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Comparison of Pressure-Controlled Ventilation Mode and Volume-Controlled Ventilation Mode in Elective Laparoscopic Cholecystectomy Surgeries

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Abstract

Background: Pneumoperitoneum and altered positioning in laparoscopic cholecystectomy predispose to alteration in pulmonary mechanics by reducing lung compliance and increasing airway pressures. Use of appropriate ventilatory mode is crucial for intraoperative respiratory function optimization. This study was designed to compare the effects of pressure-controlled ventilation (PCV) and volume-controlled ventilation (VCV) on respiratory mechanics and oxygenation during laparoscopic cholecystectomy. ***Methods:*** This study included n=80 cases of elective laparoscopic cholecystectomy. They were randomly divided into two groups. Group P (PCV mode, n=40) and Group V (VCV mode, n=40). Intraoperative ventilatory parameters (peak and plateau airway pressures, $EtCO_2$), hemodynamic variables (blood pressure, heart rate, SpO_2), arterial blood gas (ABG) values, and calculated pulmonary parameters were recorded at predefined intervals. Recovery characteristics were also assessed. ***Results:*** The overall baseline characteristics were comparable between the two groups. PCV demonstrated significantly lower peak and plateau airway pressures at all intraoperative time points ($p<0.001$). After CO_2 insufflation, $EtCO_2$ levels were significantly lower in the PCV group. At skin closure, PCV showed significantly better gas exchange with lower pCO_2 ($p=0.004$), higher pO_2 ($p=0.002$), improved oxygenation index ($p<0.001$), higher dynamic compliance ($p<0.001$), lower alveolar–arterial oxygen gradient ($p<0.001$), and reduced dead space ventilation ($p<0.001$). Hemodynamic parameters remained comparable between groups throughout surgery. Recovery characteristics, including time to extubation and Aldrete scores, were similar in both groups. ***Conclusion:*** Pressure-controlled ventilation (PCV) appears to provide superior intraoperative respiratory mechanics and improved oxygenation compared to volume-controlled ventilation during elective laparoscopic cholecystectomy. These beneficial actions were without affecting hemodynamic stability or postoperative recovery. PCV may be considered a preferable ventilatory strategy in laparoscopic procedures requiring pneumoperitoneum.

Keywords: Pressure-controlled ventilation (PCV), volume-controlled ventilation (VCV), Pneumoperitoneum, Laparoscopic Cholecystectomy

INTRODUCTION

Elective laparoscopic cholecystectomy is the most frequently performed procedure for the treatment of cholelithiasis and chronic cholecystitis. Compared to open surgery, laparoscopic surgery has several advantages, which include the use of smaller incisions, less postoperative pain, and rapid recovery. Inherent to laparoscopy is pneumoperitoneum and steep patient positioning, which may sometimes severely impact the pulmonary mechanics, reducing the lung compliance, elevating the airway pressure, and altering the gas exchange (1). These changes present a challenge for the anesthetic management, specifically in the provision of satisfactory ventilation and oxygenation. Therefore, the decision on the mode of mechanical ventilation during such procedures is a very significant aspect to be taken into account in the practice of anesthesia. There are two major modes that are used in general anesthesia to help meet the patient's respiratory requirements. These include volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV). In VCV mode, a predetermined tidal volume is administered with each breath, which maintains a steady minute ventilation, but can also increase the peak airway pressure, particularly when pneumoperitoneum is set up (2). PCV, on the other hand, utilizes a predetermined inspiratory pressure and variable tidal volumes based on the compliance of the lungs and is linked to reduced peak airway pressures and a decreasing flow pattern that can improve distribution of ventilation (3). These inherent dissimilarities have clinical inferences: increased airway pressures may tend to precondition barotrauma in patients and impede venous return; however, enhanced compliance could improve the gas exchange and diminish ventilator-associated lung injury. A number of randomized clinical trials and comparative studies have studied the effects of PCV and VCV in patients who have undergone laparoscopic cholecystectomy. One of the studies conducted by Tyagi et al. (4) showed that PCV led to much lower peak airway pressures and higher mean airway pressures than VCV with an equal level of haemodynamic stability and gas exchange profiles.

