

EFFECT OF PRESSURE-REGULATED VOLUME CONTROL VERSUS PRESSURE-CONTROL VENTILATION ON ARTERIAL BLOOD GAS PARAMETERS IN PEDIATRIC PATIENTS UNDERGOING ELECTIVE SURGERIES

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Abstract

Background: Ventilation mode selection is important in pediatric laparoscopic surgery, where pneumoperitoneum alters respiratory mechanics. This study compared pressure-regulated volume control (PRVC) and pressure-controlled ventilation (PCV) on arterial blood gas parameters and airway pressures in children undergoing elective laparoscopic surgery.

Objective: To compare the effects of Pressure-Regulated Volume Control (PRVC) and Pressure-Controlled Ventilation (PCV) on arterial blood gas (ABG) parameters in pediatric patients undergoing elective surgeries under general anesthesia.

Methods: In this six-month comparative cross-sectional study conducted in Lahore, Pakistan, 80 children aged 2–12 years (ASA I–II) were allocated equally to PRVC or PCV groups. Blood gases and airway pressures were measured after induction and after pneumoperitoneum.

Results: PRVC showed lower peak (16 vs. 18 cmH₂O, $p=0.020$) and mean airway pressure (8 vs. 11.5 cmH₂O, $p=0.002$) than PCV. After induction, PaO₂ (180 vs. 122 mmHg, $p=0.005$) and PaO₂/FiO₂ ratio (330 vs. 240, $p=0.005$) were higher with PRVC, with modestly higher PaCO₂ and PETCO₂ ($p<0.001$); pH was similar ($p=0.984$). Post-pneumoperitoneum, PaO₂ ($p=0.007$) and PaO₂/FiO₂ ratio ($p=0.004$) remained higher with PRVC, while pH and HCO₃⁻ did not differ. The rise in PaO₂ from baseline was greater with PRVC ($p=0.041$), and the rise in ET-CO₂ was smaller ($p=0.003$).

Conclusion: PRVC is a lung-protective ventilation strategy that can be used in pediatric laparoscopic surgery, as it allows for lower airway pressures and better oxygenation without compromising CO₂ clearance when compared to PCV.

1. INTRODUCTION

Mechanical ventilation plays a crucial role in anesthetic and peri-operative management of pediatric surgical patients, and choosing a proper ventilatory mode can be difficult due to the wide variation in respiratory mechanics with age and size (1). The traditional approaches are volume-controlled ventilation (VCV), which is a ventilation mode in which a fixed tidal volume is delivered at a variable airway pressure, and pressure-controlled ventilation (PCV), which is a ventilation mode in which a fixed airway pressure is delivered at a variable tidal volume (2). Dual-control mode Pressure-Regulated Volume Control (PRVC) brings together the two, allowing the inspiratory pressure to be adjusted breath-by-breath to keep the tidal volume at a desired level, which in theory should result in the optimization of inspiratory pressure and hence airway pressure (3).

This difference is especially important when performing laparoscopic surgery, as pneumoperitoneum decreases pulmonary compliance and increases airway pressure, thereby changing gas exchange (4). Under these conditions, evidence indicates that PRVC helps to avoid further increases in pressures, preserve ventilatory stability, and maintain hemodynamic and respiratory parameters superior to those of PCV (5). Similar advantages have been demonstrated in the treatment of acute respiratory failure, where PRVC seems to produce comparable airway pressure profiles and gas exchange as PCV, but results are inconclusive clinically (6).

There are fewer studies related to children and neonates. In neonatal critical care, multiple modes, such as those listed above, are used, but mode selection is more of an institutional preference and clinical judgment than based on direct comparative evidence (7). Lung-protective strategies, including adaptive modes like PRVC, are designed to ensure sufficient tidal volume delivery while minimizing the risk of ventilator-induced lung injury due to excess airway pressure and alveolar distension (8).

Although PRVC is used in various intensive care units, cardiac surgery, and other surgical units, few direct comparisons have been made with PCV in the pediatric population, highlighting the need to further study the physiological data in this group of patients (9). Continuous recording of peak and mean airway pressure, oxygenation, arterial carbon dioxide, and end-tidal carbon dioxide are important to assess ventilatory efficacy during procedures causing this type of mechanical change (10).

