ORIGINAL RESEARCH

The effects of pressure-controlled ventilation (PCV) versus volume-controlled ventilation (VCV) ventilatory parameters in patients undergoing elective laparoscopic cholecystectomy surgeries under general anaesthesia

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ABSTRACT
The most frequently used ventilation mode in general anaesthesia is VCV, which utilises a constant flow to deliver a target tidal volume and ensures minute ventilation, it may result in high airway pressures in laparoscopic surgery. PCV which has been initially proposed in ICU patients with acute respiratory distress syndrome (ARDS) as an alternative to VCV, is less frequently employed in general anaesthesia. Data was collected from all the consenting patients who will be scheduled for elective laparoscopic cholecystectomy surgery under general anaesthesia with endotracheal intubation in Department of Anaesthesiology. The mean (SD) of exhaled tidal volume in the VCV group are 424.7 (53.9), 418.9 (49.3) and 416.7 (48.5) at T1, T2 and T3 respectively. In the PCV group are 355.8 (36.4), 368.6 (33.0) and 357.8 (34.2) at T1, T2 and T3 respectively. Statistically there is a significant difference between group VCV and PCV at T1 (p=0.001), T2 (p=0.001) and T3 (p=0.001).
Key words: Pressure controlled ventilation, versus volume-controlled ventilation, elective laparoscopic cholecystectomy surgeries

INTRODUCTION

Today, laparoscopic cholecystectomy has been accepted as the gold standard in the surgical treatment of cholelithiasis and gall bladder diseases because of the shorter hospital stay, minimal postoperative pain and rapid recovery.[1]

The effects are due to creation of pneumoperitoneum and position changes incorporated to facilitate surgical access. The increase in intraabdominal pressure causes a cephalad shift of the diaphragm leading to decrease in lung compliance by 25%-40% and a more marked increase in the airway pressure.[2] Increased intra-abdominal pressure may lead to an increase in systemic vascular resistance and mean arterial pressure (MAP) in cardiovascular system, and a decrease in venous return and cardiac output because of the compression of inferior venacava. If preoperative CO_2 pneumoperitoneum continues for a long time, it can reduce renal blood flow, glomerular filtration rate and urine output. Carbon dioxide insufflation causes upward displacement of diaphragm, increased risk of regurgitation, reduced lung volumes and compliance, and increased airway compliance, and increased airway resistance, intrathoracic, peak inspiratory pressure and partial arterial carbon dioxide pressures. Various ventilatory strategies like pressure-controlled ventilation (PCV) and volume controlled ventilation (VCV) are used to prevent formation of atelectasis and deterioration of oxygenation during laparoscopy.[1]

The most frequently used ventilation mode in general anaesthesia is VCV, which utilises a constant flow to deliver a target tidal volume and ensures minute ventilation, it may result in high airway pressures in

laparoscopic surgery. PCV which has been initially proposed in ICU patients with acute respiratory distress syndrome (ARDS) as an alternative to VCV, is less frequently employed in general anaesthesia.[3]
The advantage of PCV is, it reduces risk of barotrauma and volume trauma by limiting inspiratory pressure.[4] In addition, extending inspiratory time and by using adequate positive end-expiratory pressure (PEEP) levels, we can ensure better opening up of collapsed alveoli. The effects of carbon dioxide pneumoperitoneum should be considered in the selection of the method of mechanical ventilation in general anaesthesia. Few studies conducted on this issue, recommends both VCV and PCV can be used as an alternative to each other.[1]
We intend to evaluate the effects of pressure-controlled ventilation (PCV) versus volume-controlled ventilation (VCV) in patients undergoing elective laparoscopic cholecystectomy surgeries under general anaesthesia.

METHODOLOGY

SOURCE OF DATA

Data was collected from all the consenting patients who will be scheduled for elective laparoscopic cholecystectomy surgery under general anaesthesia with endotracheal intubation in Department of Anaesthesiology.

SAMPLE SIZE

Based on the study conducted by Assad MO *et al.* in 2016, the outcome variable peak inspiratory pressure is considered for sample calculation. We hypothesised the minimum difference of 2.5 cmH_20 and standard deviation of 3.56 for volume-controlled ventilation (VCV) and 3.9 for PCV. The sample size was calculated with a statistical power of 80% and 95% confidence interval. The estimated sample size was 36 for each group. Thus, the total sample size for this study is 72.

STUDY DESIGN

Prospective randomised clinical study.

