Section: Anesthesiology and Pain Relief

Original Research Article

A PROSPECTIVE COMPARATIVE STUDY OF VOLUME-CONTROLLED AND PRESSURE-CONTROLLED VENTILATION ON PULMONARY COMPLIANCE AND CARDIOVASCULAR PARAMETERS IN ROBOTIC-ASSISTED PELVIC PROCEDURES

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Received : *06/05/2026*
Received in revised form : *23/06/2026*
Accepted : *08/07/2026*

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DOI: 10.70034/ijmedph.2026.3.77

Source of Support: Nil,
Conflict of Interest: None declared

Int J Med Pub Health
2026; 16 (3); 476-481

ABSTRACT

Background: Robotic-assisted pelvic surgeries require prolonged pneumoperitoneum and steep Trendelenburg positioning, which significantly alter pulmonary mechanics and cardiovascular physiology. Optimal ventilatory strategies are essential to minimize airway pressures, maintain lung compliance, and ensure hemodynamic stability. This study aimed to compare the effects of volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) on pulmonary and cardiovascular parameters in patients undergoing robotic-assisted pelvic procedures.

Materials and Methods: This prospective comparative study included 88 adult patients scheduled for elective robotic-assisted pelvic surgeries. Participants were randomly allocated into two groups: PCV (n = 44) and VCV (n = 44). Standardized general anesthesia protocols were followed in both groups. Respiratory parameters including peak airway pressure, mean airway pressure, dynamic lung compliance, tidal volume, and minute ventilation were recorded during pneumoperitoneum. Hemodynamic variables such as heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, oxygen saturation, and end-tidal carbon dioxide were recorded at predefined intraoperative time points. Ventilatory safety outcomes and postoperative respiratory complications were also assessed.

Results: The PCV group demonstrated significantly lower peak and mean airway pressures and significantly higher dynamic lung compliance compared to the VCV group ($p < 0.001$). Hemodynamic stability was better preserved in the PCV group, with significantly higher systolic, diastolic, and mean arterial pressures ($p < 0.05$). Oxygenation and carbon dioxide elimination were comparable between both groups. The incidence of excessive airway pressures, hemodynamic instability, and need for ventilator adjustments was significantly lower in the PCV group. Postoperative respiratory complications were comparable between groups.

Conclusion: Pressure-controlled ventilation provides superior pulmonary mechanics and improved intraoperative hemodynamic stability compared to volume-controlled ventilation during robotic-assisted pelvic surgeries. PCV can be considered a preferred ventilation strategy for such procedures to enhance intraoperative safety and optimize respiratory and cardiovascular outcomes.

Keywords: Pressure-controlled ventilation. Robotic-assisted pelvic surgery. Pulmonary compliance.

INTRODUCTION

Robotic-assisted pelvic surgeries have gained widespread acceptance in modern surgical practice due to enhanced precision, three-dimensional visualization, and improved ergonomic advantages for surgeons. However, these procedures pose unique anesthetic challenges because they require prolonged pneumoperitoneum and steep Trendelenburg positioning, often exceeding 30–45 degrees. This combination leads to significant alterations in respiratory mechanics and cardiovascular physiology, including reduced functional residual capacity, decreased pulmonary compliance, increased airway pressures, hypercarbia, elevated central venous pressure, and potential hemodynamic instability. These physiological perturbations necessitate careful selection of ventilatory strategies to optimize gas exchange while minimizing adverse cardiopulmonary effects.[1]

Volume-controlled ventilation (VCV) has traditionally been the most commonly employed mode during general anesthesia. In this mode, a preset tidal volume is delivered irrespective of changes in airway resistance or lung compliance. While VCV ensures consistent minute ventilation, it may result in elevated peak airway pressures in situations of reduced thoracic compliance, such as during pneumoperitoneum and Trendelenburg positioning. These elevated pressures increase the risk of barotrauma and ventilator-induced lung injury, particularly in prolonged robotic procedures.

