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Original Article

# Optimizing ventilation strategies in laparoscopic gynecologic surgery in the steep trendelenburg position: A prospective randomized controlled trial comparing volume-controlled, pressure-controlled, and pressure-controlled volume-guaranteed ventilation

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## ABSTRACT

**Introduction:** Laparoscopic gynecologic surgery in the steep Trendelenburg position alters pulmonary mechanics and oxygenation. The optimal ventilation mode remains uncertain.

**Materials and Methods:** In this prospective, randomized controlled trial, 60 patients (20 per group) undergoing elective laparoscopic gynecologic surgery in the steep Trendelenburg position were randomly assigned to Volume-Controlled Ventilation (VCV), Pressure-Controlled Ventilation (PCV), or Pressure-Controlled Volume-Guaranteed Ventilation (PCV-VG®). The primary outcome was peak airway pressure (Ppeak). Secondary outcomes included other respiratory variables, oxygenation parameters, and hemodynamic variables.

**Results:** Ppeak and Pplateau values were significantly higher in the VCV group compared to the PCV and PCV-VG® groups at T2, T3, and T4 ($p<0.01$). After Bonferroni correction, these differences remained significant between VCV and the other groups, while no difference was found between PCV and PCV-VG®. $PaCO_2$ levels were significantly lower in the PCV-VG® group compared to VCV and PCV at T3 ($p=0.008$). No significant differences were observed in $PaO_2$, $SaO_2$, Pmean, exhaled tidal volume, or hemodynamic parameters.

**Conclusions:** Both PCV and PCV-VG® provided lower airway pressures and better lung compliance than VCV, while PCV-VG® additionally improved $CO_2$ elimination. PCV-VG® may be a favorable ventilation strategy in laparoscopic gynecologic surgery performed in the steep Trendelenburg position.

**Keywords:** Laparoscopy, peak inspiratory pressure, pulmonary gas exchange, trendelenburg position, ventilator modes

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## Introduction

Laparoscopic surgery is widely used in gynecology due to its advantages, including reduced postoperative pain, shorter hospital stays, and faster recovery. The Trendelenburg position (30° tilt) is commonly used, but a steeper angle (>30°) provides better access to the pelvic and lower abdominal regions. The use of pneumoperitoneum and the steep Trendelenburg position during surgery can have significant physiological effects. These factors increase intra-abdominal pressure, limit diaphragmatic movement, and reduce lung compliance, ultimately disrupting normal respiration and gas exchange. Consequently, these changes may lead to a decrease in functional residual capacity, an increase in peak inspiratory pressure (Ppeak), and respiratory acidosis associated with hypercapnia.[1]

Selecting an appropriate mechanical ventilation strategy is essential to minimize respiratory complications. The three main ventilation modes used in laparoscopic surgery are Volume-Controlled Ventilation (VCV), Pressure-Controlled Ventilation (PCV), and Pressure-Controlled Volume-Guaranteed Ventilation (PCV-VG®). Each mode has distinct characteristics that may influence respiratory mechanics under conditions such as patient positioning and carbon dioxide ($CO_2$) insufflation. In VCV, tidal volume is delivered at a preset value, while airway pressures may vary depending on changes in compliance and resistance. In PCV, inspiratory pressure is set, and the delivered tidal volume may vary with respiratory system mechanics. PCV-VG® combines pressure-controlled delivery with volume targeting, aiming to achieve the set tidal volume by automatically adjusting inspiratory pressure within predefined limits.[2] Recent studies have evaluated these strategies in laparoscopic gynecologic procedures with respect to airway pressures, lung compliance, and oxygenation.[3,4] However, the optimal ventilation mode in this setting remains uncertain, and the available evidence is heterogeneous across patient populations and procedural contexts.

This study aims to compare VCV, PCV, and PCV-VG® with respect to pulmonary mechanics, gas exchange, and hemodynamic parameters during laparoscopic gynecologic surgery performed in the steep Trendelenburg position. In all groups, ventilatory settings were standardized to deliver a target tidal volume of 8 mL/kg for each patient, thereby enabling a fair comparison of airway pressures under comparable minute ventilation goals. The primary outcome was Ppeak and the secondary outcomes included gas exchange and hemodynamic parameters. We hypothesized that ventilation modes that adjust inspiratory pressure to achieve the target tidal volume (PCV and PCV-VG®) may be associated with different intraoperative Ppeak profiles and respiratory mechanics compared with VCV at the same target tidal volume.

## Materials and Methods

This study was designed as a prospective, randomized, controlled clinical trial. Ethical approval was obtained from the Zeynep Kâmil Training and Research Hospital Ethical Committee (Date: 06/01/2021, No: 2), and written informed consent was obtained from all participants. The study was registered on ClinicalTrials.gov (NCT06861959). All methods were carried out in accordance with the Declaration of Helsinki. This study has been conducted in accordance with the CONSORT guidelines for the reporting of randomized controlled trials.