INCLUSION CRITERIA

1. Patients of either gender.
2. Belonging to American society of Anaesthesiologists (ASA) physical status 1-2.
3. Aged between 18-60 yrs.
4. Undergoing elective laparoscopic cholecystectomy surgery under general anaesthesia.

EXCLUSION CRITERIA

1. Patients unwilling to give consent.
2. Respiratory infections in the past 3 weeks.
3. Known hypersensitivity to any drugs used in this study.
4. Patients in whom surgery was converted to open procedure.
5. Patients with cardiac, renal or hepatic insufficiency.
6. Patients with cerebrovascular or neuromuscular diseases.
7. Pregnant women.
8. Severe obstructive or restrictive pulmonary disease (defined as less than 50% of predicted values of forced vital capacity and forced expiratory volume in 1 second), previous lung surgery or home oxygen therapy.
9. Hemodynamic instability.
10. BMI exceeding >30 kg/m^2.

Institutional ethical committee approval was obtained before commencement of the study. Informed written consent was obtained from all patients.
All the patients were examined during the pre-operative visit, a day before surgery. Routine blood investigations including complete haemogram, renal function test, blood sugar, chest X-ray and electrocardiogram (ECG) was carried out and recorded. They were kept nil orally 8 hours before surgery and were pre-medicated with alprazolam 0.5 mg per oral (PO), the night before surgery and ranitidine 150 mg and ondansetron 2 mg PO on the morning of surgery.
In the operating room, ECG, non-invasive blood pressure (NIBP) and pulse oximeter for peripheral oxygen saturation (SpO_2) are attached. An intravenous (IV) line and an intra-arterial line was secured.
A baseline arterial blood gas (ABG) analysis was done.
All the patients were randomised into two groups (group P and group V) by using computer generated random number table.
Group P: Received pressure-controlled ventilation (PCV) during general anaesthesia.
Group V: Received volume-controlled ventilation (VCV) during general anaesthesia.

The patients were pre-medicated with IV midazolam 0.03 mg/kg.
Anaesthesia was induced with propofol 2-3 mg/kg, fentanyl 1-2 mcg/kg, vecuronium 0.1-0.2 mg/kg. Patients were manually ventilated with 100%oxygen, intubation will be performed after 3 minutes and mechanical ventilation was initiated.
After trocars placement, patients were placed in a modified reverse Trendelenburg position (30 degrees head up and 30 degrees tilt left). Following positioning, patients were randomly assigned to one of the two modes of mechanical ventilation.
Patients were ventilated by Space Labs– Blease Sirius Anaesthesia Machine (OSI Systems, Inc. Hawthorne, California).
In the PCV group (group A), inspiratory pressure was not exceeded 30 cmH_2O, the following parameters were adjusted as follows: frequency 12-18/min, I:E ratio 1:2, PEEP 5cm H_2O and $ETCO_2$ 30-35 mmHg.

In the VCV group (group B), adjustments were done as, tidal volume 8-10 ml/kg, frequency 12-14/min, I:E ratio 1:2, PEEP 5 cmH_2O and $ETCO_2$ 30-35 mmHg.
Anaesthesia was maintained with sevoflurane 1-2%, 60% N_2O and 40% O_2; analgesia was maintained with fentanyl 2-3 mcg/kg and muscle relaxation with vecuronium.
The intraperitoneal pressure was adjusted to 12 ± 2 mmHg. Immediately after the surgical specimen removal and achieving of hemostasis, the CO_2 was removed and the patients were returned to the supine position.
At the end of the procedure, neuromuscular blockade was antagonised with 0.04 mg/kg neostigmine and glycopyrrolate 0.01 mg/kg intravenous. The trachea was extubated when patient is fully awake with no residual neuromuscular paralysis.

RESULTS

Table 1: Distribution of ASA physical status between study groups

ASA physical status	Group V VCV Group n=36		Group P PCV Group n=36		p value
	N	%	N	%	
Grade I	23	63.9%	25	69.4%	0.617
Grade II	13	36.1%	11	30.6%	
Total	36	100.0%	36	100.0%	

The number of participants belonging to ASA physical status 1 are 23 (63.9%) in the VCV group and 25 (69.4%) in the PCV group. The number of participants belonging to ASA class 2 are 13 (36.1%) in the group VCV and 11 (30.6%) in the group PCV respectively. There is no statistically significant difference between both the groups (p=0.617).

