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Comparison of volume-controlled ventilation and pressure-limited ventilation in laparoscopic appendicectomy - a randomized controlled clinical trial

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ABSTRACT

Background: Laparoscopic appendicectomy is a widely performed surgery globally, offering notable benefits such as reduced postoperative pain, quicker mobility, and shorter hospital stays. **Aims and Objectives:** The study aimed to assess the changes in respiratory mechanics and compare the outcomes of volume-controlled and pressure-limited ventilation (PLV) in patients undergoing laparoscopic appendectomy. **Materials and Methods:** This randomized, prospective, single-blinded control study was conducted at K.A.P.V. Government Medical College, Tiruchirapalli, on 60 ASA I and II patients scheduled to undergo laparoscopic appendicectomy under general anesthesia. The patients were randomly divided into two groups (volume-controlled ventilation [VCV] group and the PLV group) of 30 patients. A patient's history includes age, sex, history of diabetes, hypertension, or any cardiovascular disease, respiratory tract infection, wheezing or chronic chest infections, seizures, neuromuscular disease or weakness, etc. **Results:** There was no significant difference in gender, age, or body mass index between groups. There is no significant difference in the mean arterial pressure or $ETCO_2$ between groups at various intervals. There was a significant difference in the mean heart rate between the VCV and the PLV groups at 5 and 20 min after induction. There was a significant difference in the peak airway pressure, dynamic compliance, and airway resistance between the VCV group and the PLV group at 10 min after induction (T1), 5 min after pneumoperitoneum (T2), 10 min after pneumoperitoneum (T3), and immediately after Trendelenburg position (T4). **Conclusion:** The airway resistance and peak airway pressure do not increase, and the dynamic compliance was improved in the PLV during laparoscopic appendicectomy.

Key words: Laparoscopic appendicectomy; Volume-controlled ventilation; Pressure-limited ventilation; Peak airway pressure; Dynamic compliance; Respiratory mechanics

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INTRODUCTION

Laparoscopic appendicectomy is a commonly performed surgery worldwide known for its benefits, such as reduced postoperative pain, early mobilization, and shorter hospital stays than open appendicectomy. One of the significant postoperative complications that demands close monitoring and management is pulmonary dysfunction, particularly due to factors like pneumoperitoneum creation and changes in patient positioning. Increased intra-abdominal pressure during laparoscopic appendicectomy can lead to reduced lung compliance and a substantial rise in airway pressure. Originally, laparoscopic procedures were limited to brief gynecological diagnostics. But today, they are increasingly performed on older, high-risk patients previously deemed unsuitable for laparotomies.[1] The intraperitoneal approach,

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initially used for appendicectomy and cholecystectomy, is now applied to extraperitoneal surgeries such as inguinal hernia, adrenal, and renal surgeries.[2] However, it risks increased carbon dioxide absorption and physiological changes due to patient positioning and gas insufflations, necessitating vigilance from anesthesiologists.[3] This progress in laparoscopic surgery is closely tied to advancements in anesthesia drugs and techniques.

The pneumoperitoneum shifts the diaphragm to the cephalad and reduces lung expansion, causing restrictive lung disease. The functional residual capacity, tidal volume (TV), and minute ventilation are decreased.[4] The hemodynamic effect depends on CO_2 absorption, patient position, intra-abdominal pressure, ventilator setting, and duration of the surgery. The pulmonary artery occlusion and central venous pressure are decreased by anesthesia; when carbon dioxide insufflation starts, they will be increased.[5] An elevated intraabdominal pressure causes an increase in intra-cerebral pressure by limiting cerebral venous drainage due to raised intra-thoracic pressure. The extent of the head-down tilt, age, intravascular volume status, anesthetic drugs administered, and ventilation techniques may influence cardiovascular changes.[6] In mechanical ventilation, the airway resistance depends on the length, size, and patency of the airway, endotracheal tube, and ventilator circuit.[7]

