

## Original Research Article

# A comparison of airway pressure changes in volume-controlled ventilation versus pressure-controlled ventilation with similar tidal volumes in laparoscopic surgery

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## ABSTRACT

**Background:** Whether pressure-controlled ventilation (PCV) is superior to volume-controlled ventilation (VCV) during laparoscopic surgery remains debatable. The strength and uniformity of the evidence on this topic have not been thoroughly examined, representing a significant gap in our knowledge of the comparative benefits of PCV versus VCV in laparoscopic surgery. The present study compared airway pressure changes between PCV and VCV using similar tidal volumes in patients undergoing laparoscopic procedures.

**Methods:** Seventy patients aged between 20 and 70 years, scheduled to undergo laparoscopic surgery and American Society of Anesthesiologists grades I-II, were randomly divided into two groups by computer-generated tables. Group A patients were given VCV after induction of pneumoperitoneum, while group B patients were given PCV after induction of pneumoperitoneum. Airway pressure changes and hemodynamic parameters were measured at 15-minute intervals until the end of the procedure. The primary objective was to compare peak pressure (P-peak) between the two groups, while the secondary objectives were to compare plateau pressure (P-plat), minute volume, and hemodynamic changes.

**Results:** The haemodynamic parameters were comparable at baseline and up to 75 minutes post-procedure. From the 15th minute onwards post-surgery, the mean P-peak, P-plat were significantly lower in the PCV group as compared with the VCV group till the 60th minute post-procedure. The mean minute volume and positive end-expiratory pressure were significantly lower in the VCV than the PCV group at the 30th and 45th minute.

**Conclusion:** The PCV is better than VCV in patients undergoing laparoscopic surgery.

**Keywords:** Airway pressure, Laparoscopic surgery, Pressure-controlled ventilation, Volume-controlled ventilation

## INTRODUCTION

Laparoscopic surgery has rapidly become the technique of choice for major abdominal procedures. However, the technique of laparoscopy involves significant cardiorespiratory adverse effects that should be balanced by safe anaesthetic and ventilator management to maximise the benefits without concerns of safety.<sup>1</sup> Nevertheless, laparoscopic techniques are associated with notable cardiorespiratory side effects, which must be mitigated through safe anaesthetic and ventilatory

strategies to optimise benefits without compromising patient safety. Advances in our knowledge of pressure-volume relationships, along with recent evidence of shear stress-induced injury from elevated airway pressures, have reshaped the concept of safe limits for pressure and volume fluctuations during laparoscopy—particularly in patients with pre-existing pulmonary conditions.<sup>2</sup> Safer ventilation strategies, such as lung-protective modes, the application of positive end-expiratory pressure, and recruitment methods, are being studied and incorporated to mitigate laparoscopy-induced changes.<sup>3</sup>

Volume-controlled ventilation (VCV) is the most commonly used conventional mode in anaesthesia. VCV operates with a fixed flow pattern to deliver a predetermined tidal volume (TV) within a set inspiratory time, thereby maintaining stable minute ventilation (MV). This flow pattern can result in elevated inspiratory pressures, potentially causing shear stress, barotrauma, and volutrauma to the alveoli, which may contribute to microatelectasis and the release of inflammatory mediators—hallmarks of ventilator-induced lung injury.<sup>4</sup> This mode utilises a constant flow to deliver a target TV and thus ensures a satisfactory MV, despite frequently seen high-pressure levels in patients. The mechanical consequences of reduced lung and chest wall compliance, added to the reduction of functional residual capacity induced by the surgical pneumoperitoneum, explain impaired alveolar ventilation and the high pressures.<sup>5</sup>

Pressure-controlled ventilation (PCV) is an alternative mode in laparoscopic surgeries. PCV administers tidal volume using a fixed pressure and set inspiratory duration. Unlike VCV, it features a decelerating flow pattern characterized by a rapid initial rise followed by a gradual decline. This pattern facilitates the delivery of tidal volume at lower peak inspiratory pressures and enhances oxygenation due to the early high flow. However, as lung compliance changes, the delivered tidal volume can fluctuate, posing a risk of both inadequate and excessive ventilation. The PCV has been proposed as an alternative to VCV in the intensive care unit (ICU) patients with adult respiratory distress syndrome.<sup>6</sup>