### Study Population

The study included patients aged 18–65 years, classified as American Society of Anesthesiologists (ASA) physical status I-III, undergoing elective laparoscopic gynecologic surgery with pneumoperitoneum lasting at least one hour in the steep Trendelenburg position (30°–45°). Exclusion criteria included morbid obesity (BMI>35 kg/m²), pre-existing pulmonary or cardiac disease (e.g., chronic obstructive pulmonary disease, heart failure), a history of difficult intubation, and intraoperative hemodynamic instability or conversion to laparotomy.

### Randomization and Group Allocation

Patients were randomly assigned to one of three groups (VCV, PCV, or PCV-VG®) using a computer-generated randomization sequence (1:1:1 ratio) created via calculator.net, with 20 patients in each group. Allocation concealment was ensured using sequentially numbered, sealed opaque envelopes. The allocation process is summarized in the CONSORT flow diagram (Fig. 1).

Due to the nature of the intervention, blinding of the anesthesiologists and intraoperative staff was not feasible. However, all ventilation settings and intraoperative management protocols were strictly standardized, and objective physiological parameters were used as study outcomes to minimize the risk of bias related to lack of blinding.

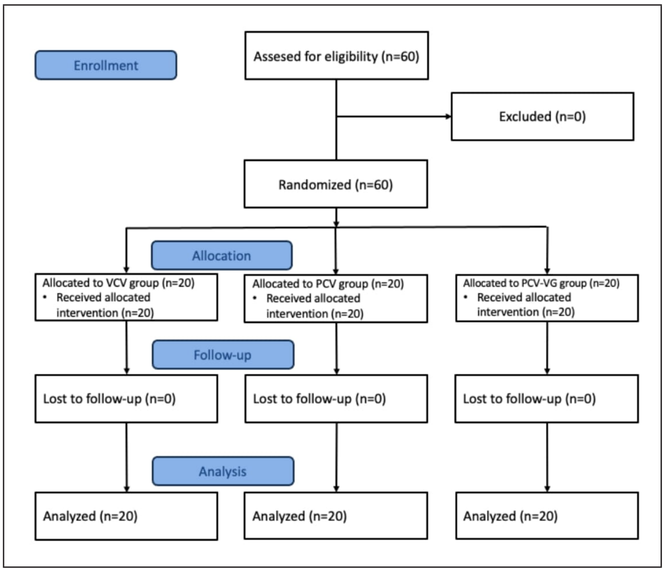


**Figure 1.** CONSORT Flow Diagram.

### Anesthesia and Ventilation Protocol

All patients were monitored according to standard ASA guidelines (electrocardiography, non-invasive blood pressure, pulse oximetry, and capnography). Anesthesia was induced with propofol (2 mg/kg), fentanyl (1 μg/kg), and rocuronium (0.6 mg/kg), followed by maintenance with sevoflurane (2%–2.5%) in an air-oxygen mixture ($FiO_2$=0.5) and additional remifentanil and rocuronium as needed. A 20G arterial catheter was inserted into the radial artery for continuous blood pressure monitoring and arterial blood sampling.

Mechanical ventilation was provided using a Datex-Ohmeda Avance Anesthesia Machine (GE Healthcare, USA). Ventilation settings were standardized: Tidal volume=8 mL/kg of ideal body weight, respiratory rate adjusted to maintain an end-tidal $CO_2$ ($EtCO_2$) level of 30–35 mmHg, inspiratory-expiratory ratio=1:2, and positive end-expiratory pressure (PEEP)=5 cm$H_2O$. If $EtCO_2$ was not within the target range (30–35 mmHg) at the target tidal volume, minute ventilation was adjusted according to the standardized intraoperative protocol while maintaining tidal volume at 8 mL/kg in all groups. Intra-abdominal pressure was maintained at 12–14 mmHg.

### Data Collection

Data were collected at four predefined time points during the study. The first time point (T1) was measured 15 minutes after the induction of anesthesia, with patients in the supine position. The second time point (T2) was recorded 30 minutes following $CO_2$ insufflation and positioning in the Trendelenburg position. The third time point (T3) represented measurements taken 60 minutes after the initiation of pneumoperitoneum. The final time point (T4) was assessed 15 minutes after $CO_2$ deflation and the return of patients to the supine position.

At each time point, various parameters were systematically recorded. Airway dynamics included measurements of Ppeak, mean inspiratory pressure (Pmean), plateau pressure (Pplateau), dynamic lung compliance (Cdyn), respiratory rate (RR), and exhaled tidal volume (exhale TV). Oxygenation parameters were assessed using arterial blood gas analysis, including arterial partial pressure of oxygen ($PaO_2$), arterial oxygen saturation ($SaO_2$), and arterial partial pressure of carbon dioxide ($PaCO_2$). Hemodynamic parameters included heart rate, mean arterial pressure (MAP), peripheral oxygen saturation ($SpO_2$), and $EtCO_2$.

Respiratory and ventilation variables and hemodynamic parameters were recorded at T1 to T4; arterial blood gas analysis was conducted at T1 and T3.