In a similar study by Aydin et al., they found that VCV achieved improved alveolar ventilation following pneumoperitoneum as indicated by the difference in alveolar-arterial gradients despite similar respiratory mechanics in both modes (5). Recent review also indicates that PCV can be used to have benefits in terms of decreasing peak airway pressures and improving oxygenation even in laparoscopic settings, which can potentially reduce the risk of ventilator-induced lung injury (3). However, there is inconclusive evidence on the superiority of one of the two modes compared to another, with researchers finding little difference in respiratory and haemodynamic results of both methods (6). Hence, additional studies are justified to find out the extent to which particular groups of patients or intraoperative factors respond to a ventilation mode more favorably. This study aimed to compare the clinical outcomes of pressure-controlled ventilation and volume-controlled ventilation modes in elective laparoscopic cholecystectomy in terms of intraoperative respiratory mechanics, gas exchange, and haemodynamic stability.

MATERIALS AND METHODS

This prospective observation study was conducted in the Department of Anesthesiology, Gandhi Medical College and Hospital, Secunderabad. Institutional Ethical approval was obtained for the study. Written consent was obtained from all the participants of the study after explaining the nature of the study and possible outcomes in the vernacular language.

Inclusion Criteria

1. Patients undergoing elective laparoscopic cholecystectomy under general anesthesia
2. Adults aged 18 – 60 years
3. Males and females
4. American Society of Anesthesiologists I and II
5. Normal pulmonary function

Exclusion Criteria

1. Emergency laparoscopic surgeries
2. History of significant cardiovascular diseases
3. History of pulmonary diseases
4. Anticipated difficult airway access
5. History of previous upper abdominal surgery affecting pulmonary mechanics.

Methodology: After attaining ethics committee approval, N=80 patients with ASA physical status 1 and 2 were studied in this prospective observational study. Group I (P-PCV mode group) (n=40 patients) and Group II (V-VCV mode group) (n=40 patients). After confirming NBM status, the patient was shifted to OT and standard ASA monitors, such as an electrocardiogram, pulse oximetry, and non-invasive blood pressure. End-tidal CO_2 monitoring was connected, and baseline vitals were recorded, and baseline ABG was taken and noted.

Premedication with Midazolam 1mg i/v, ondansetron 4 mg i/v, and glycopyrrolate-0.01 mg/kg i/v was given, and induced with propofol 1-2mg/kg i/v, fentanyl 2 µg/kg i/v, and relaxed with atracurium 0.5mg/kg i/v. After successful endotracheal intubation, the patient was connected to a ventilator. Anesthesia was started with VCV, and after the creation of pneumoperitoneum, the patients were randomized into PCV or VCV groups. In the V group (VCV), TV- 6-8 ml/kg and RR 14-16/ min, PEEP-5, FiO_2-0.5, N_2O: O_2 – 1:1, and in P group (PCV) RR 14-16/min, pressure high – Upto 20 (To generate adequate tidal volumes according to body weight) PEEP-5, FiO_2 -0.5.

Ventilatory parameters were adjusted to a CO_2 target of 35-45 mmHg. Anaesthesia was maintained with 50% O_2 + 50% Nitrous oxide, Inhalational agent sevoflurane, and fentanyl for pain. Hemodynamic data such as Blood pressure, Pulse rate, SpO_2, respiratory parameters, and arterial blood gases (pH, PCO_2, HCO_3, PO_2) of the patients were measured. Dynamic compliance of the respiratory system, oxygenation index, alveolar-arterial oxygen gradient, and dead space ventilation to tidal volume ratio were calculated, and ABG was taken during skin closure for comparison to baseline ABG, and vitals at the end of surgery were recorded, and the patient was extubated after giving reversal with neostigmine and glycopyrrolate and sent to the postoperative ward with stable vitals.