Dynamic compliance divides the volume by the pressure (i.e., peak inspiratory pressure) measured when airflow is present. Since airflow is present, airway resistance becomes a factor in measuring dynamic compliance. Abnormal compliance impairs the gas exchange mechanism. Volume control ventilation (VCV) is a well-known technique, and the controllable minute volume. The ventilator delivers the pre-set TV with a constant flow during the pre-set inspiratory time (Ti) at the pre-set respiratory rate. The concern with VCV is the constant flow that may cause high peak pressures and expose the patient to the risk of barotraumas.[8] In pressure-limited ventilation (PLV), the anesthesiologists set a target TV and maximum pressure (pressure limit), and the next cycle starts when the target TV is met. In this type of ventilation, pressure is not increased above the set pressure.[9] Pressure-limited, time-cycled breaths begin inspiration as pressure-limited breaths (pressure increases to a set value or target), and they are time-cycled (inspiration ends at a specified time interval). The clinician sets a target TV and maximum pressure (pressure limit). The ventilator delivers a test breath and calculates the patient's airway resistance and lung compliance.

Aims

To study the changes of respiratory mechanics in volume controlled ventilation and pressure limited ventilation in laparoscopic appendectomy.

Objectives

The objective in this study is to compare peak airway pressure, dynamic compliance and airway resistance between VCV mode and PLV mode, and hemodynamic changes in patients undergoing laparoscopic appendectomy.

MATERIALS AND METHODS

This randomized, prospective, single-blinded control study was conducted at K.A.P.V. Government Medical College, Tiruchirapalli, on 60 patients scheduled to undergo laparoscopic appendicectomy under general anesthesia. All the patients were explained about the study design at the time of enrollment, and detailed consent regarding their willingness to participate was obtained. Ethical committee approval was obtained before the study started.

Inclusion criteria

ASA Physical status I and II, patients aged between 16 and 40, and body mass index (BMI) <30 kg/m^2 were included.

Exclusion criteria

Emergency cases, patient refusal, anticipated inability to perform early postoperative extubation, morbid obesity with a BMI ≥ 30, inability to maintain intraoperative $ETCO_2$ <40 mmHg, and conversion to laparotomy were excluded.

The patients were randomly divided into two groups (VCV Group and PLV Group) of 30 patients. A thorough pre-anesthetic evaluation history and physical examination were done.

The pre-anesthetic evaluation involves assessing a patient's history of diabetes, hypertension, cardiovascular diseases, respiratory tract infections, seizures, neuromuscular weakness, drug intake, previous surgeries, significant events, relevant investigations like hemoglobin, blood sugar, blood urea, serum creatinine, serum electrolytes, urine analysis, and obtaining informed consent from patients.

All patients were premedicated with Inj. Ranitidine hydrochloride 50 mg IV, and injection Metocloparamide 10 mg IV, injection Midazolam 1 mg IV, and injection Glycopyrrolate 0.2 mg IV, given 1 h before surgery. After shifting the patient into the operating room, the pulse oximeter, NIBP, and ECG leads were connected. A nasogastric tube was inserted, and suction was applied to empty the stomach before intubation.

Pre-oxygenation was done with 10–12 L of 100% oxygen for 3 min. All patients received injection fentanyl citrates 2 mcg/kg IV and were induced with injection thiopentone sodium 3–5 mg/kg and succinylcholine 1.5 mg/kg for muscle relaxation. A properly sized, cuffed oral endotracheal tube was inserted; the cuff was inflated and connected to a closed circuit for controlled ventilation in the BPL eflo6 workstation. All patients were studied on BPL E-flo 6 workstations with VCV and PLV modes. Set the TV at 8 mL/kg and the respiratory rate at 12/min. In PLV mode, the target set pressure was 20 cm of water. Anesthesia was maintained with 66% nitrous oxide, 33% oxygen, and 1–2% sevoflurane. Atracurium 0.5 mg/kg bolus and 0.1 mg/kg were used to maintain muscle relaxation.

The carbon dioxide pneumoperitoneum was established, and the intra-abdominal pressure was maintained between 13 and 15 mmHg. Ringer lactate solution was administered according to the fasting period, maintenance volume, and blood loss. Neuromuscular monitoring was done using a train of four to look for any prolongation of the muscle relaxant action.

An anesthetist unaware of this study measured the hemodynamic parameters and respiratory mechanics. The airway resistance, dynamic compliance, and peak airway pressure were measured at the following intervals: 10 min after induction (T1), 5 min after pneumoperitonium (T2), 10 min after pneumoperitonium (T3), and immediately after Trendelenburg position (T4). At the end of surgery, glycopyrrolate 0.01 mg/kg and neostigmine 0.05 mg/kg were used to reverse muscle relaxation. After thorough suctioning and nasogastric tube aspiration, the tracheal tube was removed.

