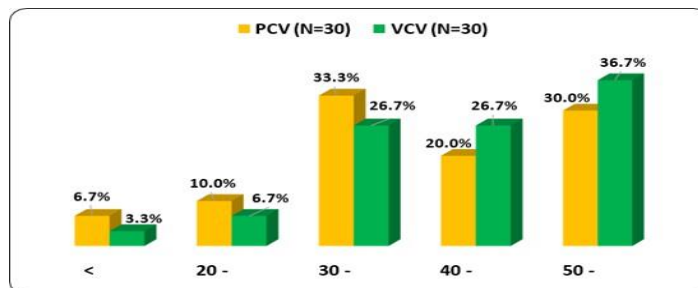
**Data Collection and Statistical Analysis**

Demographics, vitals (pulse, SBP, DBP, SpO2), ventilator parameters recorded. Categorical: frequencies, chi-square. Continuous: mean $\pm$ SD, independent t-test. Intragroup LUS: Friedman/post-hoc Bonferroni. Intergroup: Mann-Whitney U.  $p<0.05$  significant.

**Results**

60 patients of either gender, aged between 18-60 years of American Society of Anesthesiologists grade I and II undergoing laparoscopic surgeries who satisfied all the inclusion and the exclusion criteria were included in the study.

After institutional ethical committee approval, informed written valid consent was obtained from the patients/patient attenders involved in study and lung ultrasound scoring was done to assess the degree of atelectasis in both groups by performing lung ultrasound.

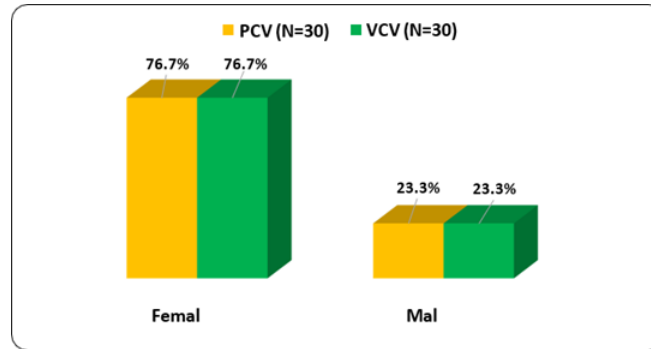


Graph 1: Age wise distribution of study participants

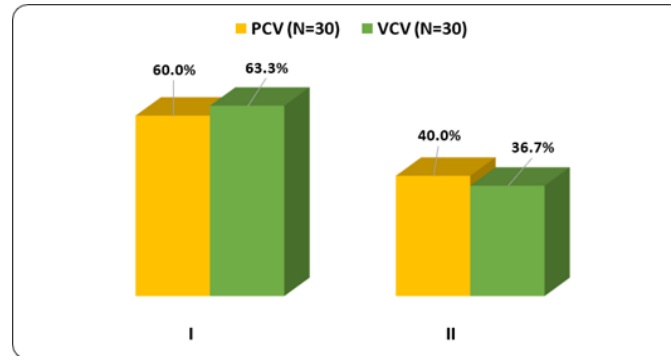
Table 1: Basic characteristics of study participants

Study Parameters		PCV (N=30) n (%)	VCV(N=30) n (%)	Total (N=60) n (%)
Age (Years)	< 20	2 (6.7)	1 (3.3)	$X^2 = 1.241$ with $p = 0.871$
	20 - 30	3 (10.0)	2 (6.7)	
	30 - 40	10 (33.3)	8 (26.7)	
	40 - 50	6 (20.0)	8 (26.7)	
	50 - 60	9 (30.0)	11 (36.7)	
	Mean $\pm$ Sd	41.8 $\pm$ 13	43.4 $\pm$ 12.4	$t = -0.498$ with $p = 0.620$
Gender	Female	23 (76.7)	23 (76.7)	$X^2 = 0.00$ with $p = 1.000$
	Male	7 (23.3)	7 (23.3)	
ASA class	I	18 (60.0)	19 (63.3)	$X^2 = 0.071$ with $p = 0.791$
	II	12 (40.0)	11 (36.7)	
BMI (Kg/m <sup>2</sup> )	Normal (18.5 - 24.9)	18 (60.0)	15 (50.0)	$X^2 = 0.773$ with $p = 0.680$
	Over weight (25.0 - 29.9)	11 (36.7)	13 (43.3)	
	Obese (30.0 - 35.0)	1 (3.3)	2 (6.7)	
	Mean $\pm$ Sd	24.8 $\pm$ 2.2	25.3 $\pm$ 2.6	$t = -0.706$ with $p = 0.483$
Duration of	Mean $\pm$ Sd	151.7 $\pm$ 19.5	156.7 $\pm$ 22.9	$t = -0.911$ with $p =$