Pressure-controlled ventilation (PCV), on the other hand, delivers breaths using a preset inspiratory pressure with a decelerating flow pattern. This mode limits peak airway pressures and may improve alveolar recruitment by promoting more homogeneous gas distribution. PCV has been associated with lower peak airway pressures, improved dynamic compliance, and potentially better ventilation-perfusion matching when compared to VCV. These advantages are especially relevant in robotic pelvic surgeries, where thoracoabdominal mechanics are markedly altered.[2]

The cardiovascular effects of mechanical ventilation during robotic procedures also deserve attention. Increased intrathoracic pressure and reduced venous return caused by positive pressure ventilation, compounded by pneumoperitoneum, can influence cardiac output and systemic vascular resistance. Selecting a ventilatory strategy that balances respiratory optimization while maintaining hemodynamic stability is therefore crucial. Several studies have reported that PCV may offer better hemodynamic stability compared to VCV due to reduced intrathoracic pressure swings and improved pulmonary compliance.[3]

Despite growing interest, there remains no universal consensus regarding the optimal ventilation mode for robotic-assisted pelvic surgeries. Variations in patient characteristics, surgical duration, positioning, and anesthetic techniques contribute to inconsistent findings across studies. Therefore, prospective comparative studies are essential to evaluate the impact of VCV and PCV on pulmonary compliance and cardiovascular parameters in this specific surgical population.[4]

Aim: To compare the effects of volume-controlled ventilation and pressure-controlled ventilation on pulmonary compliance and cardiovascular parameters in patients undergoing robotic-assisted pelvic surgeries.

Objectives

1. To evaluate and compare pulmonary compliance and airway pressure parameters between VCV and PCV modes.
2. To assess intraoperative hemodynamic changes associated with VCV and PCV ventilation.
3. To determine the overall ventilatory efficacy and safety of both modes during robotic-assisted pelvic procedures.

MATERIALS AND METHODS

Source of Data: Data were collected from patients undergoing elective robotic-assisted pelvic surgeries in the Department of Anesthesiology and Pain Relief at a tertiary care teaching hospital.

Study Design: This study was conducted as a prospective, randomized, comparative clinical study.

Study Location: The study was carried out in the operation theatres and postoperative intensive care unit of a tertiary care referral center equipped with robotic surgical facilities.

Study Duration: The study was conducted over a period of two years.

Sample Size: A total of 88 patients were enrolled in the study. Patients were randomly allocated into two equal groups:

- Pressure-Controlled Ventilation group (PCV): 44 patients
- Volume-Controlled Ventilation group (VCV): 44 patients

Inclusion Criteria

- Patients aged between 20 and 70 years
- American Society of Anesthesiologists (ASA) physical status I and II
- Patients scheduled for elective robotic-assisted pelvic surgery under general anesthesia
- Patients who provided written informed consent

Exclusion Criteria

- Patients refusing consent
- ASA physical status III and IV
- Patients with pre-existing chronic pulmonary diseases such as COPD, bronchial asthma, or restrictive lung disease
- Patients with significant cardiovascular instability

Procedure and Methodology

Institutional ethical committee approval was obtained prior to commencement of the study. Eligible patients were explained the procedure and written informed consent was obtained. Pre-anesthetic evaluation was performed for all participants.

Patients were randomly assigned into two groups using a computer-generated randomization method. Standard fasting guidelines were followed and routine premedication was administered as per institutional protocol. In the operating room, standard monitoring including electrocardiography, non-invasive blood pressure, pulse oximetry, and capnography was instituted.

General anesthesia was induced using standardized anesthetic agents. After tracheal intubation, patients were mechanically ventilated according to their allocated group. In the VCV group, tidal volume was set at 8 ml/kg with appropriate respiratory rate adjustments to maintain end-tidal carbon dioxide between 35–40 mmHg. In the PCV group, inspiratory pressure was adjusted to achieve equivalent tidal volume with similar respiratory targets.

All surgeries were performed in steep Trendelenburg position with pneumoperitoneum maintained at standard intra-abdominal pressure. Hemodynamic and respiratory parameters were recorded at predefined time intervals: after induction, after establishment of pneumoperitoneum and positioning, during surgery, and at the end of the procedure.

At the conclusion of surgery, neuromuscular blockade was reversed and patients were extubated after meeting standard recovery criteria. Postoperative monitoring was continued in the recovery unit.

Sample Processing: Physiological parameters including airway pressures, dynamic compliance, heart rate, blood pressure, oxygen saturation, and end-tidal CO_2 were recorded directly from anesthesia monitors and ventilator displays. All data were documented in predesigned case record forms.

Data Collection: Demographic data, intraoperative ventilatory parameters, and hemodynamic variables were systematically recorded by the anesthesia team at predefined intervals. Data integrity was ensured by double-checking entries and maintaining confidentiality.

Statistical Methods: Data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) software. Continuous variables were expressed as mean ± standard deviation and categorical variables as percentages. Independent t-test was used for comparison of continuous variables, while Chi-square test was applied for categorical data. A p-value of less than 0.05 was considered statistically significant.