The primary outcome of the study was to compare Ppeak among VCV, PCV, and PCV-VG® modes in patients undergoing laparoscopic surgery in the steep Trendelenburg position. Secondary outcomes of the study were: Other respiratory variables (Pmean, Pplateau, Cdyn, RR, Exhale TV), oxygenation ($PaO_2$, $SaO_2$, $PaCO_2$), and hemodynamic parameters (HR, MAP, $SpO_2$, $EtCO_2$).

### Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). The normality of continuous variables was evaluated using both the Shapiro-Wilk and Kolmogorov-Smirnov tests. A variable was considered normally distributed only if both tests yielded p-values greater than 0.05. Normally distributed continuous variables were expressed as means ± standard deviations (SD), while non-normally distributed variables were presented as medians with interquartile ranges (IQR). Categorical variables were summarized using frequencies and percentages.

For comparisons of continuous variables among more than two groups, **One-way ANOVA** was used for normally distributed variables and the **Kruskal–Wallis test** for non-normally distributed variables. For two-group comparisons, the **Mann–Whitney U test** was applied for non-normally distributed variables. When overall group differences were statistically significant ($p<0.05$), **post-hoc pairwise analyses were conducted.** Specifically:

- For normally distributed variables, **Bonferroni correction** was applied following ANOVA.
- For non-normally distributed variables, **Mann–Whitney U tests with Bonferroni correction** were performed after Kruskal–Wallis tests.
- For comparisons involving **groups** (i.e., three pairwise comparisons), the Bonferroni-adjusted significance threshold was set at **$\alpha$=0.05/3=0.017.**

Significant post-hoc differences are marked in Table 1 and Table 2 with superscript letters (a–c), and only p-values that remained below the Bonferroni-adjusted thresholds were considered statistically significant.

A power analysis using G*Power, based on previously reported Ppeak (VCV: 27 [26–29] $cmH_2O$ vs. PCV-VG®: 24 [22–27] $cmH_2O$), determined that for the VCV vs. PCV-VG® comparison ($\alpha$=0.05, power=80%, effect size d=1.08), the required sample size is ~14 participants per group (or ~18 with a 20% dropout adjustment).[3]

## Results

### Study Population

A total of 60 patients (20 per group) were enrolled and all completed the study. No significant differences were found among the groups in terms of demographic data (Table 3).

### Respiratory and Ventilation Variables

The Ppeak values were significantly higher in the VCV group at T2, T3, and T4 compared to the PCV and PCV-VG® groups (T2: p<0.001; T3: p<0.001; T4: p=0.002). Significant differences were observed between the VCV vs. PCV (a) and VCV vs. PCV-VG® (b) groups. However, no significant difference was found between the PCV and PCV-VG® groups at any time point (p>0.017) (Table 1A) (Fig. 2).

Regarding Pplateau, no significant differences were detected among the groups at T1 and T4 (p>0.05). Since no significance was found at these time points. However, at T2 and T3, Pplateau was significantly higher in the VCV group compared to the PCV and PCV-VG® groups (T2: p<0.001; T3: p<0.001). Significant differences were found between VCV vs. PCV (a) and VCV vs. PCV-VG® (b). No significant difference was found between the PCV and PCV-VG® groups (p>0.017) (Table 1A).

Regarding RR, no significant differences were observed among the groups at T1, T2, and T3 (p>0.05). However, at T4, a significant difference in RR was observed between the groups (p=0.027). The significant difference between the VCV and PCV-VG® groups (b) was maintained (p<0.017). No significant difference was observed between the VCV and PCV groups, or between the PCV and PCV-VG® groups (p>0.017) (Table 1B).

Regarding Cdyn, no significant differences were observed among the groups at T1, T2, and T4 (p>0.05). Since no significance was found at these time points. At T3, although the initial p-value (p=0.039) indicated a significant difference between the VCV group and both the PCV and PCV-VG® groups. No significant difference was found between the PCV and PCV-VG® groups at any time point (p>0.017) (Table 1B).

Lastly, Pmean, $ETCO_2$ and Exhale TV did not show significant differences among the groups at any time point (p>0.05). Since no significant differences were observed for these parameters (Table 1A-B).

### Hemodynamic Parameters

There was no statistically significant difference among the groups in regarding HR, MAP, and $SpO_2$ at T1, T2, T3, and T4 (p>0.05) (Table 4).

### Gas Exchange Values

No statistically significant difference was observed among the groups in terms of $PaO_2$ and $SaO_2$ levels at T1 and T3 (p>0.05). However, at T3, $PaCO_2$ levels in the PCV-VG® group were significantly lower compared to the VCV and PCV groups (p=0.008). Significant differences were found between VCV vs. PCV-VG® (b) and PCV vs. PCV-VG® (c). No significant difference was observed between the VCV and PCV groups (p>0.017) (Table 2).

## Discussion

This study compared the effects of VCV, PCV, and PCV-VG® ventilation modes on pulmonary mechanics, oxygenation and hemodynamic parameters in patients undergoing laparoscopic gynecologic surgery in the steep Trendelenburg position. Our findings indicate that PCV and PCV-VG® resulted in significantly lower Ppeak and Pplateau values compared to VCV, while Cdyn values were also significantly higher in these groups at T3. However, oxygenation and hemodynamic parameters remained comparable across all groups.