Table 2: Comparison of PIP between study groups

PIP	Group V VCV Group		Group P PCV Group		p value
	Mean	SD	Mean	SD	
T1 (5 mins after induction of anaesthesia insupine position and before initiation of thepneumoperitoneum)	13.4	1.2	12.8	1.0	0.020*
T2 (post pneumoperitoneum and Trendelenburgposition at 15 mins)	33.5	2.2	27.1	1.8	<0.001*
T3 (post pneumoperitoneum and Trendelenburgposition at 60 mins)	34.6	1.5	27.0	1.8	<0.001*

Note: p value* significant at 5% level of significance (*p*<0.05).

The mean (SD) of PIP in the VCV group are 13.4 (1.2), 33.5 (2.2) and 34.6 (1.5) at T1, T2 and T3 respectively. In the PCV group are 12.8 (1.0), 27.1 (1.8) and 27.0 (1.8) at T1, T2 and T3 respectively. There is a significant statistical difference between VCV and PCV groups at T1 (p=0.020), T2 and T3 (p=0.001).

Table 3: Comparison of respiratory rate between study groups

Respiratory Rate	Group V VCV Group		Group P PCV Group		p value
	Mean	SD	Mean	SD	
T1 (5 mins after induction of anaesthesia insupine position and before initiation of thepneumoperitoneum)	12.9	1.0	15.2	1.0	<0.001*
T2 (post pneumoperitoneum and Trendelenburgposition at 15 mins)	13.6	1.1	16.9	1.2	<0.001*
T3 (post pneumoperitoneum and Trendelenburgposition at 60 mins)	13.7	0.9	17.2	1.4	<0.001*

Note: p value* significant at 5% level of significance (*p*<0.05).

The mean (SD) of respiratory rate in the VCV group are 12.9 (1.0), 13.6 (1.1) and 13.7 (0.9) at T1, T2 and T3 respectively. In the PCV group are 15.2 (1.0), 16.9 (1.2) and 17.2 (1.4) at T1, T2 and T3 respectively. Statistically there is a significant difference between group VCV and PCV at T1 (p=0.001), T2 (p=0.001) and T3 (p=0.001).

Table 4: Comparison of exhaled tidal volume between study groups

Exhaled tidal volume	Group V VCV Group		Group P PCV Group		p value
	Mean	SD	Mean	SD	
T1 (5 mins after induction of anaesthesia insupine position and before initiation ofthepneumoperitoneum)	424.7	53.9	355.8	36.4	<0.001*
T2 (post pneumoperitoneum and Trendelenburgposition at 15 mins)	418.9	49.3	368.6	33.0	<0.001*
T3 (post pneumoperitoneum and Trendelenburgposition at 60 mins)	416.7	48.5	357.8	34.2	<0.001*

Note: p value* significant at 5% level of significance ($p<0.05$).

The mean (SD) of exhaled tidal volume in the VCV group are 424.7 (53.9), 418.9 (49.3) and 416.7 (48.5) at T1, T2 and T3 respectively. In the PCV group are 355.8 (36.4), 368.6 (33.0) and 357.8 (34.2) at T1, T2 and T3 respectively. Statistically there is a significant difference between group VCV and PCV at T1 (p=0.001), T2 (p=0.001) and T3 (p=0.001).

Table 5: Comparison of $ETCO_2$ between study groups

$ETCO_2$	Group V VCV Group		Group P PCV Group		p value
	Mean	SD	Mean	SD	
T1 (5 mins after induction of anaesthesia insupine position and before initiation of thepneumoperitoneum)	34.2	1.5	34.1	1.5	0.988
T2 (post pneumoperitoneum and Trendelenburgposition at 15 mins)	35.3	0.8	35.2	0.8	0.387
T3 (post pneumoperitoneum and Trendelenburgposition at 60 mins)	35.3	0.9	35.1	0.9	0.635

The mean (SD) of $ETCO_2$ (end tidal carbon-dioxide) in the VCV group are 34.2 (1.5), 35.3 (0.8) and 35.3 (0.9) at T1, T2 and T3 respectively. In the PCV group are 34.1 (1.5), 35.2 (0.8) and 35.1 (0.9) at T1, T2 and T3 respectively. Statistically there is no significant difference between group VCV and PCV at T1 (p=0.988), T2 (p=0.387) and T3 (p=0.635).

DISCUSSION

Under anaesthesia, the primary goal of mechanical ventilation is to provide adequate gas exchange with minimum lung injury and lowest possible degree of haemodynamic impairment. Our prospective randomized clinical study comparing volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) modes of ventilation has shown a difference in the peak airway pressures in favour of PCV mode. However, the oxygenation has remained similar in both modes.[5]

The principle finding of our study is, PCV mode was associated with lower peak inspiratory pressures (PIP) when compared with VCV mode at all intervals of study. No significant difference was observed in oxygenation, haemodynamic and other ventilatory parameters between VCV and PCV modes.