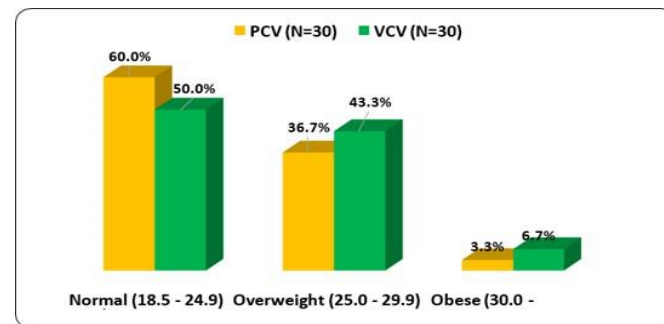
anesthesia (mins)	Range	120 - 200	105 - 200	0.366
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Graph 2: Gender wise distribution of study participants



Graph 3: ASA classification of study participants



Graph 4: BMI wise distribution of study participants

Table 2: Comparison of LUS within a group

		PCV	VCV
Mean Ranks	T1 (Pre-Induction)	1.27	1.2
	T2 (Post Intubation)	1.88	1.9
	T3 (Post Extubation)	2.85	2.9
$\chi^2$ (df=2)		48.274	51.529
p-value		< 0.001*	< 0.001*

\*Significant difference at  $p \leq 0.05$ , p-value for significance calculated using Friedman test

Table 3: Vitals at different time points

Study Parameters		PCV (N=30) Mean $\pm$ Sd	VCV (N=30) Mean $\pm$ Sd	Significance
Pulse Rate (Beats/min)	T1 (Pre-Induction)	78.5 $\pm$ 8.2	85.1 $\pm$ 12.7	0.019*
	T2 (Post Intubation)	82.8 $\pm$ 8.4	91.4 $\pm$ 12.6	0.003*
	T3 (Post Extubation)	92.3 $\pm$ 7.9	91.7 $\pm$ 10.1	0.798
SBP (mmHg)	T1 (Pre-Induction)	125 $\pm$ 11.4	125.3 $\pm$ 12.5	0.923
	T2 (Post Intubation)	119 $\pm$ 12.1	124.3 $\pm$ 13.0	0.107
	T3 (Post Extubation)	130.7 $\pm$ 7.9	131.3 $\pm$ 10.7	0.785
DBP (mmHg)	T1 (Pre-Induction)	78.7 $\pm$ 7.3	78.7 $\pm$ 6.8	1.000
	T2 (Post Intubation)	75.7 $\pm$ 9.0	77.7 $\pm$ 7.3	0.347
	T3 (Post Extubation)	81.3 $\pm$ 8.2	82 $\pm$ 8.1	0.752
SPO2 (%)	T1 (Pre-Induction)	98.3 $\pm$ 0.9	97.9 $\pm$ 0.9	0.177
	T2 (Post Intubation)	98.7 $\pm$ 0.8	98.6 $\pm$ 0.6	0.580
	T3 (Post Extubation)	96.8 $\pm$ 1.3	96.4 $\pm$ 1.1	0.162

\*Significant difference at  $p \leq 0.05$ , p-value for significance calculated using t-test