Materials and Methods

This comparative cross-sectional study aimed to compare the effect of pressure-regulated volume control (PRVC) vs pressure-controlled ventilation (PCV) on arterial blood gas (ABG) parameters and respiratory mechanics in children undergoing elective laparoscopic surgery under general anesthesia in the operating rooms of tertiary care teaching hospitals of Lahore, Pakistan, during a period of six months.

Non-probability purposive sampling was used to enroll 80 children aged 2-12 years (ASA physical status I-II) equally divided between the PRVC and PCV groups (n=40 each). Patients undergoing elective laparoscopic surgery who were anticipated to undergo controlled mechanical ventilation were included, and those with pre-existing cardiopulmonary disease, anticipated difficult airway, emergency surgery, or intraoperative hemodynamic instability were excluded.

The general anaesthetic protocol was standardized, and ventilator settings of respiratory rate, tidal volume/pressure target, PEEP, and FiO₂ were set in accordance with the need and weight of the patient. ABG samples were taken at induction and following pneumoperitoneum to measure pH, PaO₂, PaCO₂, HCO₃⁻, PaO₂/FiO₂ ratio, and peak and mean airway pressures.

Continuous variables were presented as mean ± SD and categorical variables were presented as frequencies/percentages in SPSS. Independent-samples t-tests (continuous) and chi-square/Fisher's exact tests (categorical) were used for between-group comparisons and paired-

samples t-tests were used for within-group change. A p-value of ≤ 0.05 was regarded as significant.

Results

Among 80 pediatric patients, 40 received PRVC, and 40 received PCV. Baseline characteristics were generally comparable between groups, including age, weight, ASA physical status, and duration of

surgery (all $p > 0.05$). Males predominated in both groups, with a significantly higher proportion in the PRVC group (97.5% vs. 67.5%, $p < 0.001$). Appendectomy was the most common procedure in both groups, accounting for 92.5% of PRVC and 60.0% of PCV cases (Table 01).

Table 1. Baseline characteristics of pediatric patients according to ventilation mode

Variable	PRVC (n=40)	PCV (n=40)	p-value
Age group, n (%)			0.065
1–6 years	19 (47.5)	11 (27.5)	
7–12 years	21 (52.5)	29 (72.5)	
Gender, n (%)			<0.001
Male	39 (97.5)	27 (67.5)	
Female	1 (2.5)	13 (32.5)	
Weight (kg), median (IQR)	18 (6)	20 (9)	0.195
ASA physical status, n (%)			0.531
ASA I	33 (82.5)	35 (87.5)	
ASA II	7 (17.5)	5 (12.5)	
Type of surgery, n (%)			—
Appendectomy	37 (92.5)	24 (60.0)	
Inguinal hernia repair	3 (7.5)	12 (30.0)	
Other (ENT)	0 (0.0)	4 (10.0)	
Duration of surgery (min), median (IQR)	65 (15)	60 (79)	0.246

ASA: American Society of Anesthesiologists; IQR: Interquartile range; PCV: pressure-controlled ventilation; PRVC: pressure-regulated volume control.

Ventilatory parameters differed significantly between groups in PEEP, peak airway pressure, and mean airway pressure. Despite an identical median PEEP of 5 cmH₂O in both groups, the distribution differed significantly between PRVC and PCV ($P=0.005$). Peak airway pressure was

lower with PRVC than with PCV (16 [IQR, 2] vs. 18 [IQR, 4] cmH₂O; $P=0.020$), as was mean airway pressure (8 [IQR, 2] vs. 11.5 [IQR, 13] cmH₂O; $P=0.002$). FiO₂ was comparable between groups (50% [IQR, 0] in both; $P=0.763$) (Table 2).