Both PCV-VG® and VCV ensure a constant VT; however, in PCV mode, tidal volume may fluctuate depending on lung

**Table 1A. Respiratory and ventilation variables**

| | Time | VCV (n=20) | PCV (n=20) | PCV-VG (n=20) | p[1] | ǂ*Significant Differences (p<0.0167)* |
|---|---|---|---|---|---|---|
| Ppeak ($cmH_2O$), Median (IQR) | T1 | 16 (13.25-19.75) | 15.5 (14-18) | 15 (13-19.5) | 0.909 | |
| | T2 | 28.5 (27-29) | 23 (21-25) | 23 (22-24) | **<0.001*** | a, bǂ |
| | T3 | 28 (26-29.75) | 25 (21.25-26) | 24 (21-25.75) | **<0.001*** | a, bǂ |
| | T4 | 20 (19-21.75) | 17.5 (15.25-19) | 18 (16-19) | **0.002*** | a, bǂ |
| Pmean ($cmH_2O$), Median (IQR) | T1 | 7.5 (7-8.75) | 8 (6.25-8) | 7 (6.25-8) | 0.542 | |
| | T2 | 10 (9-10.75) | 10 (9-11) | 9 (9-11) | 0.863 | |
| | T3 | 10 (9-11) | 10 (9-11) | 9.5 (9-11) | 0.763 | |
| | T4 | 8.5 (8-10) | 8 (7.25-9) | 8 (7.25-9) | 0.578 | |
| Pplateau ($cmH_2O$), Median (IQR) | T1 | 14.5 (12.25-16) | 14 (12-18) | 14 (12.25-15.75) | 0.918 | |
| | T2 | 25 (23-26.75) | 19.5 (18.25-21) | 18.5 (17.25-19) | **<0.001*** | a, bǂ |
| | T3 | 25 (24-25.75) | 20.5 (18-22) | 20 (19-22) | **<0.001*** | a, bǂ |
| | T4 | 17.5 (16.25-20.5) | 18 (17-19) | 17 (16-19) | 0.733 | |

**Table 1B.**

| | Time | VCV (n=20) | PCV (n=20) | PCV-VG (n=20) | p[1] | ǂ*Significant Differences (p<0.0167)* |
|---|---|---|---|---|---|---|
| RR, Median (IQR) | T1 | 12 (12-12) | 12 (12-12) | 12 (11.25-12.75) | 0.966 | |
| | T2 | 12 (11.25-13) | 12 (12-13) | 12 (12-13) | 0.397 | |
| | T3 | 12 (12-13) | 13 (12-13.75) | 12 (12-13) | 0.103 | |
| | T4 | 13 (12-13) | 12 (12-13) | 12 (11-12) | **0.027*** | **bǂ** |
| Exhale TV (mL), Median (IQR) | T1 | 500.5 (490-529) | 500.5 (490.5-515) | 499 (490-515) | 0.848 | |
| | T2 | 495 (476.25-507.75) | 487.5 (476-496) | 490 (482.75-497) | 0.476 | |
| | T3 | 493.5 (478.25-499.5) | 484 (478.25-498.25) | 489 (479-500) | 0.768 | |
| | T4 | 499 (491.25-513) | 496.5 (487-500.75) | 495 (479-500.75) | 0.145 | |
| Cdyn ($mL/cmH_2O$), Median (IQR) | T1 | 42.5 (34.75-50.25) | 42 (38.75-49) | 41.5 (38.25-47.5) | 0.967 | |
| | T2 | 23.5 (19.25-28.5) | 28 (21-30) | 27 (21-30.5) | 0.238 | |
| | T3 | 20 (18.25-29.25) | 27 (25-29) | 27 (24.25-28) | **0.039*** | NS |
| | T4 | 35 (30.25-38) | 34.5 (31.25-37.75) | 37 (34.25-41.75) | 0.340 | |
| $ETCO_2$ (mmHg), Median (IQR) | T1 | 31.5 (30-32) | 31.5 (30-33) | 32 (30-33) | 0.849 | |
| | T2 | 34 (31.5-34.75) | 34 (33-35) | 34 (33.25-35) | 0.355 | |
| | T3 | 34 (32.25-35.75) | 33.5 (33-34) | 33.5 (32.25-34) | 0.341 | |
| | T4 | 34 (33-35) | 34 (33-35.75) | 33 (32.25-35) | 0.554 | |