Statistical analysis: All the available data were refined, segregated, and uploaded to an MS Excel spreadsheet and analyzed by SPSS version 26 in Windows format. The continuous variables were represented as mean, standard deviation, and percentage, and the categorical variables were calculated by the Chi-square test to determine differences between the two groups. The values of p (<0.05) were considered significant.

RESULTS

A total of 80 cases, equally distributed in two groups, were used to determine the outcomes of this study. The demographic profile of the cohort is given in Table 1. Analysis of the table showed that the distribution of cases was equal in both groups with no statistically significant differences in any of the characteristics, including age, sex, ASA physical status, and duration of surgery and duration of pneumoperitoneum. The analysis of baseline vital parameters, including blood pressure, pulse rate, $SpO_{2,}$ and ABG, was distributed similarly between the two groups. The results show that the two groups were well matched and no potential confounding factor existed between the groups, which could influence the results.

Table 1: Baseline Demographic and Clinical Characteristics

Characteristic	Group P (PCV Mode) (n=40)	Group V (VCV Mode) (n=40)	p-value
Age (Years)	42.5 ± 11.8	44.2 ± 12.3	0.424
Sex (Male: Female)	18:22	16:24	0.651
ASA Physical Status			
I	28 (70%)	26 (65%)	0.751
II	12 (30%)	14 (3.5%)	0.501
Duration of Surgery (min)	58.5 ± 15.2	60.2 ± 16.8	0.642
Duration of Pneumoperitoneum (min)	42.8 ± 12.5	44.5 ± 13.7	0.561
Baseline Vitals			
BP (mmHg)	124.5/78.2 ± 12.8/8.5	126.2/79.5 ± 135/9.2	0.562/0.514
PR (bpm)	78.5 ± 10.2	79.8 ± 9.8	0.571
SpO_2 (%)	99.2 ± 0.8	99.1 ± 0.9	0.614
Baseline ABG			
pH	7.40 ± 0.03	7.39 ± 0.04	0.324
pCO_2 (mmHg)	38.5 ± 3.2	39.2 ± 3.5	0.348
pO_2 (mmHg)	92.8 ± 8.5	91.5 ± 9.2	0.414
HCO_3 (mmol/L)	24.2 ± 2.1	24.5 ± 2.3	0.547

Intraoperative Ventilatory Parameters are given in Table 2. Peak airway pressure (P peak) and plateau pressure (P plateau) were found to be significantly lower in the PCV group at all measured time intervals ($p < 0.001$). The difference was more significant after CO_2 insufflation. VCV showed markedly higher airway pressures. This indicates that PCV better accommodates reduced lung compliance during pneumoperitoneum by limiting airway pressure. End-tidal CO_2 ($EtCO_2$) values were slightly lower in the PCV group at most time points, with statistically significant differences after CO_2 insufflation and during later intraoperative periods. These findings suggest improved CO_2 elimination with PCV during pneumoperitoneum. Therefore, PCV demonstrated superior ventilatory mechanics, particularly under the stress of increased intra-abdominal pressure.

Hemodynamic Parameters in the cohort at different intervals of time are given in Table 3. The hemodynamic variables (BP, HR, SpO_2) were found to be similar between the two groups at all intraoperative time points. Although transient increases in blood pressure and heart rate were observed after CO_2 insufflation in both groups, the differences were not statistically significant. This indicates that both ventilation modes maintained similar hemodynamic stability during laparoscopic surgery.

Arterial Blood Gas and Pulmonary Parameters values are depicted in Table 4. The overall analysis of the table showed that at skin closure, the PCV group showed significantly better gas exchange. The PCV group had a higher pH ($p = 0.048$), lower pCO_2 ($p = 0.004$), and higher pO_2 ($p = 0.002$). More importantly, the calculated pulmonary parameters favored the PCV method with higher oxygenation index (PaO_2/FiO_2), higher dynamic compliance, lower alveolar-arterial oxygen gradient (A-a DO_2), and lower dead space ventilation ratio (VD/VT). All these differences were statistically significant ($p < 0.001$). These findings indicate better oxygenation, improved lung compliance, and more efficient ventilation-perfusion matching with PCV.