Statistical analysis

The information collected from all the selected cases was recorded in a master chart using a Microsoft Excel worksheet. The statistical presentation and analysis of the present study were conducted using the mean, standard deviation (t-test), and chi-square test in SPSS V.20 and Sigma Stat 3.5 versions. An analysis of variance test was used to compare different times in the same group of quantitative data. A P<0.05 was taken to denote a significant relationship.

RESULTS

The male patient was 21.6% in the VCV group and 25% in the PLV group. The female patient was found to be 28.3% in the VCV group and 25% in the PLV group, and there was no significant difference in the sex distribution between the VCV and PLV groups.

The mean age was 22.80±2.60 in the VCV group and 21.16±2.17 in the PLV group, showing no significant difference in the age distribution between groups. The male patient's mean BMI was 23.32±1.22 in the VCV group and 22.70±0.98 in the PLV group. The female patient's mean BMI was 22.74±1.41 in the VCV group and 22.50±1.32 in the PLV group, which showed no significant difference in the mean BMI between groups (Table 1).

There is no significant difference in the mean arterial pressure between the VCV and PLV groups at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 min after induction (Figure 1).

There was a significant difference in the mean heart rate between the VCV and the PLV groups at 5 and 20 min after induction, but no significant difference was seen at 0, 10, 15, 25, 30, 35, 40, 45, and 50 min (Figure 2).

There was no significant difference in the $ETCO_2$ between the VCV and the PLV groups at 0, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 min after induction (Figure 3).

There was a significant difference in the peak airway pressure and dynamic compliance between the VCV group and the PLV group at 10 min after induction (T1), 5 min after pneumoperitoneum (T2), 10 min after pneumoperitoneum (T3), and immediately after Trendelenburg position (T4).

There was a significant difference in the airway resistance between the VCV group and the PLV group at 10 min

Table 1: Comparison of age and body mass index between groups

Variables	Mean±SD		P-value
	VCV group	PLV group	
Age (years)			
Up to 19	19±0	19±0	0.09
19–24	21.82±1.30	21.60±1.35	
24–29	27.16±1.32	26.50±2.12	
Total	22.80±2.60	21.16±2.17	
BMI			
Male	23.323±1.221	22.7±0.928	>0.09
Female	22.741±1.533	22.293±1.655	
Total	22.293±1.414	22.503±1.323	

VCV: Volume control ventilation, PLV: Pressure-limited ventilation, BMI: Body mass index, SD: Standard deviation

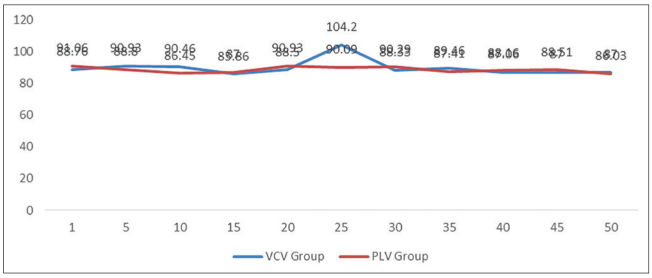

Figure 1: Mean arterial pressure between groups

after induction (T1), 5 min after pneumoperitoneum (T2), 10 min after pneumoperitoneum (T3), and immediately after Trendelenburg position (T4) (Table 2).

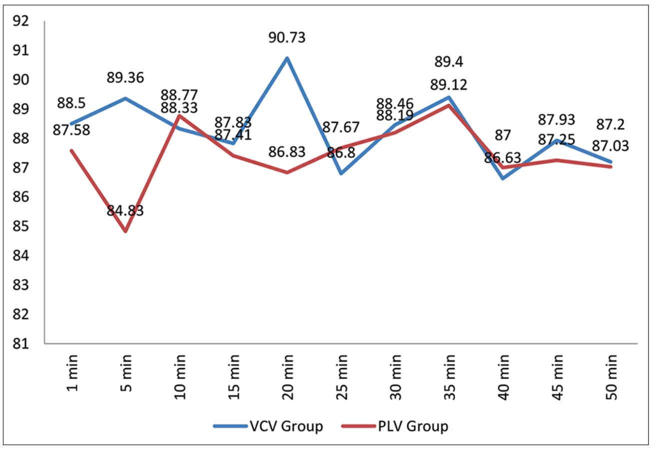

Figure 2: Mean heart rate between volume controlled ventilation and pressure limited ventilation group