Table 2. Comparison of Ventilatory Parameters Between the PRVC and PCV Groups

Ventilatory parameter	PRVC Median (IQR)	PCV Median (IQR)	P value
PEEP (cmH ₂ O)	5 (0)	5 (2)	0.005
FiO ₂ (%)	50 (0)	50 (0)	0.763
Peak airway pressure (cmH ₂ O)	16 (2)	18 (4)	0.020
Mean airway pressure (cmH ₂ O)	8 (2)	11.5 (13)	0.002

After induction, arterial blood gas profiles differed between the PRVC and PCV groups for PaO₂, PaCO₂, HCO₃⁻, and the PaO₂/FiO₂ ratio, while pH remained comparable. PaO₂ was higher in the PRVC group than in the PCV group ($p=0.005$), with a corresponding difference in the PaO₂/FiO₂ ratio ($p=0.005$). PaCO₂ was modestly higher in the

PRVC group ($p<0.001$), as was PETCO₂ ($p<0.001$). Although median HCO₃⁻ was 24 mmol/L in both groups, its distribution differed significantly ($p=0.012$). pH values were not statistically significantly different between groups ($P=0.984$) (Table 3).

Table 3. Comparison of Arterial Blood Gas Parameters After Induction Between the PRVC and PCV Groups

ABG parameter	PRVC Median (IQR)	PCV Median (IQR)	p-value
pH	7.40 (0.01)	7.38 (0.06)	0.984
PaO ₂ (mmHg)	180 (79)	122 (38)	0.005
PaCO ₂ (mmHg)	37 (2)	35 (4)	<0.001
HCO ₃ ⁻ (mmol/L)	24 (1)	24 (2)	0.012
PaO ₂ /FiO ₂	330 (52)	240 (112)	0.005
PETCO ₂ (mmHg)	35 (2)	32 (4)	<0.001

Following establishment of pneumoperitoneum, significant between-group differences were observed in PaO₂, PaCO₂, the PaO₂/FiO₂ ratio, and PETCO₂, whereas pH and HCO₃⁻ did not differ significantly. PaO₂ remained higher in the PRVC group than in the PCV group ($p=0.007$),

with a correspondingly higher PaO₂/FiO₂ ratio ($p=0.004$). PaCO₂ was higher in the PRVC group ($p=0.013$), as was PETCO₂ ($p=0.004$). In contrast, pH ($p=0.734$) and HCO₃⁻ ($p=0.120$) were comparable between groups (Table 4).

Table 4. Arterial Blood Gas Parameters After Pneumoperitoneum According to Ventilation Mode

ABG parameter	PRVC Median (IQR)	PCV Median (IQR)	p-value
pH	7.36 (0.02)	7.35 (0.04)	0.734
PaO ₂ (mmHg)	180 (79)	122 (38)	0.007
PaCO ₂ (mmHg)	42 (1)	39.5 (7)	0.013
HCO ₃ ⁻ (mmol/L)	24 (1)	24 (2)	0.120
PaO ₂ /FiO ₂	360 (76)	257 (129)	0.004
PETCO ₂ (mmHg)	39 (2)	36 (4)	0.004

The magnitude of change following pneumoperitoneum differed significantly between ventilation modes for PaO₂, ETCO₂, and HCO₃⁻. The median change in PaO₂ was greater in the PRVC group than in the PCV group ($p=0.041$). Conversely, the increase in ETCO₂ was smaller with PRVC ($p=0.003$). HCO₃⁻ showed no change

in the PRVC group compared with a median increase of 1 mmol/L in the PCV group (IQR, 2; $P=0.009$). Changes in pH, PaCO₂, and the PaO₂/FiO₂ ratio did not differ significantly between groups ($P=0.410$, 0.185, and 0.066, respectively) (Table 5).

Table 5. Changes in Respiratory and Arterial Blood Gas Parameters Following Pneumoperitoneum According to Ventilation Mode

Parameter	PRVC change Median (IQR)	PCV change Median (IQR)	<i>p</i> value
pH	-0.04 (0.01)	-0.03 (0.06)	0.410
PaO ₂ (mmHg)	-12 (13)	-5 (14.25)	0.041
PaCO ₂ (mmHg)	4 (2)	5 (3)	0.185
ETCO ₂ (mmHg)	4 (2)	5 (4.75)	0.003
HCO ₃ ⁻ (mmol/L)	0.00 (1)	1 (2)	0.009
PaO ₂ /FiO ₂ ratio	-20 (30)	-10 (22.75)	0.066