The two differences between VCV and PCV are the flow pattern and the chosen target. The PCV uses a decelerating flow which reaches the highest possible value at the beginning of inspiration, while having a preset pressure limitation but no minimum TV. Flow diminishes throughout inspiration according to the pressure target, and the resulting TV depends on the pressure limitation and the chest compliance. These features of PCV—rapid tidal volume delivery, altered gas distribution, and a high initial followed by decelerating inspiratory flow—help offset any possible decline in ventilation resulting from pressure restrictions.<sup>7</sup>

Furthermore, the limitation of pressure levels has a positive effect on the patient's haemodynamics and might even reduce the risk of barotrauma.

The superiority of PCV over VCV during laparoscopic surgery remains uncertain and continues to be a topic of debate. In some studies, VCV provides better alveolar ventilation than PCV, while PCV results in better oxygenation in others. The quality and consistency of the evidence on this topic have not been systematically investigated, an important gap in our understanding of the relative advantages of PCV versus VCV in laparoscopic surgery.<sup>8-10</sup> The present study compared airway pressure changes between PCV and VCV using similar tidal volumes in patients undergoing laparoscopic procedures.

## METHODS

The present randomised controlled study was conducted between January 2024 and August 2024 in the major operation theatres of Poona Hospital and Research Centre, a tertiary care hospital, Pune, India. An institutional ethics committee approval (Letter #RECH/ECBHR/2023-24/254 dated 02 December 2023) was obtained before the commencement of the study. The potential advantages and complications of the procedure were discussed with the patients, and written informed consent was obtained from each participant.

### Inclusion criteria

The patients aged between 20 and 70 years, scheduled to undergo laparoscopic surgeries such as cholecystectomy, hernia repair, vaginal hysterectomy, appendicectomy, diagnostic laparoscopy and American Society of Anesthesiologist (ASA) grades I-II were included.

### Exclusion criteria

Patients with cardiovascular diseases, deranged renal and hepatic function tests, patients with pneumonia on chest X-ray, lower respiratory tract infections/upper respiratory tract infections and bronchial asthma were excluded.

Seventy-five patients were evaluated for inclusion. Five patients were excluded. Seventy patients were randomly divided into two groups by computer-generated tables. Group A patients were given VCV after induction of pneumoperitoneum, while group B patients were given PCV after induction of pneumoperitoneum (Figure 1). The sample size was calculated using the formula for comparing two means.