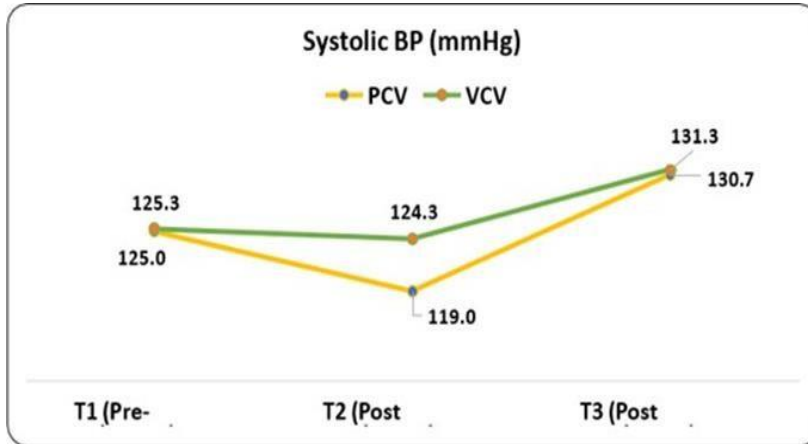
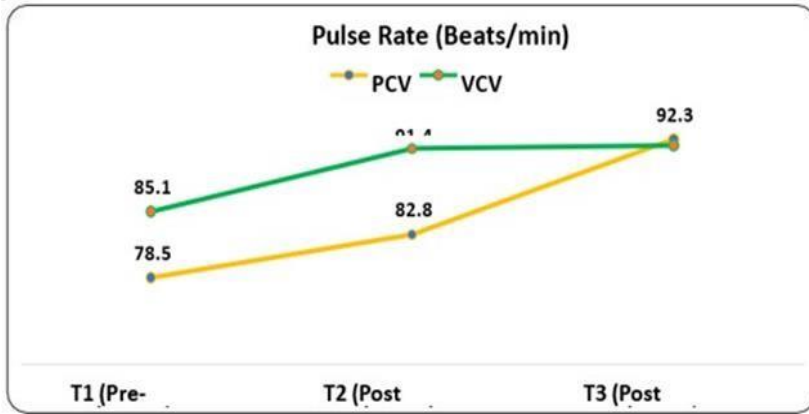
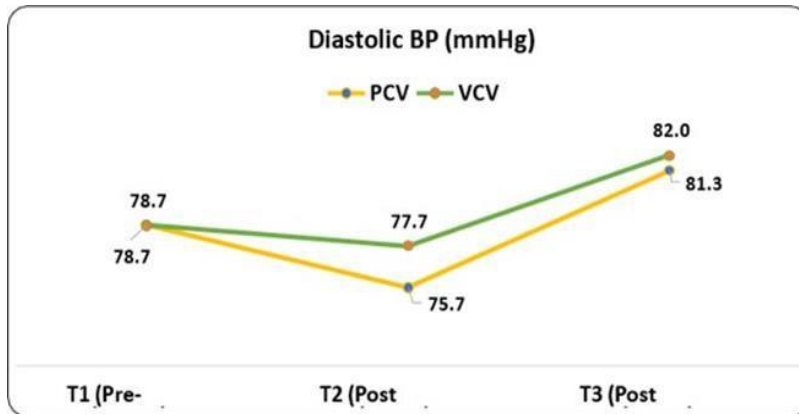
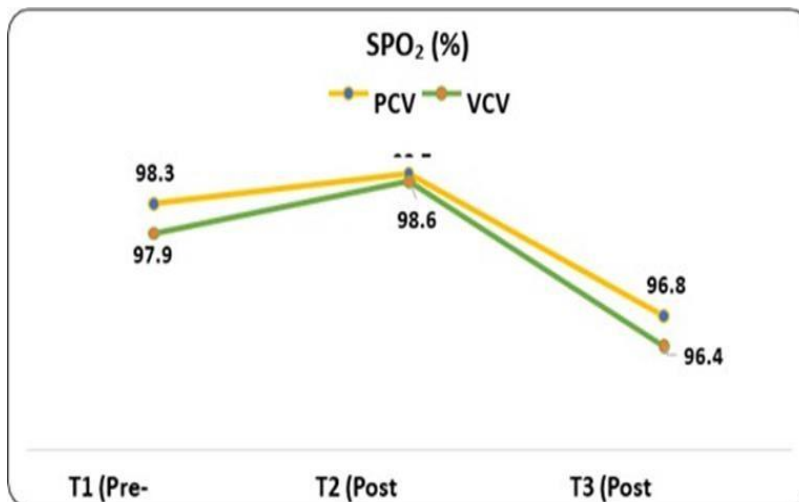