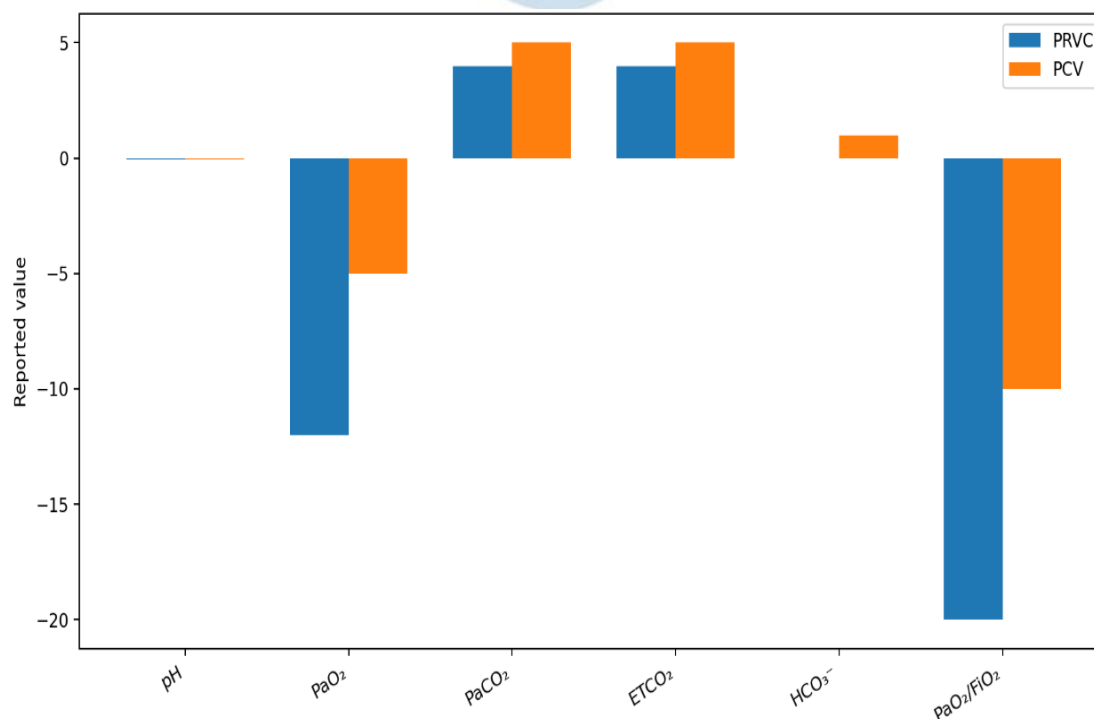


Figure 1: Changes after pneumoperitoneum

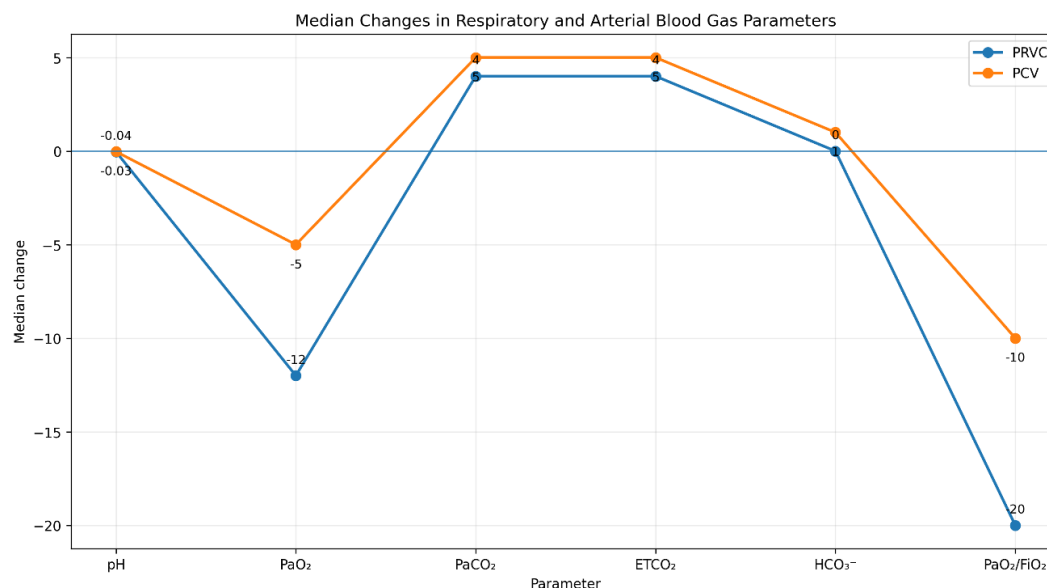


Figure 2: Median Changes in Respiratory and Arterial Blood Gas Parameters following pneumoperitoneum in PRVC and PCV groups.