IQR: Inter quartile range; Ppeak: peak airway pressure; Pmean: mean airway pressure; Pplateau: plateau pressure; VCV: volume-controlled ventilation; PCV: pressure-controlled ventilation; PCV-VG: pressure-controlled ventilation-volume guaranteed; T1: in the supine position 15 min after the induction of anesthesia; T2: 30 min after the $CO_2$ insufflation; T3: 60 min after the initiation of pneumoperitoneum; T4: 15 min after $CO_2$ deflation, NS: Not Significant. *Statistical significance was initially set at a p-value of <0.05. p[1]: overall three-group comparison. The methodology used to correct for multiple comparisons was as follows: Kruskal-Wallis Test (Post Hoc: Mann-Whitney U Test with Bonferroni correction). Multiple comparisons were corrected using the Bonferroni method. Post hoc tests (Mann-Whitney U tests) were Bonferroni-adjusted to account for the number of pairwise comparisons (3 group pairs in total: VCV vs. PCV, VCV vs. PCV-VG, PCV vs. PCV-VG). Accordingly, the adjusted alpha level was 0.05/3=0.0167. Only p-values that remained significant after Bonferroni correction are marked with an asterisk (ǂ). Significant pairwise differences are indicated as follows: a=VCV vs. PCV, b=VCV vs. PCV-VG, c=PCV vs. PCV-VG.

**Table 2. Arterial blood gas analysis**

| | Time | VCV(n=20) | PCV(n=20) | PCV-VG(n=20) | p | ǂSignificant Differences (p<0.0167) |
|---|---|---|---|---|---|---|
| $PaO_2$ (mmHg), Mean ± SD | T1 | 180.25±14.68 | 176.85±16.83 | 178.80±16.38 | 0.797[1] | |
| | T3 | 183.05±15.38 | 179.50±9.89 | 186.20±10.71 | 0.232[1] | |
| $PaCO_2$ (mmHg), Mean ± SD | T1 | 33 (32-34) | 34 (33-34.75) | 33.5 (32-34.75) | 0.421[2] | |
| | T3 | 35.5 (34-36) | 35.5 (34.25-36) | 34 (33-35) | **0.008**[2,*] | **b,cǂ** |
| $SaO_2$ (%), Median (IQR) | T1 | 99 (99-100) | 99 (98.25-99) | 99 (99-100) | 0.178[2] | |
| | T3 | 99 (99-100) | 99 (99-99) | 99 (99-100) | 0.469[2] | |

IQR: Inter quartile range; VCV: volume-controlled ventilation; PCV: pressure-controlled ventilation; PCV-VG: pressure-controlled ventilation-volume guaranteed; $PaO_2$: arterial oxygen tension; $PaCO_2$: arterial carbon dioxide tension; $SaO_2$: oxygen saturation; T1: in the supine position 15 min after the induction of anesthesia; T3: 60 min after the initiation of pneumoperitoneum. *Statistical significance was initially set at a p-value of <0.05. The methodology used to correct for multiple comparisons was as follows: Kruskal-Wallis Test (Post Hoc: Mann-Whitney U Test with Bonferroni correction). Multiple comparisons were corrected using the Bonferroni method. Post hoc tests (Mann-Whitney U tests) were Bonferroni-adjusted to account for the number of pairwise comparisons (3 group pairs in total: VCV vs. PCV, VCV vs. PCV-VG, PCV vs. PCV-VG). Accordingly, the adjusted alpha level was 0.05/3=0.0167. Only p-values that remained significant after Bonferroni correction are marked with an asterisk (ǂ). Significant pairwise differences are indicated as follows: a=VCV vs. PCV, b=VCV vs. PCV-VG, c=PCV vs. PCV-VG.

**Table 3. Patient characteristics and perioperative data**

| | VCV (n=20) | PCV (n=20) | PCV-VG (=20) | p |
|---|---|---|---|---|
| Age (years) | 46.55±8.96[a] | 48.6±8.28[a] | 49.6±7.86[a] | 0.507[1] |
| Body mass index (kg/m²) | 25.7±3.13[a] | 26.49±3.14[a] | 26.61±3.77[a] | 0.651[1] |
| ASA PS | 2 (1-2)[b] | 2 (1-3)[b] | 2 (1-2)[b] | 0.968[2] |
| Duration of pneumoperitoneum (min) | 98.35±23.28[a] | 96.35±12.93[a] | 96.5±17.65[a] | 0.930[1] |
| Duration of surgery (min) | 128.25±29.06[a] | 124.5±13.09[a] | 125±18.29[a] | 0.832[1] |
| Duration of anesthesia (min) | 138.6±29.2[a] | 134.45±13.07[a] | 135.45±19.04[a] | 0.817[1] |

VCV: volume-controlled ventilation; PCV: pressure-controlled ventilation; PCV-VG: pressure-controlled ventilation-volume guaranteed; ASA PS: American Society of Anesthesiologists physical status. a: Mean ± SD, b: Median [IQR: Inter quartile range], 1: Oneway ANOVA Test, 2: Kruskal Wallis Test. Since no significant differences were found among the groups (all p-values >0.05), there was no need for post hoc corrections such as the Bonferroni test.