$$n^{11} = \{2SD^2(Z_{\alpha} + Z_{\beta})^2\}/\Delta^2$$

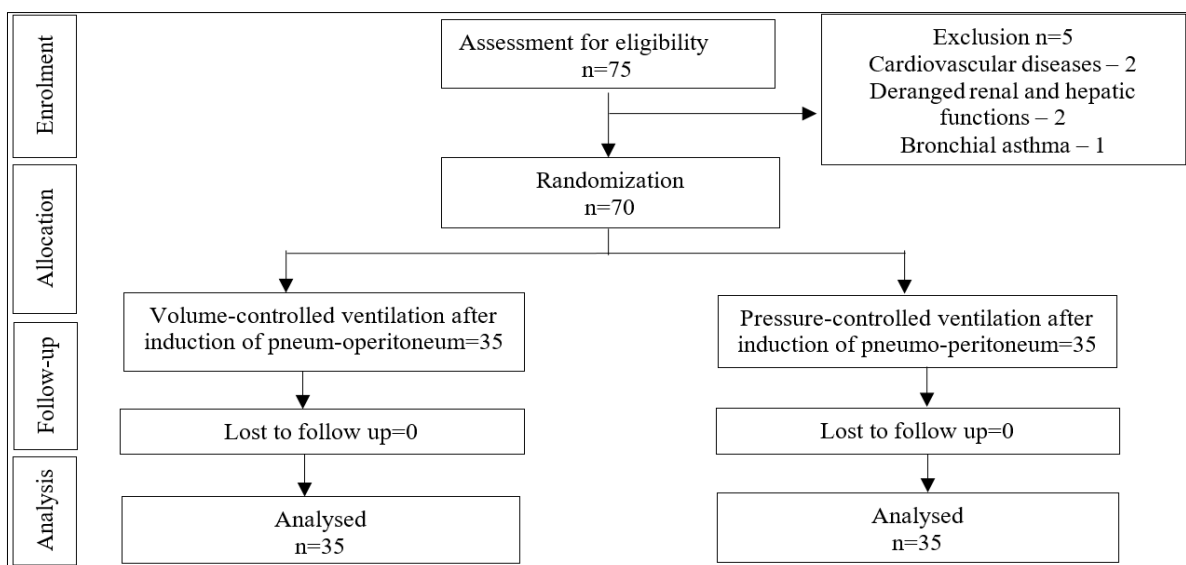
Where n is the number of subjects per group. The calculation was based on the standard deviation (SD) from a previous study.  $\Delta$  denotes the minimum expected difference between the population means.  $Z_{\alpha}$  represents the standard normal variate for 5% type I error ( $p < 0.05$ ), which is 1.96, and  $Z_{\beta}$  corresponds to 80% power (type II error of 20%), with a value of 0.842. The mean  $\pm$  SD of peak airway pressure (P-peak) was reported as 20.1  $\pm$  2.9 in the PCV group and 23.3  $\pm$  3.8 in the VCV group.<sup>12</sup> The pooled SD was 4.7. Based on these values, 35 patients were included in each group.

A detailed pre-anaesthesia check-up was conducted for anaesthesia fitness. In the operating room, sufficient intravenous (IV) access was verified. Heart rate, non-invasive blood pressure (NIBP), mean arterial blood pressure, pulse oximeter, electrocardiogram, SpO<sub>2</sub> and end-tidal carbon dioxide (EtCO<sub>2</sub>) were monitored after intubation. Anaesthesia was induced with fentanyl 2  $\mu$ g/kg IV, injection propofol 2 mg/kg IV and injection atracurium 0.5 mg/kg IV. As per the anaesthesia protocol, injection

Ondansetron 4 mg was given to all the patients as an antiemetic. Intubation with an appropriately sized cuffed oral endotracheal tube was done, and placement was confirmed by auscultation over the chest. The orogastric tube was placed to deflate the stomach. The tube was removed at the end of the surgery. The anaesthesia was maintained with oxygen: air 50:50, sevoflurane 1–2.5% (adjusted according to hemodynamic parameters) with controlled ventilation. EtCO<sub>2</sub> was maintained between 30–35 mm of Hg injection Atracurium in supplemental doses of 0.1 mg/kg was used. The airway pressure changes and hemodynamic parameters were measured at intervals of 15 minutes till the end of the procedure, irrespective of the type of laparoscopic surgery. The maximum airway pressure in both VCV and PCV was kept ≤40 cm H<sub>2</sub>O to prevent a rare risk of barotrauma.

**Statistical tests**

The data on categorical variables is shown as n (% of cases), and the data on normally distributed continuous variables is presented as mean and SD. The comparison of categorical variable distribution between groups was performed using the Chi-square test or Fisher’s exact test. The inter-group comparison of means of normally distributed continuous variables was done using an independent sample t-test. Normality of the data was assessed before conducting the t-test on the study variables. A p<0.05 was considered statistically significant. The data was analyzed using statistical package for social sciences (SPSS version 24.0, IBM Corporation, USA) for MS Windows.



**Figure 1: Consolidated standards of reporting trials (CONSORT) flow diagram.**

**RESULTS**

Of 75 patients assessed for eligibility, 5 were excluded (cardiovascular diseases – 2, deranged renal and hepatic functions – 2, bronchial asthma – 1). Seventy patients were randomized into two groups (Figure 1).

