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SCIENTIFIC ARTICLE

Comparison of pressure-controlled volume-guaranteed ventilation and volume-controlled ventilation in obese patients during gynecologic laparoscopic surgery in the Trendelenburg position

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Abstract

Background and objectives: The aim of this study was to investigate the efficacy of the pressure-controlled, volume-guaranteed (PCV-VG) and volume-controlled ventilation (VCV) modes for maintaining adequate airway pressures, lung compliance and oxygenation in obese patients undergoing laparoscopic hysterectomy in the Trendelenburg position.

Methods: Patients (104) who underwent laparoscopic gynecologic surgery with a body mass index between 30 and 40 $kg.m^{-2}$ were randomized to receive either VCV or PCV-VG ventilation. The tidal volume was set at 8 $mL.kg^{-1}$, with an inspired oxygen concentration of 0.4 with a Positive End-Expiratory Pressure (PEEP) of 5 mmHg. The peak inspiratory pressure, mean inspiratory pressure, plateau pressure, driving pressure, dynamic compliance, respiratory rate, exhaled tidal volume, $etCO_2$, arterial blood gas analysis, heart rate and mean arterial pressure at 5 minutes after induction of anesthesia in the and at 5, 30 and 60 minutes, respectively, after pneumoperitoneum in the Trendelenburg position were recorded.

Results: The PCV-VG group had significantly decreased peak inspiratory pressure, mean inspiratory pressur, plateau pressure, driving pressure and increased dynamic compliance compared to the VCV group. Mean PaO_2 levels were significantly higher in the PCV-VG group than in the VCV group at every time point after pneumoperitoneum in the Trendelenburg position.

Conclusions: The PCV-VG mode of ventilation limited the peak inspiratory pressure, decreased the driving pressure and increased the dynamic compliance compared to VCV in obese patients

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undergoing laparoscopic hysterectomy. PCV-VG may be a preferable modality to prevent barotrauma during laparoscopic surgeries in obese patients.

PALAVRAS-CHAVE
Laparoscopia;
Obesidade;
Ventilação mecânica;
Complacência pulmonar;
Anestesia geral

Comparação entre ventilação garantida por volume controlado por pressão e ventilação controlada por volume em pacientes obesos durante cirurgia laparoscópica ginecológica na posição de Trendelenburg

Resumo
Justificativa e objetivos: O objetivo deste estudo foi investigar a eficácia dos modos de ventilação garantida por volume controlado por pressão (PCV-VG) e ventilação controlada por volume (VCV) para manter pressões adequadas nas vias aéreas, complacência pulmonar e oxigenação em pacientes obesos submetidos à histerectomia laparoscópica na posição de Trendelenburg.
Métodos: Cento e quatro pacientes submetidos à cirurgia ginecológica laparoscópica, com índice de massa corporal entre 30 e 40 kg.m^{-2}, foram randomizados para receber ventilação com VCV ou PCV-VG. O volume corrente foi fixado em 8 mL.kg^{-1}, com uma concentração inspirada de oxigênio de 0,4 e pressão positiva expiratória final (PEEP) de 5 mmHg. Registramos os seguintes parâmetros: pressão de pico inspiratório, pressão inspiratória média, pressão de platô, *driving pressure*, complacência dinâmica, frequência respiratória, volume corrente expirado, etCO_2, gasometria arterial, frequência cardíaca e pressão arterial média aos 5, 30 e 60 minutos, respectivamente, após o pneumoperitônio na posição de Trendelenburg.
Resultados: O grupo PCV-VG apresentou uma redução significativa da pressão de pico inspiratório, pressão inspiratória média, pressão de platô, *driving pressure* e aumento da complacência dinâmica comparado ao grupo VCV. Os níveis médios de PaO_2 foram significativamente maiores no grupo PCV-VG do que no grupo VCV em todos os momentos após o pneumoperitônio na posição de Trendelenburg.
Conclusões: O modo de ventilação PCV-VG limitou a pressão de pico inspiratório, diminuiu a *driving pressure* e aumentou a complacência dinâmica, comparado ao VCV em pacientes obesas submetidas à histerectomia laparoscópica. O PCV-VG pode ser uma modalidade preferida para prevenir o barotrauma durante cirurgias laparoscópicas em pacientes obesos.