compliance changes. Factors such as perioperative positioning (transition from supine to Trendelenburg), intra-abdominal and intrathoracic pressure alterations due to pneumoperitoneum, and anesthesia depth variations can cause tidal volume instability.[5] Consequently, optimal ventilation strategies are crucial for maintaining oxygenation and preventing intraoperative hypoventilation or hyperventilation.[6,7] PCV-VG®, by operating within a predefined pressure limit, prevents excessive inspiratory pressures while utilizing a decelerating inspiratory flow pattern.[5,8]

Maintaining adequate tidal volume is particularly important in laparoscopic surgeries due to frequent positional changes and abrupt intra-abdominal pressure fluctuations caused by $CO_2$ insufflation. The steep Trendelenburg position and pneumoperitoneum elevate intrathoracic pressure, decrease pulmonary compliance, increase Ppeak, and predispose to atelectasis.[5,9,10] In PCV mode, frequent adjustments in Ppeak may be required to ensure adequate ventilation as lung compliance fluctuates.[8] Although Ppeak does not directly reflect alveolar pressure, it is considered a key clinical indicator of alveolar stress and barotrauma.[11] However, some authors argue that Ppeak alone may not accurately represent alveolar pressures, while others highlight its importance as a read-

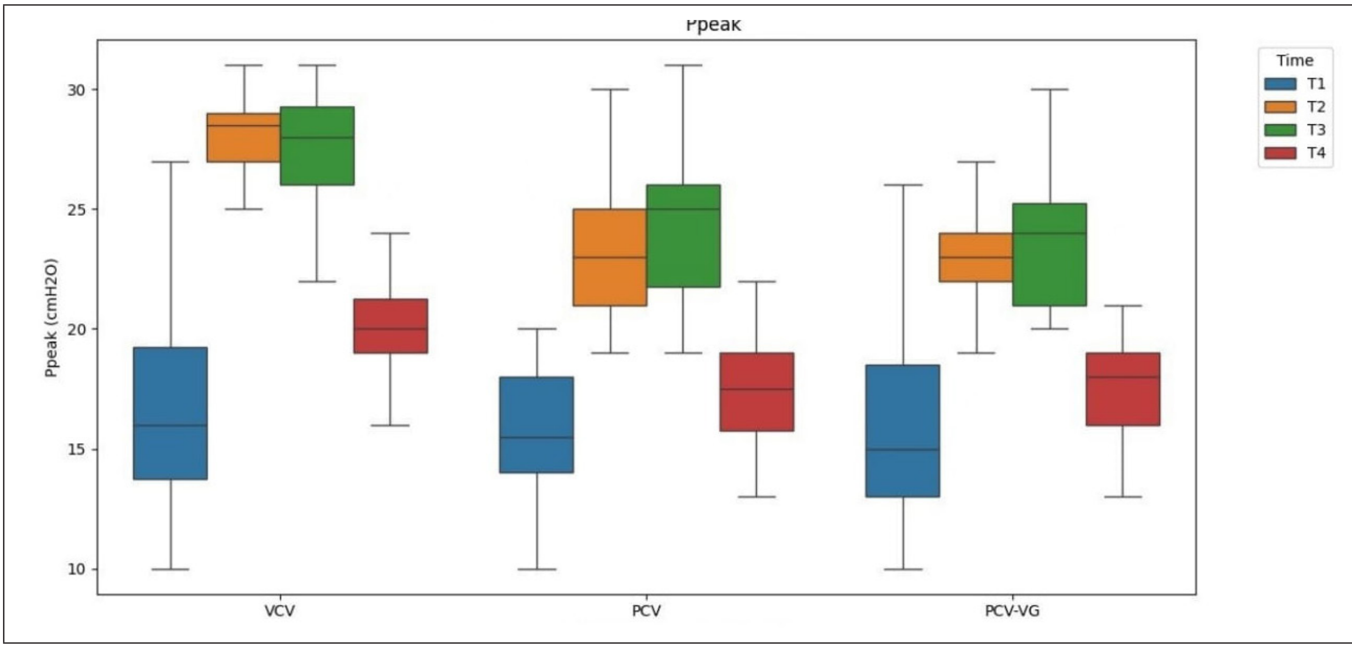


**Figure 2.** Changes in peak inspiratory pressure (Ppeak) at four timepoints in each group.

VCV: volume-controlled ventilation; PCV: pressure-controlled ventilation; PCV-VG®: pressure-controlled ventilation volume-guaranteed; T1: in the supine position 15 min after the induction of anesthesia; T2: 30 min after the $CO_2$ insufflation; T3: 60 min after the initiation of pneumoperitoneum; T4: 15 min after $CO_2$ deflation.