Group A patients were given VCV after induction of pneumoperitoneum, and Group B patients were given PCV after the same. The mean age, gender, mean body mass index (BMI), ASA grades and the mean duration of surgery were comparable between the two groups (Table 1). The mean pulse rate, mean arterial pressure, respiratory

rate, oxygen saturation, and EtCO<sub>2</sub> were comparable at baseline and up to 75 minutes post-procedure. The mean P-peak, mean plateau pressure (P-plat), MV and positive end-expiratory pressure (PEEP) in the VCV and PCV groups were similar at the baseline. However, from the 15th minute onwards, the mean P-peak, P-plat were significantly lower in the PCV group as compared with the VCV group till the 60th minute post-procedure. The mean minute volume and PEEP were significantly lower in the VCV than the PCV group at the 30th and 45th minute, while they were comparable in the 15th minute, 60th and 75th minute (Tables 2-5). The driving pressure was comparable between the two groups throughout the study period (Table 6).

**Table 1: Comparison of baseline characteristics between the two groups.**

Characteristics	VCV, N (%)	PCV, N (%)	P, N (%)
Age±SD in years	36.1±10.1	37.7±10.9	0.810 *
Gender	Male	7 (20.0)	0.770**
	Female	26 (74.3)	

Continued.

Characteristics	VCV, N (%)	PCV, N (%)	P, N (%)
Mean BMI±SD in kg/m <sup>2</sup>	22.3±3.2	23.2±3.0	0.370*
ASA grades	I	30 (85.7)	0.750**
	II	7 (20.0)	
Mean duration of laparoscopic surgery±SD in minutes	64.3±19.9	61.5±23.2	0.230*

\*An unpaired t-test was used, \*\*the Chi-square test was used, VCV - volume-controlled ventilation, PCV - pressure-controlled ventilation, SD – standard deviation, BMI – body mass index and ASA – American Society of Anesthesiologists

**Table 2: Comparison of peak inspiratory pressure.**

P-peak (cm H <sub>2</sub> O)	VCV, mean±SD	PCV, mean±SD	P value
Baseline	18.6±3.5	19.0±3.9	0.49
15 min	24.1±4.8	20.5±3.0	0.01
30 min	23.9±4.9	20.4±2.9	0.01
45 min	23.8±3.8	20.7±2.8	0.01
60 min	23.4±4.0	20.4±2.9	0.01
75 min	22.6±4.2	20.8±3.3	0.08

An unpaired t-test was used, VCV - Volume-controlled ventilation and PCV - pressure-controlled ventilation

**Table 3: Comparison of plateau pressure,**

P-plateau (cm H <sub>2</sub> O)	VCV, mean±SD	PCV, mean±SD	P value
Baseline	17.2±3.1	17.7±3.6	0.44
15 min	22.7±4.4	19.1±2.7	0.01
30 min	22.5±4.5	19.1±2.6	0.01
45 min	22.4±3.4	19.4±2.5	0.01
60 min	22.0±3.6	19.0±2.6	0.01
75 min	21.4±3.8	20.0±2.9	0.09

An unpaired t-test was used, VCV - volume-controlled ventilation and PCV - pressure-controlled ventilation

**Table 4: Comparison of minute volume.**

Minute volume, l/minute	VCV, mean±SD	PCV, mean±SD	P value
Baseline	7.8±0.7	7.8±0.6	0.81
15 min	8.9±0.4	8.6±0.9	0.09
30 min	8.9±0.9	9.6±0.1	0.02
45 min	8.5±0.8	9.8±0.5	0.02
60 min	8.2±0.7	9.0±0.6	0.13
75 min	8.4±0.9	8.9±0.6	0.33

An unpaired t-test was used, VCV - volume-controlled ventilation and PCV - pressure-controlled ventilation

**Table 5: Comparison of positive end-expiratory pressure.**

PEEP (cm H <sub>2</sub> O)	VCV, mean±SD	PCV, mean±SD	P value
Baseline	8.8±0.9	8.8±0.8	0.87
15 min	8.9±0.6	9.0±1.1	0.08
30 min	9.7±1.1	10.6±0.2	0.01
45 min	9.5±1.0	10.8±0.7	0.01
60 min	9.2±0.9	10.0±0.8	0.12
75 min	9.4±1.1	9.9±0.8	0.39

An unpaired t-test was used, PEEP - positive end-expiratory pressure, VCV - volume-controlled ventilation, PCV - pressure-controlled ventilation and SD – standard deviation

**Table 6: Comparison of driving pressure.**

Driving pressure (cm H <sub>2</sub> O)	VCV, mean±SD	PCV, mean±SD	P value
Baseline	8.6±0.6	8.9±0.6	0.11
15 min	11.8±1.1	11.7±0.7	0.77

Continued.