Figure 2



Graph 5,6,7 – Pulse rate, SBP, DBP at different time points



Graph 8: Spo2 at different time points

**Table 4: Post-Extubation Atelectasis Incidence**

Group	Atelectasis n(%)	No Atelectasis n(%)
PCV	2 (6.7)	28 (93.3)
VCV	8 (26.7)	22 (73.3)

## Discussion

Lung atelectasis is a common and well-recognized complication during general anaesthesia that requires diligent monitoring by anaesthetists. Early diagnosis and timely management play a critical role in preventing perioperative hypoxemia and pulmonary complications. Furthermore, identifying risk factors for atelectasis enables closer surveillance and more effective perioperative respiratory care for vulnerable patients.<sup>2</sup>

In recent years, laparoscopic surgery has increasingly replaced open techniques because it is associated with less incisional pain, fewer pulmonary complications, and shorter hospital stays. Despite these advantages, pneumoperitoneum can significantly decrease pulmonary compliance due to cephalad displacement of the diaphragm. This upward shift leads to intraoperative lung volume reduction and increases the risk of atelectasis formation. Consequently, early detection of atelectasis and the development of preventive ventilation strategies remain essential goals in modern perioperative care.<sup>1</sup>

The present study was designed to evaluate the association between general anaesthesia and perioperative atelectasis during laparoscopic surgeries and to determine whether pressure-controlled ventilation (PCV) or volume-controlled ventilation (VCV) is associated with a lower degree of lung aeration loss.

### Correlation Between General Anaesthesia and Perioperative Atelectasis

Our findings demonstrated that laparoscopic surgeries performed under general anaesthesia resulted in a significant degree of atelectasis, reflected by the marked increase in lung ultrasound scores (LUS) from the preoperative to postoperative period. This highlights the strong association between anaesthesia, pneumoperitoneum, and deterioration in lung aeration.

The study by Shailendra K. Patel et al.<sup>2</sup> supports these findings by demonstrating that lung ultrasonography (LUS) is a valuable tool for detecting intraoperative atelectasis and assessing perioperative lung aeration changes. Their results revealed a significant increase in LUS scores following induction of general anaesthesia, with further deterioration after pneumoperitoneum creation, especially in dependent lung zones. Longer pneumoperitoneum duration and prolonged anaesthesia were associated with greater aeration loss. Moreover, higher ASA grades correlated with increased LUS scores, suggesting a greater likelihood of postoperative pulmonary complications. The study reinforces the utility of LUS for perioperative monitoring, predicting oxygenation impairment, and guiding individualized ventilation to minimize atelectasis-related morbidity.

Similarly, Sumit Bansal et al.<sup>4</sup> examined anaesthesia-induced changes in lung aeration and compared different ventilatory modes to identify the strategy associated with minimal aeration loss. The study showed a significant rise in LUS scores after induction and pneumoperitoneum, indicating progressive atelectasis. Atelectasis was more pronounced in dependent lung regions, and the magnitude correlated with the duration of anaesthesia and pneumoperitoneum, supporting the relationship observed in our study.

The study by Acosta et al.<sup>6</sup> evaluated the accuracy of transthoracic LUS in diagnosing anaesthesia-induced atelectasis in paediatric patients undergoing MRI. Sevoflurane anaesthesia led to notable perioperative atelectasis, and LUS showed strong agreement with MRI findings across various lung regions. This underscores the usefulness of LUS as a non-invasive bedside technique for real-time detection of atelectasis, especially in paediatric settings where CT or repeated MRI is impractical.

Additionally, the study conducted by Audrey Monastesse et al.<sup>7</sup> confirmed that induction of general anaesthesia results in significant lung aeration loss. Interestingly, this aeration loss did not correlate with BMI. Pneumoperitoneum further decreased lung aeration, and this effect reached statistical significance when evaluated using the modified LUS score, highlighting its superior sensitivity. The greatest aeration loss consistently occurred in posterior and basal lung zones, consistent with findings from CT and LUS-based studies. Their conclusion aligns closely with our results, further supporting that atelectasis is primarily driven by anaesthesia and physiological changes related to pneumoperitoneum.