**Table 4. Perioperative hemodynamic parameters**

| | Time | VCV (n=20) | PCV (n=20) | PCV-VG (n=20) | p |
|---|---|---|---|---|---|
| HR (bpm), Mean±SD | T1 | 78.75±10.34 | 76.60±9.35 | 76.25±9.93 | 0.689[1] |
| | T2 | 72.65±8.49 | 75.35±7.43 | 76.00±6.68 | 0.339[1] |
| | T3 | 82.60±12.3 | 80.75±9.24 | 79.15±8.28 | 0.560[1] |
| | T4 | 78.10±10.58 | 79.00±7.03 | 77.65±7.39 | 0.877[1] |
| MAP (mmHg), Mean±SD | T1 | 79.00±12.13 | 80.15±12.12 | 79.6±12.36 | 0.957[1] |
| | T2 | 81.20±12.47 | 82.90±8.16 | 81.70±8.28 | 0.855[1] |
| | T3 | 89.80±10.40 | 87.35±10.15 | 86.15±6.88 | 0.453[1] |
| | T4 | 81.30±11.83 | 87.80±7.59 | 84.60±5.06 | 0.067[1] |
| $SpO_2$ (%), Median (IQR) | T1 | 99 (99-100) | 99 (98.25-100) | 99 (99-100) | 0.915[2] |
| | T2 | 99 (99-100) | 99 (98-99) | 99 (98-99.75) | 0.424[2] |
| | T3 | 98 (98-99) | 99 (98-99) | 99 (99-99.75) | 0.055[2] |
| | T4 | 99 (99-99.75) | 99 (98-99) | 99 (99-100) | 0.166[2] |

IQR: Inter quartile range, VCV: volume-controlled ventilation; PCV: pressure-controlled ventilation; PCV-VG: pressure-controlled ventilation-volume guaranteed; HR: heart rate; MAP: mean arterial pressure; $SpO_2$: peripheral oxygen saturation. T1: in the supine position 15 min after the induction of anesthesia; T2: 30 min after the $CO_2$ insufflation; T3: 60 min after the initiation of pneumoperitoneum; T4: 15 min after $CO_2$ deflation. 1: Oneway ANOVA Test, 2: Kruskal Wallis Test. Since no significant differences were found among the groups (all p-values >0.05), there was no need for post hoc corrections such as the Bonferroni test.

ily accessible and widely reported respiratory parameter in clinical practic.[2,12] In our study, we aimed to predict the optimal ventilation mode by comparing Ppeak values across all groups at different time points.

Several studies have compared VCV and PCV during laparoscopic surgery in the Trendelenburg position, consistently reporting lower Ppeak and higher Cdyn with PCV.[4,5,7,10,13] However, there is limited evidence regarding the superiority of PCV-VG® over other ventilation modes during laparoscopic procedures in steep Trendelenburg positioning. A systematic review and meta-analysis suggested that PCV-VG® may offer advantages over VCV in improving airway dynamics during elective non-cardiac surgery.[14] Lee et al.[3] found that PCV-VG® provided significantly lower Ppeak and higher Cdyn compared to VCV. Similarly, Gad et al.[9] demonstrated that PCV-VG® and PCV resulted in significantly lower Ppeak and higher Cdyn than VCV during laparoscopic surgery in the Trendelenburg position. Additionally, Assad et al.[5] compared PCV-VG® and VCV in patients undergoing laparoscopic surgery in a 30° Trendelenburg position, reporting that PCV-VG® led to lower peak inspiratory pressures and improved lung compliance.[5] Toker et al.[4] demonstrated that PCV-VG® provided lower Ppeak and higher Cdyn at all time points compared to VCV in obese patients undergoing laparoscopic hysterectomy. These findings are consistent with our study, where Ppeak was significantly higher in the VCV group at T2, T3, and T4 compared to PCV and PCV-VG®, suggesting that PCV and PCV-VG® may provide safer airway pressures in these patients. The decelerating inspiratory flow pattern in PCV and PCV-VG® modes may explain these findings, as they allow better gas distribution with lower airway pressures, reducing the risk of barotrauma.

The primary objectives of anesthesia management in laparoscopic surgeries are to maintain oxygenation and prevent barotrauma.[15] In laparoscopic procedures performed in the steep Trendelenburg position, PCV-VG® has been reported to offer advantages over VCV, particularly in minimizing the risk of barotrauma. This advantage is attributed to the ability of PCV-VG® and PCV modes to generate high initial inspiratory flow rates, thereby maximizing the pressure gradient between driving pressure and alveolar pressure, ultimately promoting alveolar recruitment. The decelerating inspiratory flow pattern characteristic of PCV and PCV-VG® modes has been proposed to reduce Ppeak, thereby mitigating lung injury and optimizing the distribution of inspiratory gases. This mechanism is thought to contribute to the preservation of the ventilation/perfusion ratio.[16] Additionally, elevated Pmean has been associated with improved oxygenation.[17] A higher Pmean facilitates the reopening of collapsed alveoli, thereby enhancing arterial oxygenation.[18] Furthermore, PCV-VG® has been suggested as a superior alternative in terms of oxygenation, as it provides lower mean airway pressures and reduces intrapulmonary shunting compared to VCV.[19]