Introduction

Since the approval of laparoscopic surgery for benign and malignant gynecologic procedures in the 1990s there has been an increase in the number of patients undergoing laparoscopic hysterectomies.[1] However, these operations are performed in the Trendelenburg position together with CO_2 pneumoperitoneum, which is challenging for anesthesiologists. Pneumoperitoneum results in intense intra-abdominal pressure and systemic absorption of CO_2.[2] CO_2 absorption can result in hypercapnia and acidosis due to impaired ventilation.

''Obesity, defined as a Body Mass Index (BMI) >30 kg.m^{-2}'',[3] is characterized by increased airway resistance, labored breathing and decreased respiratory system compliance.[4] In obese surgical patients, a number of techniques, such as extrinsic Positive End-Expiratory Pressure (PEEP) applications with recruitment maneuvers, respiratory rate increments and proper patient positioning to optimize intraoperative ventilation have been proposed.[5] In a meta-analysis, Aldenkortt et al. evaluated mechanical ventilation strategies in obese surgical patients and found that there was no evidence of any difference between pressure-controlled ventilation and volume-controlled ventilation in obese patients.[6]

The most preferred ventilation mode for general anesthesia is Volume-Controlled Ventilation (VCV). This ventilation mode which uses a consistent flow to provide a target Tidal Volume (TV) and guarantee minute ventilation may result in high airway pressure in laparoscopic surgery.[7]

New ventilation, Pressure-Controlled Ventilation (PCV), with a Volume Guarantee (PCV-VG) has been introduced to the field of anesthesiology. In PCV-VG mode, the ventilator regulates the Peak Inspiratory Pressure (PIP) to achieve the optimal TV.[8] To achieve the target volume, ventilator parameters are regularly changed without adjusting airway pressures. Hence, PCV-VG has the advantages of both VCV and PCV to preserve the target minute ventilation while maintaining a low incidence of barotraumas.[9] Applications of pressure-controlled ventilation with a volume-guarantee also include one-lung ventilation in thoracic surgery.

The aim of this study was to compare the efficacy of VCV and PCV-VG in maintaining adequate airway pressure in obese patients undergoing laparoscopic hysterectomy in the Trendelenburg position. The secondary aim of the study was to investigate whether PCV-VG could improve oxygenation compared to VCV in these groups of patients.

Materials and methods

After obtaining approval from the Institutional Review Board, the study was designed as a prospective, randomized, controlled, comparative trial in an affiliated university hospital. The trial was registered with the Australian New Zealand Clinical Trials Registry (ACTRN12618000663257). After obtaining written informed consent from the participants, patients who underwent laparoscopic hysterectomy were considered for the study. Patients who were classified as American Society of Anesthesiologists (ASA) physical status II or III, with a BMI between 30 and 40 $kg.m^{-2}$, and who received at least 1 h of pneumoperitoneum in the Trendelenburg position were enrolled in the study. The exclusion criteria were possible difficult airways, intracranial pathology, and severely obstructive pulmonary disease (Predicted Forced Expiratory Volume in 1 s – FEV1, below 70%).

After the enrolled patients arrived at the Operating Room (OR), standard monitoring procedures were applied per the ASA guidelines. All patients received a standard general anesthetic regimen, which included remifentanil (IV 0.5–1 $\mu g.kg^{-1}.min^{-1}$), propofol (IV 1–2 $mg.kg^{-1}$ titrations), and rocuronium bromide (IV 0.6 $mg.kg^{-1}$) during anesthesia. After the induction of general anesthesia, a 20 G arterial catheter was applied to the radial artery of the nondominant hand for blood sampling and continuous blood pressure monitoring. Anesthesia was maintained using desflurane at 1% minimum alveolar concentration with fractional inspired oxygen of 0.4 and an air mixture of 0.6 to maintain a bispectral index of 40–60 during all operations. Using a sealed envelope randomization order, each patient was assigned into one of the two ventilation mode groups (PCV-VG or VCV) at the same anesthesia workstation (Datex Ohmeda Avance CS2; GE Healthcare, Helsinki, Finland). For both modes of ventilation, the tidal volume was set at 8 $mL.kg^{-1}$ calculated based on the predicted body weight, an inspired oxygen concentration of 0.4 with air, the inspiratory/expiratory ratio was 1:2, the respiratory rate was adjusted to maintain an end tidal CO_2 pressure ($etCO_2$) of 35–40 mmHg, and a standard PEEP of 5 mmHg, was applied for all patients. The intraperitoneal pressure was adjusted to 14 mmHg after pneumoperitoneum and a 30° Trendelenburg position was implemented. Data collection was performed at the following time points:

Time point 1 (T1): 5 minutes after induction of anesthesia in a supine position and before initiation of the pneumoperitoneum;

Time point 2 (T2): 5 minutes after complete CO_2 insufflation while in the Trendelenburg position;

Time point 3 (T3): 30 minutes after the start of the pneumoperitoneum while in the Trendelenburg position;

Time point 4 (T4): 60 minutes after the start of the pneumoperitoneum while in the Trendelenburg position.

Ventilatory parameters such as peak inspiratory preassure (PIP), mean inspiratory pressure (Pmean), Plateau Pressure (Pplateau), dynamic compliance, Respiratory Rate (RR), Exhaled Tidal Volume (TVe), and $etCO_2$ were collected at every time point. The driving pressure was calculated as the difference between the plateau pressure and PEEP. Additionally, arterial blood gas analysis including arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$), pH, and oxygen saturation (SaO_2) were recorded at every time point. Heart Rate (HR) and Mean Arterial Pressure (MAP) were also recorded at all time points.

After the conclusion of the surgery, the patient was transferred to the post anesthesia care unit.

For the statistical analysis Number Cruncher Statistical System (NCSS) 2007 and Power Analysis and Sample Size (PASS) 2008 Statistical Software (Utah. USA) were used. Descriptive data were specified with mean, standard deviation, median, and interquartile range. After the evaluation of the distribution using the Shapiro–Wilk test, normally and nonnormally distributed data were analyzed using an independent *t* test or the Mann–Whitney U test, respectively. A repeated measures test (variance analysis in repeated measures) and a Bonferroni test for the evaluation of binary comparisons were used to evaluate the follow-ups of normally distributed variables. A Friedman test was used to assess the follow-up of nonnormally distributed variables and the Bonferroni-Dunn test was used to evaluate binary comparisons; $p < 0.05$ was considered statistically significant.

Sample size estimation

Sample size estimation was performed using the Power and Sample Size Program (PS version 3.1.2) based on a pilot study with 10 patients in each group. The sample size was based on this pilot study, in which the difference in mean PIP between the two modes of ventilation at T2 was 5.3 cm H_2O, with a standard deviation of 6.5 cm H_2O. A total of 47 patients in each group was estimated using an α error of 0.01 and a desired power of 90% to detect a significant difference. It was decided to recruit 20% more patients to reach 113 patients to compensate for drop-outs.

Results

The statistical analysis included 100 patients (Fig. 1). Patient recruitment and enrollment started in June 2018 and lasted through August 2018.

There were no statistically significant differences between the groups in terms of demographics duration of pneumoperitoneum, or preoperative pulmonary functions (Table 1).

The peak inspiratory pressure significantly increased at T2, T3, and T4 in both groups compared to the baseline at T1 ($p < 0.01$). The T1 PIP measurements of the two groups were not significantly different ($p = 0.602$, $p > 0.05$); however, the PIP measurements of the VCV group at T2 ($p = 0.001$) T3 ($p = 0.001$) and T4 ($p = 0.001$) were significantly higher than those of the PCV-VG group at these three time points.