Driving pressure (cm H <sub>2</sub> O)	VCV, mean±SD	PCV, mean±SD	P value
30 min	11.8±1.2	11.8±1.5	0.88
45 min	11.5±1.1	11.5±1.0	0.84
60 min	11.3±1.3	11.3±0.8	0.97
75 min	11.9±1.2	11.8±1.0	0.78

An unpaired t-test was used, VCV - volume-controlled ventilation, PCV - pressure-controlled ventilation, SD – standard deviation

## DISCUSSION

VCV is the most commonly used conventional mode in anaesthesia. VCV follows a constant flow pattern to deliver a preset TV in the preset inspiratory time, thus ensuring constant MV. PCV mode came as an alternative mode in laparoscopic surgeries. PCV delivers TV at a preset pressure and inspiratory time. The flow, unlike VCV, is decelerating. The question of whether PCV offers advantages over VCV during laparoscopic surgery remains unresolved.<sup>8,13</sup>

In the present study, the mean P-peak, mean P-plat, MV, and PEEP in the VCV and PCV groups were similar at baseline. However, from the 15th minute onwards, the mean P-peak, P-plat were significantly lower in the PCV group as compared with the VCV group till the 60th minute post-procedure. The mean MV and PEEP were significantly lower in the VCV than the PCV group at the 30th and 45th minute.

Tyagi et al conducted a randomized controlled study in non-obese patients undergoing laparoscopic cholecystectomy at Guru Teg Bahadur Hospital, Delhi, India. The study reported that compared with VCV, PCV resulted in a significant decrease in mean (SD) P-peak at 10 min (20.4 (2.7) versus 24.0 (4.7) cm H<sub>2</sub>O, p=0.004) and 30 min (20.7 (3.0) versus 23.9 (4.9) cm H<sub>2</sub>O, p=0.015) and an increase in mean airway pressure at 10 min (10.5 (0.9) versus 9.6 (1.1) cm H<sub>2</sub>O, p = 0.007) and 30 min (10.5 (1.1) versus 9.6 (1.2) cm H<sub>2</sub>O, p=0.016) after the start of surgery. The study concluded that the PCV is a safe alternative and offers some advantages over VCV during laparoscopic cholecystectomy in non-obese patients.<sup>14</sup>

A randomized controlled study conducted on obese patients undergoing laparoscopic cholecystectomy by Movassagi et al at Tabriz University of Medical Sciences, Iran, reported that the P-plat and mean airway pressure in the two groups didn't have a significant difference between the two groups but P-peak in 35 and 55 minutes after pneumoperitoneum was significantly higher in the VCV group than the PCV group.<sup>15</sup>

A randomized controlled study conducted on patients with BMI <30 kg/m<sup>2</sup> undergoing laparoscopic surgery by Sen et al at Haseki Training and Research Hospital, Istanbul, Turkey reported that the P-peak levels observed before (18.9±3.8 versus 15±2.2 cmH<sub>2</sub>O) and during (23.3±3.8 versus 20.1±2.9 cmH<sub>2</sub>O) pneumoperitoneum in group VCV were significantly higher.<sup>12</sup>