Although previous one-lung ventilation (OLV) studies have consistently demonstrated that PCV-VG® reduces Ppeak, the impact of this mode on arterial oxygenation remains controversial.[20,21] However, there is currently no conclusive evidence to suggest that PCV and PCV-VG® provide superior oxygenation compared to VCV in the presence of Trendelenburg positioning and $CO_2$ pneumoperitoneum.[5,13,22] A study by Gad et al.[9] reported no significant differences in oxygenation parameters among PCV-VG®, PCV, and VCV, despite slightly higher $PaO_2$ levels in the VCV group.[9] Similarly, Assad et al.[5] compared PCV-VG® and VCV during laparoscopic surgeries in the Trendelenburg position and found no significant advantage of PCV-VG® in enhancing oxygenation.[5] Lee et al.[3] also reported no significant differences in oxygenation indices between the two ventilation modes.[3] Consistent with these findings, our study did not demonstrate any significant differences in oxygenation parameters among the three groups. One possible explanation for this observation is the similarity in Pmean values across the groups. Additionally, since our study was conducted in hemodynamically stable patients without significant cardiopulmonary comorbidities, oxygenation differences may have been less pronounced. These findings suggest that all three ventilation modes are effective in maintaining oxygenation and alveolar recruitment; however, PCV-VG® and PCV offer the advantage of lower Ppeak levels.

Beyond oxygenation, the effects of ventilation modes on tidal volume were also evaluated. Our results revealed no significant differences in tidal volume at any time point among the groups, indicating that both PCV and PCV-VG® delivered the target ventilation volumes under the standardized settings. At T3, $PaCO_2$ levels in the PCV-VG® group were statistically lower than those in the VCV and PCV groups. However, the absolute differences were small and $PaCO_2$ values remained within a narrow, clinically acceptable range across all groups (approximately 33–36 mmHg). Therefore, this finding should be interpreted primarily as a statistical difference rather than definitive evidence of clinically meaningful superiority in $CO_2$ elimination. Similar observations have been reported in previous studies, although the clinical relevance of modest $PaCO_2$ differences within the normal range remains uncertain, particularly when ventilation targets are met in all groups.[22]

In the context of barotrauma prevention, monitoring Pplateau, in addition to Ppeak, is critical, as it reflects end-expiratory alveolar pressure. In a study by Toker et al.[4], Pplateau values in the VCV group were significantly higher at T2 and T3 compared to the other groups, which was associated with an increased risk of barotrauma. Our findings were consistent with these results, as Pplateau values in the VCV group were significantly elevated at T2 and T3. These findings further support the notion that PCV and PCV-VG® may reduce the risk of barotrauma by limiting excessive airway pressures.

Maintaining hemodynamic stability is a critical concern during laparoscopic surgeries, particularly in the steep Trendelenburg position. In our study, HR, MAP, and $SpO_2$ values were comparable across all groups, indicating that the ventilation modes did not significantly affect hemodynamic parameters. However, within-group analysis revealed a significant increase in MAP at T3 in the VCV, PCV, and PCV-VG® groups. This may be attributed to increased intrathoracic pressure and reduced venous return during pneumoperitoneum. Additionally, a transient decrease in $SpO_2$ was observed in the VCV group at T2, although this change was not clinically significant and subsequently recovered at later time points. These findings indicate that all three ventilation modes were effective in maintaining oxygen delivery and hemodynamic stability.

This study has several limitations. Blinding was not implemented for anesthesiologists or outcome assessors due to the study design, which may have introduced bias, although a standardized anesthesia protocol and objective outcome parameters were used to minimize this risk. Patients with significant cardiopulmonary comorbidities and morbid obesity were excluded, limiting the generalizability of the findings to high-risk populations. Postoperative pulmonary complications (e.g., atelectasis, prolonged mechanical ventilation) were not assessed, preventing conclusions about the long-term impact of different ventilation modes. Further research involving larger cohorts and extended postoperative follow-up is needed.

## Conclusion

In conclusion, PCV and PCV-VG® provided lower Ppeak and Pplateau values compared to VCV in patients undergoing laparoscopic gynecologic surgery in the steep Trendelenburg position. While PCV-VG® was associated with lower $PaCO_2$ levels and maintained stable tidal volumes at lower airway pressures, oxygenation and hemodynamic parameters were comparable among the groups. These findings suggest that PCV and PCV-VG® may offer advantages over VCV in reducing airway pressures, and PCV-VG® may be a potentially favorable ventilation strategy for such procedures. However, these results are based solely on intraoperative physiological parameters, and further studies involving larger and higher-risk populations with postoperative outcome assessments are needed to confirm these findings.

### Disclosures

**Ethics Committee Approval:** This study was approved by the local ethics committee of Zeynep Kâmil Training and Research Hospital (Date: 06/01/2021, No:2).

**Peer-review:** Externally peer-reviewed.

**Conflict of Interest:** The authors declare no conflict of interest.

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**Institutional Review Board Statement:** This study was designed as a prospective, randomized controlled trial. The study was registered on ClinicalTrials.gov (NCT06861959).

**Informed Consent Statement:** Written informed consent was obtained from all study participants prior to participation. All methods were carried out in accordance with the Declaration of Helsinki.

**Data Availability:** The research data supporting the results of this manuscript are available upon reasonable request. Interested researchers can contact the corresponding author at drkubrataskin@gmail.com for access to the data.

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