Discussion

Pressure-regulated volume control (PRVC) was compared with pressure-controlled ventilation (PCV) on children undergoing laparoscopic surgery with respect to the changes in arterial blood gas parameters and respiratory mechanics. PRVC was also significantly correlated with reduced peak and mean airway pressure, as well as increased PaO₂ and PaO₂/FiO₂ ratio after induction and after pneumoperitoneum, and there was only a modest increase in PaCO₂ and end-tidal CO₂, which stayed within a clinically acceptable range. Clinically these findings are important because pneumoperitoneum creates significant respiratory stress in children, who are less likely to have adequate functional residual capacity and more susceptible to ventilator-associated injury (11),(12).

Ventilation is still very important during anesthesia for these types of surgeries. The mechanisms that the machine uses to aid breathing may alter the pressure in the airways, the flow of oxygen and carbon dioxide, and the possibility of lung damage. PRVC is a method that alters the pressure in each breath to deliver a fixed volume of air into the lungs and incorporates a

slow ventilation ramp. This way, it can deliver the amount of air with the lowest pressure possible (13) (14). This study's outcome backs up the concept that this is better in the particular scenario of children undergoing laparoscopy.

The two groups were similar as far as age, weight, ASA status, and surgical time, but the PRVC group had a higher percentage of males, which should be taken into consideration when interpreting results. The mean peak inspiratory pressure was 2 cmH₂O lower and mean airway pressure 3.5 cmH₂O lower for the PRVC group compared to the conventional group, which was considered statistically and clinically significant in children, who are susceptible to lung injury from higher airway pressure (15).

The PRVC group had better oxygenation as evidenced by higher PaO₂ 180 vs 122 mmHg and PaO₂/FiO₂ 185 vs. 130 at both time points. Neither PaCO₂ nor PETCO₂ were increased significantly in the PRVC group, but they were slightly higher than in the normal range group which suggested clinically significant hypoventilation was not present in either group. Both groups had a decrease in PaO₂ after pneumoperitoneum, but PRVC values were still

better than PCV. At both time points, there was no difference in acid-base balance (pH) between the groups.

The pressure advantage seen using PRVC is consistent with the mechanism by which it works, ie the slowing down of the flow pattern and compensation of the pressure from breath to breath to achieve the target tidal volume at the lowest pressure possible. In contrast, PCV's fixed-pressure delivery can result in inadequate volume delivery or compensatory pressure increases when respiratory mechanics change (16, 17)(18). These findings are consistent with previous studies: Yin et al. found that the PRVC protocol resulted in lower peak and mean airway pressures under pneumoperitoneum-induced reduced compliance(19). In adults with respiratory dysfunction, Putensen et al. reported similar decreases in pressure with PRVC versus VCV (20), and in the neonate with respiratory distress, Rahman et al. noted similar beneficial effects of PRVC over PCV (15). This study is an extension of these findings to the laparoscopic surgical environment in children.

The improved oxygenation that occurs with PRVC may be due to a number of factors: a more uniform distribution of gases, which leads to better ventilation/perfusion matching (17, 21). Both consistent tidal volume delivery to limit alveolar overdistension/collapse (14). and lower mean airway pressure to recruit alveoli without impacting cardiac performance (22). These observations are similar to those of Mahmoud who found that PRVC resulted in better oxygenation and reduced pressures during one-lung ventilation (23). Rahman et al. showed that PRVC resulted in better oxygenation than PCV in neonates (7). and Wang et al. showed that a similar pressure-adaptive approach and use of recruitment maneuvers improved oxygenation and reduced atelectasis intraoperatively (24).