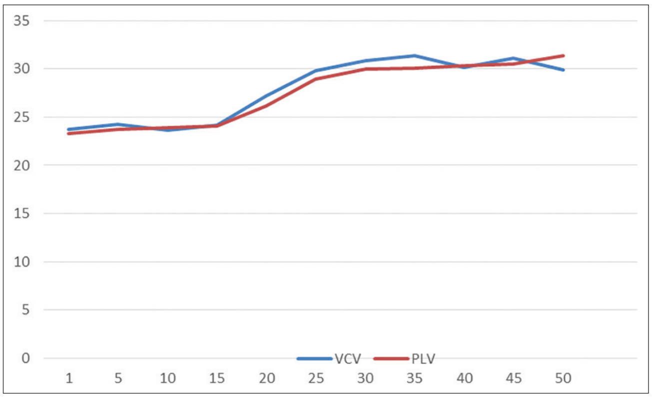

Figure 3: $ETCO_2$ between group

DISCUSSION

Our study showed no significant difference in the age, sex, or BMI distribution between the VCV and PLV groups (P>0.05). Like the Tyagi et al., study, Balick-Weber et al., and Cadi et al., reported no significant difference in patient age, gender, or BMI between the two groups.[9-11] Our study's mean arterial pressure was higher in the volume-controlled group than the pressure-limited group at 5, 10, 15, 25, 35, and 50-min intervals. The results showed no significant difference in mean arterial pressure between the VCV and PLV groups at all-time intervals (P>0.05). The studies done by Balick-Weber et al., Dion et al., and Gupta et al., show no significant difference in mean arterial pressure between the volume-controlled (VCV) and pressure-controlled ventilation (PCV) groups.[11-13]

In our study, the mean heart rate was higher in the volume-controlled (VCV) group than the pressure-limited (PLV) group at various intervals. There was no statistically significant difference between the two groups. But clinically, the heart rate was higher in volume-controlled group studies done by Balick-Weber et al., Dion et al., and Gupta et al.[11-13] Also, the study conducted by Kwak et al.,[14] in which the heart rate was high in VCV, which is statistically insignificant.

In our study, the peak airway pressure at 10 min after induction (T1) was 19±2.51 and 13.93±1.43 in the volume-controlled (VCV) and pressure-limited (PLV) groups, respectively. The peak airway pressure at 5 min after pneumoperitoneum (T2) was 24.1±1.98 and 17.56±1.22 in the (VCV) and (PLV) groups, respectively. The peak airway pressure at 10 min after pneumoperitoneum (T3) was 25.1±1.91 and 18.2±1.12 in the (VCV) and (PLV) groups,

Table 2: Comparison of peak airway pressure, dynamic compliance and airway resistance between groups

Variables	Mean±SD		P-value
	VCV	PLV	
Peak airway pressure			
10 min after induction (T1)	19±2.51	18.23±1.43	0.001
5 min after pneumoperitoneum (T2)	24.1±1.98	18.46±1.22	0.001
10 min after pneumoperitoneum (T3)	25.1±1.91	18.82±1.12	0.001
Immediately after Trendelenburg's position (T4)	27.76±2.07	19.6±1.03	0.001
Dynamic compliance			
10 min after induction (T1)	31.93±1.79	32.66±1.15	0.008
5 min after pneumoperitoneum (T2)	27.8±4.53	29.2±1.62	0.002
10 min after pneumoperitoneum (T3)	27.43±6.15	28.46±1.79	0.001
Immediately after Trendelenburg's position (T4)	25.33±6.61	27.13±2.47	0.004
Airway resistance			
10 min after induction (T1)	12.96±2.92	11.6±0.9	0.023
5 min after pneumoperitoneum (T2)	17.93±5.78	12.1±2.26	0.001
10 min after pneumoperitoneum (T3)	20.1±7.41	13.33±1.66	0.003
Immediately after Trendelenburg's position (T4)	23.56±9.43	14.86±1.73	0.001