PCV mode has also been established ventilatory mode for patients with acute lung injury, pediatric patients, patients with bronchopleural fistula and one lung ventilation in view of decreased airway pressures. The PIP during mechanical ventilation is clinically important as high PIP leads to development of barotrauma.[6]

PIP is a reflection of the dynamic compliance of the respiratory system and depends on factors such as exhaled tidal volume, inspiratory time, endotracheal size and airway resistance. Alternatively, mean airway pressure (P_{mean}) correlates with alveolar ventilation and gas oxygenation whereas $P_{plateau}$ is associated with static lung compliance.

Bohm *et al.*recommended using PCV in all circumstances requiring artificial ventilation. The primary advantage of PCV vs VCV seems to be lower peak airway pressure, which might decrease the risk of barotrauma during mechanical ventilation. However, the available literature for implementation of ventilator mode in laparoscopic cholecystectomy is limited.[7]

Barotrauma is a condition where high inflating pressures causes alveoli rupture leading to extra-alveolar air seepage and pulmonary interstitial emphysema. This results in pneumothorax, pneumomediastinum and cardiorespiratory failure. In lung injury patients, Eisner *et al.*have found that high peak airway pressures (P_{peak}) is a major risk factor for early barotraumas.

Laparoscopic approach for cholecystectomy has been popular nowadays. VCV, the conventional mode is generally preferred without evaluating alternate ventilation modes because most anaesthesiologists are more familiar with VCV because it maintains adequate tidal volume and effectively eliminates CO_2. However, tidal volume is increased if CO_2 cannot be eliminated effectively, and in this condition, increased peak airway pressure may be achieved.[8]

VCV is associated with increased peak inspiratory pressures. Thus, PCV has been used to reduce the lung injury associated with the increase in peak inspiratory pressure encountered with VCV. This is attributed to the decelerating inspiratory flow delivery method of PCV. The high initial flow rate inflates the compliant alveoli and during the decelerating phase of flow, the noncompliant alveoli with higher time constants are ventilated without over inflation of the other units thus delivering the same tidal volume at a lower airway pressure.

Furthermore, studies suggest that the risk of lung injury can be minimized during VCV by limiting plateau airway pressure. Few studies propose a strong correlation between plateau airway pressure and mechanical ventilation-induced barotraumas when plateau airway pressure exceeds 35 cm H_2O.[9]

In our study, the airway pressures were within the normal range in both modes. Although airway pressures of <30 cm H_2O is considered acceptable, so far no safe pressure limits have been proposed. Hence, lower airway pressures with PCV provides better protection to the lung offering more advantage in patients with lower lung compliance.

Monitoring $ETCO_2$ is an adequate guide for determining the minute ventilation required to maintain normocarbia, and it provides a reasonable approximation of $PaCO_2$ in healthy patients undergoing laparoscopic cholecystectomy. Therefore, in our study, we maintained $ETCO_2$ between 35 and 40 mmHg in both the groups for comparison of oxygenation between the two groups. After pneumoperitoneum, it takes about 15 min for $PaCO_2$ to reach a plateau. Thus, in this study, arterial blood samples were taken for analysis 15 minutes after creation of pneumoperitoneum. In our study, lower respiratory rate was required to maintain normocarbia in group VCV compared with group PCV. Although the difference in respiratory rate was statistically significant, it was not clinically relevant (p=0.001).

In VCV, higher tidal volume and minute ventilation were required to maintain normocarbia. The large tidal volume delivered can lead to adverse consequences like rise in peak inspiratory pressures, volutrauma and inflammatory lung injury in VCV. The large tidal volume mainly ventilates the non-dependent portion of the lung, which leads to excessive stretching of those regions without improving the overall ventilation. Whereas, PCV requires low tidal volume and lower peak inspiratory pressures to maintain normocarbia. Thus, the adverse effects of VCV can be avoided in PCV. In PCV, there is improved lung ventilation as there is recruitment of the collapsed alveoli due to high flow rate in the early inspiratory phase.[10]

CONCLUSION

According to our findings, in patients who underwent laparoscopic cholecystectomy, PCV mode was better than VCV, as it was associated with lower peak inspiratory pressure. PCV delivers the targeted tidal volume at lower peak inspiratory pressures thus preventing barotrauma.

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