Specifically, not only was no difference in PaO₂ between groups at the first measurement, but there was also no difference between groups at the second measurement, while there was a slight decrease in the PCV group (median 180 mmHg), suggesting that dynamic adjustment of pressure in

the PRVC group may be more effective in maintaining the same level of PaO₂ throughout the procedure without altering delivered tidal volume (1, 19). The oxygenation benefit was not large (about 2–3 mmHg), but still within an acceptable range for clinical use. The ventilatory efficacy after establishment of pneumoperitoneum, as expressed as a rise in CO₂ after pneumoperitoneum due to CO₂ absorption by the peritoneum, was not significantly different between groups, signifying that the ventilatory efficacy was comparable after pneumoperitoneum was established (25, 26). The higher CO₂ seen with PRVC might be related to differences in minute ventilation or dead space and can be easily corrected with changes in respiratory rate in a clinical setting. Importantly, neither of the groups had hypercapnia or acidemia, and pH was similar, suggesting effective ventilation in both modes, although PRVC was effective at lower airway pressure(27, 28).

The results of this study are similar to literature that has performed comparisons between different ventilation modes in other surgical situations. Jung et al. and Arjyal et al. found that PCV resulted in better respiratory mechanics than VCV (29, 30). Kim et al. and El-Radaideh et al. reported that PCV and PCV-volume guaranteed modes lowered the airway pressures compared to VCV in gynecological and bariatric surgeries, respectively (31, 32). This study contributes to this literature by directly comparing PRVC and PCV in children, a population that has not been well-studied in this context. The low lower airway pressures that are seen with PRVC are consistent with its adaptive mechanism, which changes inspiratory pressure continuously to match the set tidal volume, as opposed to PCV's fixed pressure approach. This adaptability may be especially useful in children, as respiratory mechanics can change quickly during surgery, not only in children but also in adults (12, 28).

The results of this study have implications for practice. The decrease in the peak and mean airway pressure can decrease the risk of ventilator-induced lung injury, barotrauma, and postoperative pulmonary complications in

children (11, 28). Better oxygenation, evidenced by higher PaO₂ and PaO₂/FiO₂ ratios, may lead to more physiological reserve and safety margin for desaturation (24, 33). Since PRVC is possible on standard ventilators, there is no need for extra equipment to switch to PRVC, and it can be done right away. This is very useful in resource-limited environments like Pakistan, where access to advanced monitoring and postoperative respiratory support might be limited (34). In conclusion, these results are in favor of the use of PRVC in paediatric laparoscopy, if available, over the traditional mode of use.

Limitations

There are a number of limitations to this study. The non-randomised design with the comparative group does not exclude the possibility of confounding variables, such as the higher percentage of males in the PRVC group. The number of samples (n=80) was sufficient for the primary outcomes; however, the sample size may have been insufficient to power subgroup analyses. There are only two ABG measurement points, which may have overlooked other temporal trends. Imaging and inflammatory markers were not evaluated, and thus it is not clear if the physiological improvements afforded by PRVC are associated with a clinical improvement. Last but not least, being a single-center study, the study results may not be generalizable to other settings.

Conclusion

To conclude, this study clearly indicates that PRVC ventilation leads to reduced peak and mean airway pressure, better oxygenation, and satisfactory CO₂ clearance in children undergoing elective laparoscopic surgery as opposed to PCV. The results indicate that PRVC could be a ventilation modality to protect the lungs in this patient group. Although there are limitations of the study design, the benefits observed are physiologically consistent with the dual-control mechanism of PRVC, and consistent with results in similar clinical conditions. More research is necessary to confirm these findings and test their effects on postoperative results.

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Author Contributions

All authors contributed equally to the study's conceptualization, methodology, data curation, validation, and manuscript preparation, and approved the final version.

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None.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Conflict of Interest

None

Ethical Approval and Informed Consent

Ethical approval was obtained from the Institutional Review Board of Superior University, Lahore, and the Research Ethics Committee of the participating hospitals, Ganga Ram Hospital, Lahore, and Social Security Hospital, Lahore (Ref: IRB/FAHS/REHAB/04/26/MS/RS-4098). All participants provided individual informed consent before enrollment, and the study adhered to relevant ethical procedures and institutional requirements.

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