Table 2: Intraoperative Ventilatory Parameters at Different Time Intervals

Time Point	Parameter	Group P (PCV Mode) (n=40)	Group V (VCV Mode) (n=40)	p-value
5 min after intubation	P peak (cm H_2O)	16.2 ± 2.5	18.5 ± 3.2	<0.001
	P plateau (cm H_2O)	14.5 ± 2.2	16.8 ± 2.8	<0.001
	$EtCO_2$ (mmHg)	32.5 ± 2.8	33.2 ± 3.1	0.285
10 min after intubation	P peak (cm HO)	16.8 ± 2.6	19.2 ± 3.4	<0.001
	P plateau (cm H_2O)	15.2 ± 2.4	17.5 ± 3.0	<0.001
	$EtCO_2$ (mmHg)	33.2 ± 3.0	34.1 ± 3.2	0.198
After CO_2 insufflation	P peak (cm H_2O)	20.5 ± 3.5	26.8 ± 4.5	<0.001
	P plateau (cm H_2O)	18.2 ± 3.2	22.5 ± 4.0	<0.001
	$EtCO_2$ (mmHg)	36.5 ± 3.5	38.2 ± 4.0	0.042
30 min after intubation	P peak (cm H_2O)	19.8 ± 3.2	25.5 ± 4.2	<0.001
	P plateau (cm H_2O)	17.5 ± 3.0	21.8 ± 3.8	<0.001
	$EtCO_2$ (mmHg)	35.2 ± 3.2	36.8 ± 3.6	0.038
60 min after intubation	P peak (cm H_2O)	19.2 ± 3.1	25.2 ± 4.1	<0.001
	P plateau (cm H_2O)	17.0 ± 2.8	21.2 ± 3.6	<0.001
	$EtCO_2$ (mmHg)	34.8 ± 3.1	36.5 ± 3.5	0.022
90 min after intubation	P peak (cm H_2O)	18.8 ± 3.0	2.88 ± 4.0	<0.001
	P plateau (cm H_2O)	16.8 ± 2.6	21.0 ± 3.5	<0.001
	$EtCO_2$ (mmHg)	34.2 ± 3.0	35.8 ± 3.4	0.041
120 min after intubation	P peak (cm H_2O)	18.5 ± 2.8	24.2 ± 3.9	<0.001
	P plateau (cm H_2O)	16.5 ± 2.5	20.5 ± 3.4	<0.001
	$EtCO_2$ (mmHg)	33.8 ± 2.9	35.2 ± 3.3	0.045

P peak: Peak Airway Pressure; P plateau: Plateau Pressure; $EtCO_2$: End-tidal Carbon Dioxide.

Table 3: Intraoperative Hemodynamic Parameters at Different Time Intervals

Time Point	Parameter	Group P (PCV Mode) (n=40)	Group V (VCV Mode) (n=40)	p-value
5 min after intubation	BP (mmHg)	118.5/74.2 ± 10.5/6.8	120.2/75.5 ± 11.2/7.2	0.482/0.412
	HR (bpm)	72.5 ± 8.5	73.8 ± 9.2	0.512
	SpO_2(%)	99.5 ± 0.5	99.4 ± 0.6	0.428
10 min after intubation	BP (mmHg)	116.8/73.5 ± 10.2/6.5	118.5/74.8 ± 08/7.0	0.462/0.392
	HR (bpm)	71.8 ± 8.2	73.2 ± 9.0	0.482
	SpO_2(%)	99.6 ± 0.4	99.5 ± 0.5	0.352
After CO_2 insufflation	BP (mmHg)	128.5/82.5 12.5/8.5	132.8/85.2 13.5/9.2	0.142/0.168
	HR (bpm)	82.5 ± 9.5	85.2 ± 10.5	0.224
	SpO_2(%)	98.8 ± 0.8	98.5 ± 1.0	0.142
30 min after intubation	BP (mmHg)	124.5/80.2 ± 11.5/7.8	12.85/82.8 ± 12.5/8.5	0.152/0.158
	HR (bpm)	80.2 ± 92	82.8 ± 10.2	0.238
	SpO_2(%)	99.0 ± 07	98.8 ± 0.9	0.268
60 min after intubation	BP (mmHg)	122.5/78.5 ± 11.2/7.5	125.8/81.2 ± 12.2/8.2	0.212/0.138
	HR (bpm)	78.5 ± 8.8	80.5 ± 9.8	0.342
	SpO_2(%)	99.2 ± 0.6	99.0 t 0.8	0.212
90 min after intubation	BP (mmHg)	120.8/77.2 ± 10.8/7.2	123.5/79.8 11.8/78	0.282/0.152
	HR (bpm)	77.2 ± 8.5	79.2 ± 0.328	
	SpO_2(%)	99.3 ± 0.5	99.2 ± 0.7	0.468
120 min after intubation	BP (mmHg)	119.5/76.5 ± 10.5/7.0	121.8/78.5 ± 11.5/7.5	0.348/0.212
	HR (bpm)	76.2 ± 8.2	78.2 ± 9.2	0.312
	SpO_2(%)	99.4 ± 0.5	99.3 ± 0.6	0.428