A randomized controlled study conducted on patients with colorectal cancer scheduled for laparoscopic colectomy, by Choi et al at Seoul, Korea, reported that the P-peak at T2 (the primary end-point) was lower in the PCV group than in the VCV group (26.57±3.67 versus 21.65±2.27 mm Hg). The P-plat at T2 and T3 were higher in the VCV group than in the PCV group (T2: 21.91±4.27 versus 18.17±2.13 mm Hg; T3: 15.17±4.07 versus 13.09±2.78 mm Hg). The overall P-peak and P-plat were lower in the PCV group than in the VCV group (F [1, 113.225]=5.710, p=0.021 and F [1, 118.725]=6.540, p=0.014). However, there were no significant differences between the two groups with respect to P mean (F [3.0, 42.0]=1.314, p=0.283; Wilk's lambda=0.021, partial eta<sup>2</sup>=0.086).<sup>16</sup>

In the present study, the mean pulse rate, mean arterial pressure, respiratory rate, oxygen saturation, and EtCO<sub>2</sub> were comparable at baseline and up to 75 minutes post-procedure. Tyagi et al reported that the gas exchange and haemodynamic stability were similar in both VCV and PCV groups.<sup>14</sup> Gupta et al conducted a randomized controlled study on obese patients undergoing laparoscopic cholecystectomy at Kolkata, India. The study reported that the haemodynamic variables were similar in both the VCV and PCV groups, and SpO<sub>2</sub> and EtCO<sub>2</sub> were comparable in both groups.<sup>9</sup> Movassagi et al observed that there were no significant differences between the two groups (VCV and PCV) regarding PO<sub>2</sub>, PCO<sub>2</sub> and pH, except 35 and 55 minutes after pneumoperitoneum.

The study further stated that in the mentioned times, patients in the PCV group had significantly higher PO<sub>2</sub> levels compared to the VCV group.<sup>15</sup> Sen et al reported that postoperative partial arterial oxygen pressure (PaO<sub>2</sub>) values (98±12 versus 86±11 mmHg) and arterial carbon dioxide pressure (PaCO<sub>2</sub>) values (41.8±5.4 versus 36.7±3.5 mmHg) were higher in group PCV during pneumoperitoneum.<sup>12</sup> Choi et al reported that there were no significant differences between the PCV group and the VCV group with respect to PaO<sub>2</sub>/FiO<sub>2</sub>, and A-aDO<sub>2</sub> (F [1, 99920.503]=1.304, p=0.260 and F [1, 9627.718]=1.177, p=0.284, respectively).<sup>16</sup>

Creation of a pneumoperitoneum during laparoscopic surgery is associated with hemodynamic changes, including an increase in cardiac workload. PCV may produce an enhanced effect by the increased mean airway pressure, which may adversely affect hemodynamic variables through its effects on pleural pressure.<sup>17</sup> Despite a significant increase in the mean airway pressure with PCV, we did not observe any significant change in hemodynamic variables in this study. This may again be related to the small magnitude of change in mean airway

pressure. Inflation pressures during mechanical ventilation hold considerable clinical importance, as elevated pressures increase the risk of barotrauma. Barotrauma refers to a condition where excessive inflation pressures cause alveolar rupture, leading to leakage of air into the surrounding tissues and resulting in pulmonary interstitial emphysema.<sup>18</sup>

The decrease in P-peak associated with PCV is likely due to its decelerating inspiratory flow pattern, with the maximum value reached early in inspiration. This is then followed by a deceleration of the flow rate, resulting in its characteristic form. The initial rapid flow leads to early alveolar inflation, and PCV may thus be associated with an increase in mean airway pressure.<sup>19</sup> The mean airway pressure is related to the mean alveolar pressure and may directly improve oxygenation.

### Limitations

The patients enrolled in our study didn't have any cardiac or underlying pulmonary diseases, which may alter clinical findings; so, our results may not apply to populations with underlying pulmonary or cardiac problems. The study population was from a single institution, with a small sample size. A multicentric study with a larger sample size should be conducted for the generalizability of these results and to substantiate the findings reported in this paper.

### CONCLUSION

In patients undergoing laparoscopic surgery, the PCV mode delivered the targeted TV at significantly lower airway pressures as compared to VCV. The present study showed that the use of PCV led to lower airway pressure (peak and plateau), and higher MV in eliminating carbon dioxide for surgical patients. Under typical conditions, the choice between PCV and VCV may hold minimal clinical impact and can be based on the clinician's discretion.

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