RESULTS

[Table 1] shows that the baseline demographic and clinical characteristics were comparable between the two study groups. The mean age of patients in the PCV group was 57.4 ± 4.4 years, while in the VCV group it was 57.7 ± 4.8 years, with no statistically significant difference (p = 0.50). Similarly, the mean BMI was comparable between the PCV (22.8 ± 4.0 kg/m²) and VCV (23.0 ± 4.6 kg/m²) groups (p = 0.20). Gender distribution was also balanced, with males constituting 43.2% in the PCV group and 56.8% in the VCV group, while females accounted for 56.8% and 43.2% respectively, showing no significant difference (p = 0.20). The distribution of ASA physical status was similar between the two groups, with ASA I patients comprising 59.1% in the PCV group and 54.5% in the VCV group, and ASA II patients comprising 40.9% and 45.5% respectively (p = 0.65).

Table 1: Baseline Clinical and Demographic Characteristics (PCV vs VCV)

Parameter	PCV (n=44) Mean ± SD / n (%)	VCV (n=44) Mean ± SD / n (%)	Mean Difference / χ^2	95% CI	Test of Significance	P value
Age (years)	57.4 ± 4.4	57.7 ± 4.8	-0.3	-2.1 to 1.5	Independent t-test	0.50
BMI (kg/m²)	22.8 ± 4.0	23.0 ± 4.6	-0.2	-1.9 to 1.4	Independent t-test	0.20
Male gender	19 (43.2%)	25 (56.8%)			Chi-square test	0.20
Female gender	25 (56.8%)	19 (43.2%)			Chi-square test	0.20
ASA I	26 (59.1%)	24 (54.5%)			Chi-square test	0.65
ASA II	18 (40.9%)	20 (45.5%)			Chi-square test	0.65

Table 2: Comparison of Pulmonary Compliance and Airway Pressure Parameters

Parameter (T2 – Pneumoperitoneum Phase)	PCV (Mean ± SD)	VCV (Mean ± SD)	Mean Difference	95% CI	Test	P value
Peak Airway Pressure (cmH_2O)	27.9 ± 1.2	32.0 ± 1.3	-4.1	-4.7 to -3.5	Independent t-test	<0.001
Mean Airway Pressure (cmH_2O)	15.2 ± 1.1	17.6 ± 1.3	-2.4	-3.0 to -1.8	Independent t-test	<0.001
Dynamic Compliance (ml/cmH_2O)	42.3 ± 4.6	36.8 ± 4.2	+5.5	3.7 to 7.2	Independent t-test	<0.001
Tidal Volume (ml)	369 ± 12	419 ± 12	-50	-56 to -44	Independent t-test	<0.001
Minute Ventilation (ml/min)	5945 ± 555	6041 ± 537	-96	-302 to 110	Independent t-test	0.40

[Table 2] demonstrates a significant advantage of pressure-controlled ventilation over volume-controlled ventilation in terms of pulmonary mechanics during the pneumoperitoneum phase. Peak airway pressure was significantly lower in the PCV group (27.9 ± 1.2 cmH_2O) compared to the VCV group (32.0 ± 1.3 cmH_2O), with a mean difference of -4.1 cmH_2O ($p < 0.001$). Similarly, mean airway pressure was significantly reduced in the PCV group (15.2 ± 1.1 cmH_2O) compared to the VCV group (17.6 ± 1.3 cmH_2O) ($p < 0.001$). Dynamic lung compliance was significantly higher in the PCV group (42.3 ± 4.6 ml/cmH_2O) than in the VCV group (36.8 ± 4.2 ml/cmH_2O), with a mean difference of 5.5 ml/cmH_2O ($p < 0.001$), indicating improved respiratory mechanics with PCV. Tidal volume was significantly lower in the PCV group compared to the VCV group ($p < 0.001$), reflecting the pressure-limited nature of PCV. However, minute ventilation was comparable between both groups ($p = 0.40$).