BP: Blood Pressure; HR: Heart Rate; SpO_2: Oxygen Saturation.

Table 4: Arterial Blood Gas Analysis and Calculated Pulmonary Parameters at Skin Closure			
Parameter	Group P (PCV Mode) (n=40)	Group V (VCV Mode) (n=40)	p-value
ABG at Skin Closure			
pH	7.35 ± 0.04	7.33 ± 0.05	0.048
pCO_2 (mmHg)	42.5 ± 4.2	45.8 ± 5.5	0.004
pO_2 (mmHg)	185.5 ± 25.5	168.2 ± 22.8	0.002
HCO_3 (mmoI/L)	23.5 ± 2.2	24.1 ± 2.4	0.248
Calculated Parameters			
Oxygenation Index (PaO_2/FiO_2)	380.5 ± 45.2	342.8 ± 40.5	<0.001
Dynamic Compliance (mL/cm H_2O)	42.5 ± 8.2	32.8 ± 7.5	<0.001
Alveolar-arterial O_2 Gradient (A-a DO_2, mmHg)	185.5 ± 28.5	215.8 ± 32.5	<0.001
Dead Space Ventilation/Tidal Volume Ratio (VD/VT)	0.32 ± 0.06	0.38 ± 0.07	<0.001

Comparison of changes from baseline and recovery characteristics in the two groups is given in Table 5. The increase in pCO_2 from baseline was significantly greater in the VCV group ($p < 0.001$), indicating comparatively reduced CO_2 clearance. Similarly, improvement in pO_2 was significantly greater in the PCV group ($p = 0.002$). Mean peak airway pressure and mean $EtCO_2$ during surgery were significantly lower in the PCV group. However, recovery characteristics, including time to extubation, Aldrete score at 10 minutes, and incidence of PONV, were comparable between groups. This suggests that although PCV improved intraoperative respiratory mechanics and gas exchange, it did not significantly alter immediate postoperative recovery outcomes.

Table 5: Comparison of Changes from Baseline and Recovery Characteristics			
Parameter	Group P (PCV Mode) (n=40)	Group V (VCV Mode) (n=40)	p-value
Change in ABG Parameters (Baseline to Skin Closure)			
Δ pH	-0.05 ± 0.02	-0.06 ± 0.03	0.089
Δ pCO_2 (mmHg)	+4.0 ± 2.5	+6.6 ± 3.2	<0.001
Δ pO_2 (mmHg)	92.7 ± 22.5	76.7 ± 20.8	0.002
Δ $HC0_3$ (mmol/L)	-0.7 ± 1.5	-0.4 ± 1.8	0.428
Peak Airway Pressure During Surgery (mean)	18.5 ± 3.2	24.8 ± 4.5	<0.001
End-tidal CO_2 During Surgery (Mean)	34.2 ± 3.1	35.8 ± 3.4	0.032
Recovery Characteristics			
Time to Extubation (min)	8.5 ± 2.5	9.2 ± 2.8	0.248
Aldrete Score at 10 min post-Extubation	9.2 ± 0.8	9.1 ± 0.9	0.614
PONV in PACU, n (%)	3 (7.5%)	4 (10%)	0.692
Δ = Change from baseline to end of surgery; PONV: Postoperative Nausea and Vomiting; PACU: Post-Anesthesia Care Unit.			