VCV: Volume control ventilation, PLV: Pressure-limited ventilation, SD: Standard deviation respectively. The peak airway pressure immediately after Trendelenburg position (T4) was 27.76±2.07 and 19.8±1.03 in the (VCV) and (PLV) groups, respectively. The peak airway pressure was not much increased in the pressure-limited group at all 4 time intervals, i.e., 10 min after induction, 5 min after pneumoperitoneum, 10 min after pneumoperitoneum, and immediately after Trendelenburg position. The airway pressure difference between the two groups was statistically significant.

The study conducted by Kumar and Nanda[15] shows the baseline peak airway pressure was 13.21±1.13 and 18.3±1.74 in the pressure-controlled group (PCV) and volume-controlled group (VCV), respectively. The peak airway pressure at the pneumoperitoneum was 17.58±1.07 and 21.58±3.21 in the PCV and VCV groups, respectively. The peak airway pressure at post-pneumoperitoneum was 15±1.474 and 19.214±1.999 in the PCV and VCV groups, respectively. So, the peak pressure was decreased in the pressure-controlled group (PCV) at all 3-time intervals, i.e., at baseline, pneumoperitoneum, and post-pneumoperitoneum, which coincides with our study. Similarly, Tyagi et al.,[9] study results show that PCV significantly decreased peak airway pressure at 10- and 30-min intervals, which was statistically significant ($P<0.05$).

In our study, the dynamic compliance was higher in the pressure-limited group at all 4-time intervals, i.e.,10 min after induction, 5 min after pneumoperitoneum, 10 min after pneumoperitoneum, and immediately after Trendelenburg position, and this difference between the two groups was statistically significant ($P<0.05$). The study conducted by Tyagi et al.,[9] results show that the dynamic compliance at 5, 10, and 30 min after intubation was 38, 23, 25, and 44, 28, 29 in the volume-controlled (VCV) and pressure-limited (PLV) groups, respectively, and the difference between the two groups was statistically significant ($P=0.02$), which coincides with our study.

The study conducted by Dusitkasem et al., observed that dynamic compliance at 10 min after induction was 30.7±5.38 and 31.9±8.07 in the volume-controlled (VCV) and pressure-regulated volume-controlled (PRVC) groups, respectively. At 30 min after induction, dynamic compliance was 17.5±4.04 and 19.7±4.86 in the VCV and PRVC groups, respectively. Dynamic compliance at 60 min after induction was 17.5±3.74 and 19.9±3.85 in the VCV and PRVC groups, respectively. The difference was statistically significant ($P=0.009$) between the two groups, similar to our study.[16]

In our study, the airway resistance was less in the pressure-limited group at all 4-time intervals, i.e., 10 min after induction, 5 min after pneumoperitoneum, 10 min after pneumoperitoneum, and immediately after Trendelenburg position, and this difference between the two groups was statistically significant ($P<0.05$). But a study conducted by Tyagi et al.,[9] observed that airway resistance at 5, 10, and 30 min after intubation was 12, 14, 14, and 10, 12, 12 in volume-controlled (VCV) and pressure-limited (PLV), respectively, and the difference was statistically not significant ($P=0.082$), which does not coincide with our study.

Limitations of the study

The limitations of our study include the absence of measurements for intrinsic PEEP and reliance solely on noninvasive hemodynamic monitoring.

CONCLUSION

In laparoscopic appendicectomy, one of the most crucial complications to monitor and manage is pulmonary dysfunction. Anesthesiologists often favor the conventional VCV mode due to their familiarity. Nevertheless, VCV, when maintaining constant flow rates, can lead to increased intraoperative airway pressure, potentially raising the risk of lung injury. In contrast, PLV does not allow the pressure to exceed the preset limit. To address this concern, I compared peak airway pressure, dynamic compliance, and airway resistance between the VCV and PLV groups. The results indicate that airway resistance and peak airway pressure remained stable, while dynamic compliance improved with PLV during laparoscopic appendicectomy.

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IJ- Literature review, data collection, data analysis; **GR-** Editing manuscript; **AR-** Review manuscript; **NS-** Manuscript preparation.

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