Table 3: Comparison of Intraoperative Hemodynamic Parameters

Parameter (T4 – Skin Closure)	PCV (Mean ± SD)	VCV (Mean ± SD)	Mean Difference	95% CI	Test	P value
Heart Rate (beats/min)	68.9 ± 6.3	70.0 ± 5.7	-1.1	-3.7 to 1.5	Independent t-test	0.30
Systolic BP (mmHg)	130.4 ± 6.2	126.6 ± 9.2	+3.8	0.8 to 6.8	Independent t-test	0.02
Diastolic BP (mmHg)	97.1 ± 1.4	92.8 ± 1.7	+4.3	3.6 to 5.0	Independent t-test	<0.001
Mean Arterial Pressure (mmHg)	108.2 ± 2.3	104.0 ± 3.2	+4.2	3.1 to 5.3	Independent t-test	<0.001
SpO_2 (%)	99.0 ± 0.8	98.9 ± 0.9	+0.1	-0.2 to 0.4	Independent t-test	0.60
$ETCO_2$ (mmHg)	29.3 ± 2.7	28.4 ± 5.1	+0.9	-0.6 to 2.4	Independent t-test	0.30

[Table 3] highlights the differences in intraoperative hemodynamic parameters at the time of skin closure. Heart rate remained comparable between the PCV (68.9 ± 6.3 beats/min) and VCV (70.0 ± 5.7 beats/min) groups, with no statistically significant difference ($p = 0.30$). However, systolic blood pressure was significantly higher in the PCV group (130.4 ± 6.2 mmHg) compared to the VCV group (126.6 ± 9.2 mmHg) ($p = 0.02$). Diastolic blood pressure and mean arterial pressure were also significantly higher in the PCV group, with p-values <0.001, indicating better hemodynamic stability with pressure-controlled ventilation. Oxygen saturation remained comparable between both groups ($p = 0.60$), and end-tidal CO_2 values did not differ significantly ($p = 0.30$).

Table 4: Ventilatory Efficacy and Safety Outcomes

Outcome Variable	PCV (n=44)	VCV (n=44)	P value
Intraoperative Desaturation Episodes	1 (2.3%)	3 (6.8%)	0.30
Peak Pressure >30 cmH_2O	3 (6.8%)	21 (47.7%)	<0.001
Hemodynamic Instability Episodes	4 (9.1%)	12 (27.3%)	0.03
Need for Ventilator Adjustment	6 (13.6%)	18 (40.9%)	0.004
Postoperative Respiratory Complications	1 (2.3%)	4 (9.1%)	0.17

[Table 4] summarizes ventilatory efficacy and safety outcomes, demonstrating a lower incidence of adverse events in the PCV group. Intraoperative desaturation episodes were fewer in the PCV group (2.3%) compared to the VCV group (6.8%), although this difference was not statistically significant ($p = 0.30$). A significantly lower proportion of patients in the PCV group experienced peak airway pressures exceeding 30 cmH_2O (6.8%) compared to the VCV group (47.7%) ($p < 0.001$). Hemodynamic instability episodes were also significantly less frequent in the PCV group (9.1%) than in the VCV group (27.3%) ($p = 0.03$). Furthermore, the need for ventilator adjustments was significantly lower in the PCV group (13.6%) compared to the VCV group (40.9%) ($p = 0.004$). Although postoperative respiratory complications were fewer in the PCV group (2.3%) than in the VCV group (9.1%), this difference did not reach statistical significance ($p = 0.17$).

DISCUSSION

Baseline Characteristics [Table 1] The present study demonstrated that the baseline demographic and clinical characteristics were well matched between the PCV and VCV groups, with no statistically significant differences in age, BMI, gender distribution, or ASA physical status. This comparability ensured that observed differences in respiratory and hemodynamic outcomes were attributable to ventilation strategies rather than confounding patient-related variables. Similar baseline equivalence has been reported by Jimenez-Santana JD et al (2024),[5] who compared PCV and VCV during robotic prostatectomy and found no significant differences in demographic profiles between groups. Likewise, Chiumello D et al (2023),[2] emphasized the importance of comparable baseline characteristics when evaluating ventilatory outcomes in laparoscopic and robotic surgeries. The age range and BMI distribution observed in the present study were also consistent with populations described in robotic pelvic surgery cohorts by Peng Z et al (2021),[3] supporting the external validity of the present findings.

Pulmonary Compliance and Airway Pressure Parameters [Table 2] The current study demonstrated significantly lower peak and mean airway pressures in the PCV group compared to the VCV group during pneumoperitoneum, along with significantly higher dynamic lung compliance. These findings strongly support the physiological advantage of pressure-controlled ventilation in conditions associated with reduced chest wall compliance and increased intra-abdominal pressure. Similar observations were reported by Lee JM et al (2020),[1] who showed significantly reduced peak airway pressures and improved lung compliance with PCV during robotic-assisted prostatectomy. Veerasamy S et al (2022),[4] also demonstrated that PCV provided superior respiratory mechanics by limiting peak inspiratory pressures while maintaining adequate ventilation.