### Comparison of VCV and PCV Ventilatory Modes

In our study, although perioperative atelectasis was significant in patients undergoing laparoscopic surgery under general anaesthesia, we found no significant difference in LUS scores between VCV and PCV at any time point. This suggests that both ventilation modes exert a similar influence on perioperative lung aeration when used with standard perioperative ventilatory parameters.

The study by Lee YY et al.<sup>1</sup> similarly compared VCV and PCV in patients undergoing pneumoperitoneum surgery in the Trendelenburg position and found that induction of anaesthesia significantly reduced lung aeration, which further deteriorated following pneumoperitoneum. Atelectasis was predominantly observed in posterior and basal lung regions. Notably, there was no significant difference in the extent of atelectasis between VCV and PCV, matching the results of our analysis. Their findings emphasize the importance of LUS for perioperative lung monitoring and highlight the need for preventive strategies regardless of ventilation mode.

The systematic review and meta-analysis by Schick et al.<sup>8</sup> evaluated PCV-VG versus VCV in adult patients undergoing elective non-cardiac surgery. Their analysis demonstrated that PCV-VG offers certain advantages such as lower peak and plateau airway pressures and improved dynamic compliance during two-lung ventilation. In one-lung ventilation, PCV-VG was associated with better oxygenation and reduced airway pressures. Importantly, the review reported no significant disadvantages of PCV-VG compared with VCV, reinforcing its safety. Though advantageous in airway dynamics, the findings did not conclusively support superiority in terms of lung aeration or prevention of atelectasis.

Furthermore, Lee JM et al.<sup>9</sup> compared VCV, PCV, and PCV-VG in patients undergoing laparoscopic surgery in Trendelenburg with CO<sub>2</sub> pneumoperitoneum. PCV and PCV-VG resulted in lower peak inspiratory pressures and higher dynamic compliance than VCV due to decelerating inspiratory flow. However, tidal volume variations were observed during posture changes or CO<sub>2</sub> insufflation. Although increased mean airway pressure theoretically enhances oxygenation, no significant improvement in oxygenation was observed in PCV or PCV-VG compared with VCV. Hemodynamic variations—such as decreased cardiac output and cardiac index—were attributed to pneumoperitoneum, but no significant intergroup differences occurred. Despite potential lung-protective benefits of pressure-controlled strategies, their impact on lung aeration or oxygenation remains inconclusive, consistent with our findings.

## Conclusion

In conclusion, this study demonstrates a clear and significant association between general anaesthesia and the development of perioperative atelectasis in patients undergoing laparoscopic surgeries. The observed rise in postoperative lung ultrasound (LUS) scores compared with preoperative values reinforces the well-established understanding that anaesthetic induction, pneumoperitoneum, and patient positioning collectively contribute to reduced lung aeration and collapse of dependent lung regions. These perioperative physiological alterations highlight the importance of structured respiratory assessment and vigilant perioperative monitoring.

Importantly, when comparing the two commonly used ventilatory strategies—volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV)—our findings indicate no statistically significant difference in their impact on the extent of atelectasis. Despite theoretical advantages attributed to PCV, such as lower peak airway pressures and improved dynamic compliance, the present study suggests that these do not translate into measurable differences in lung aeration loss during laparoscopic procedures. This reinforces that, within the parameters of standard intraoperative care, both modes perform similarly in preserving perioperative pulmonary aeration.

The findings also emphasize the utility of lung ultrasound as a valuable non-invasive bedside tool for early detection of atelectasis, allowing prompt identification of at-risk patients and guiding timely interventions. Given that atelectasis remains a major contributor to postoperative pulmonary complications, optimizing perioperative respiratory strategies remains a clinical priority.

Further research with larger sample sizes, inclusion of high-risk populations, evaluation of recruitment manoeuvres, individualized PEEP strategies, and long-term postoperative outcomes is warranted to refine ventilation practices. Such evidence may help develop tailored perioperative respiratory protocols aimed at minimizing atelectasis and improving overall patient safety and recovery in laparoscopic surgical settings.

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