DISCUSSION

The results of this study show that pressure-controlled ventilation (PCV) has tremendous benefits over volume-controlled ventilation (VCV), especially in terms of airway pressures, pulmonary mechanics, and gas exchange without compromising hemodynamic stability and recovery features in patients undergoing elective laparoscopic cholecystectomy. The presence of pneumoperitoneum in the laparoscopic surgery enhances pressure in the abdominal cavity, which causes a cephalad displacement of the diaphragm, a decrease in functional residual capacity, and a decrease in pulmonary compliance (1). These changes are normally known to be related to elevated airway pressures and the absence of ventilation-perfusion matching. Peak and plateau airway pressures in the current study were significantly and continuously reduced in the PCV group at all time points during the intraoperative period, especially at the time following CO2 insufflation. This observation is in line with the earlier research that has reported that the slowing inspiratory flow pattern of PCV facilitates the more homogenous alveolar distribution of tidal volume and lower peak inspiratory pressure than VCV (7,8). After pneumoperitoneum, the increase in airway pressures was more pronounced, which confirms the hypothesis that PCV is superior in terms of being able to adapt to decreased lung compliance during laparoscopy. Tyagi et al. have also found reduced peak airway pressures on PCV during laparoscopic cholecystectomy without affecting minute ventilation (9). The clinical significance of lower airway pressures is that they decrease the incidence of barotrauma and decrease the negative impact on the venous return and cardiac output. The PCV group had a much better gas exchange at skin closure due to improved airway mechanics. The levels of pCO_2 in the arteries were lower, pO2 was higher, and the oxygenation index (ratio of PaO2/FiO2) was much better than in the VCV group. A decreased dead space fraction (VD/VT) in the PCV group and lower alveolar-arterial oxygen gradient indicate enhanced matching ventilation-perfusion. Aydin et al. [4] have reported similar results, which showed an improvement in oxygenation and compliance parameters in the laparoscopic procedures with PCV. Its beneficial impact on the lung mechanics is further supported by the fact that the dynamic compliance was improved in the PCV group in the current study. Although there were respiratory benefits, hemodynamic measures (blood pressure, heart rate, and oxygen saturation) were similar across the groups during surgery. This indicates that the two ventilation modes are safe from a cardiovascular standpoint in laparoscopic cholecystectomies of ASA I & 2 patients. Minimal hemodynamic changes between PCV and VCV in laparoscopy have also been reported in the previous comparative trials (10). Notably, the postoperative recovery outcomes, such as time to extubation, Aldrete score, and postoperative nausea and vomiting, were not significantly different in terms of recovery between groups. It means that PCV does not have a negative impact on the postoperative outcomes in the short term but only enhances intraoperative respiratory performance. The results of this study are consistent with the existing evidence that indicates that PCV has even better control of airway pressures and improved oxygenation during laparoscopic surgery, particularly when pneumoperitoneum is observed. Although the two ventilation modes are both clinically acceptable, PCV can be a better option in those patients where limiting airway pressures and optimization of pulmonary mechanics are a priority.

CONCLUSION

Within the limitations of the current study, we found that pressure-controlled ventilation (PCV) showed advantages over volume-controlled ventilation (VCV) for elective laparoscopic cholecystectomy. It provided lower peak and plateau airway pressures, better oxygenation, improved dynamic compliance, and effective carbon dioxide elimination following pneumoperitoneum. Although both modes had similarities as far as hemodynamic and recovery profiles were concerned. The volume-controlled ventilation was able to produce adequate ventilation, but it was associated with higher airway pressures, which were relatively less favourable for gas exchange. Therefore, pressure-controlled ventilation must be preferred in cases where minimizing airway pressures and optimizing pulmonary mechanics are priorities.

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