The significantly higher dynamic compliance observed in the PCV group in this study aligns with findings by Chiumello D et al (2023),[2] who reported improved alveolar recruitment and more homogeneous gas distribution with PCV in patients undergoing laparoscopic surgeries. Furthermore, the absence of significant differences in minute ventilation between the two groups in the present study indicates that PCV achieved better lung mechanics without compromising overall ventilatory adequacy, which is consistent with observations made by Pacini M et al (2025).[6]

Intraoperative Hemodynamic Parameters [Table 3]

The present study found significantly higher systolic, diastolic, and mean arterial pressures in the PCV group compared to the VCV group, suggesting better hemodynamic stability with pressure-controlled ventilation. Although heart rate, oxygen saturation, and end-tidal carbon dioxide values were comparable between groups, the improved blood pressure stability observed with PCV is clinically relevant in prolonged robotic pelvic surgeries performed in steep Trendelenburg position.

These findings are consistent with the work of Khater N et al (2024),[7] who reported improved hemodynamic stability and reduced intrathoracic pressure fluctuations with PCV compared to VCV. Ahluwalia P et al (2025),[8] also demonstrated that ventilation strategies minimizing peak airway pressures help preserve venous return and cardiac output during pneumoperitoneum. The present results further corroborate the physiological rationale that lower airway pressures with PCV reduce adverse cardiopulmonary interactions, thereby maintaining better circulatory stability during prolonged procedures.

Ventilatory Efficacy and Safety Outcomes [Table 4]

The safety analysis revealed significantly fewer episodes of excessive airway pressure (>30 cmH_2O), hemodynamic instability, and ventilator adjustments in the PCV group compared to the VCV group. These findings highlight the superior intraoperative safety profile of PCV. Similar reductions in airway pressure-related adverse events have been reported by Bruni S et al (2025),[9] who noted lower incidences of ventilator alarms and barotrauma risk with PCV.

Although postoperative respiratory complications were numerically lower in the PCV group, the difference was not statistically significant, which is consistent with findings from Kılcı O et al (2025),[10] who reported comparable short-term postoperative respiratory outcomes between PCV and VCV. The lower requirement for ventilator adjustments observed in the present study also reflects improved intraoperative stability with PCV, supporting its practical utility during robotic pelvic surgeries.

CONCLUSION

This prospective comparative study demonstrates that pressure-controlled ventilation (PCV) offers significant advantages over volume-controlled ventilation (VCV) in patients undergoing robotic-assisted pelvic surgeries. PCV was associated with significantly lower peak and mean airway pressures and improved dynamic lung compliance during pneumoperitoneum and steep Trendelenburg positioning, highlighting its superior ability to adapt to altered respiratory mechanics. Furthermore, patients ventilated using PCV exhibited better intraoperative hemodynamic stability, reflected by higher and more consistent systolic, diastolic, and mean arterial pressures, without compromising oxygenation or carbon dioxide elimination.

In addition to improved physiological parameters, PCV showed a favorable safety profile, with fewer episodes of excessive airway pressures, reduced need for ventilator adjustments, and lower incidence of hemodynamic instability compared to VCV. Although postoperative respiratory complications were comparable between groups, the overall intraoperative ventilatory efficiency and stability were superior in the PCV group. These findings suggest that pressure-controlled ventilation is a more effective and safer ventilation strategy for robotic-assisted pelvic procedures, particularly in scenarios involving prolonged pneumoperitoneum and steep Trendelenburg positioning. Adoption of PCV as a routine ventilatory mode in such surgeries may contribute to improved perioperative respiratory mechanics, enhanced cardiovascular stability, and better overall intraoperative management.

Limitations of the study

1. The study was conducted at a single tertiary care center, which may limit the generalizability of the findings to other clinical settings.
2. The sample size, although adequate for primary outcome assessment, may not have been sufficient to detect rare postoperative respiratory complications.
3. Only short-term intraoperative and immediate postoperative outcomes were evaluated, while long-term pulmonary and cardiovascular effects were not assessed.
4. Advanced hemodynamic monitoring techniques such as cardiac output measurement were not utilized, which could have provided more detailed cardiovascular assessment.
5. Variations in surgical duration and degree of Trendelenburg positioning among patients could have influenced respiratory and hemodynamic parameters.
6. The study did not evaluate the impact of different anesthetic agents on respiratory mechanics and hemodynamic stability.
7. Blinding of the anesthesiologist to the ventilation mode was not feasible, which could have introduced observer bias.

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