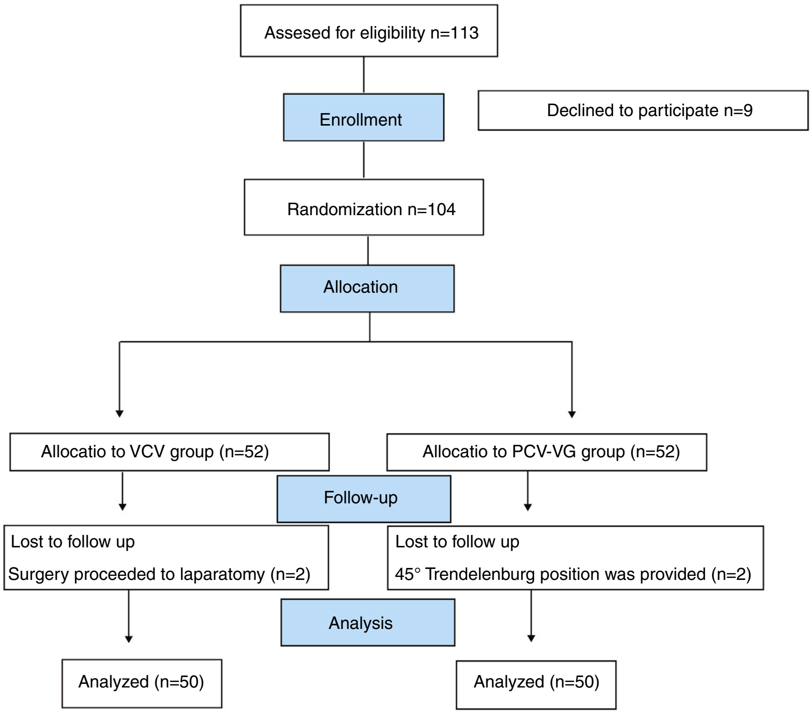

Fig. 1 Consort diagram of the study.

Table 1 Patient characteristics and preoperative pulmonary function.

	Group VCV (n = 50)	Group PCV-VG (n = 50)	[a]p
Age (years)	50.5 ± 9.4	51 ± 7.7	0.79
BMI (kg. m^{-2})	32.8 ± 2.07	33.1 ± 3.1	0.63
ASA physical status (II/III)	28/22	29/21	
Duration of pneumoperitoneum (min)	132.5 ± 33.9	136.6 ± 42.2	0.59
Preoperative FEV_1 (% predicted)	94.3 ± 7.7	93.2 ± 9.8	0.54
Preoperative FVC (% predicted)	91.9 ± 7.6	91.9 ± 8.4	0.99

Results are expressed as the mean ± SD or as the number of patients.
ASA, American Society of Anesthesiologists; BMI, Body Mass Index; FEV_1, Forced Expiratory Volume in 1 s; FVC, Forced Vital Capacity.
[a] Student's *t* test.

Pmean also showed a significant increase in both groups at T2, T3 and T4 compared with T1. For the PCV-VG group, the T1 Pmean was lower than the T3 ($p = 0.001$) and T4 Pmean values ($p = 0.001$), the T2 Pmean was also lower than the T3 and T4 Pmean values ($p < 0.01$), and the T3 Pmean was lower than T4 Pmean ($p = 0.007$). In the VCV group, the increase in Pmean values between T1 and T4 was also significant ($p = 0.001$, $p < 0.01$, respectively).

The T1 Pplateau measurements of the groups were not significant ($p > 0.05$); however, in the VCV group at T2 (n = 0.001), T3 ($p = 0.001$) and T4 ($p = 0.001$). Pplateau measurements were significantly higher than those in the PCV-VG group. The change in Pplateau measurements from T1 to T4 was significant in both groups. T1 measurements in both groups were significantly lower than T2, T3 and T4 measurements. No statistically significant difference was found in other pairwise comparisons ($p > 0.05$). The driving pressure showed a significant increase after pneumoperitoneum and Trendelenburg timepoints compared with T1 in both groups. The T1 driving pressure (DP) measurements of the groups were not significantly different, but the Dp measurements of the PCV-VG group at T2 ($p = 0.001$), T3 ($p = 0.001$) and T4 ($p = 0.001$) were significantly lower than those of the VCV group at these three timepoints.

Likewise, dynamic compliance significantly decreased at T2, T3, and T4 in both groups compared to T1; nevertheless, dynamic compliance was higher at T2, T3, and T4 in the PCV-VG group than in the VCV group ($p < 0.01$). After establishment of pneumoperitoneum and the Trendelenburg position the decrease from baseline dynamic compliance was smaller in the PCV-VG mode, with a 44% decrease in the PCV-VG group compared to a 55% decrease in the VCV group.

The effects of pneumoperitoneum and the Trendelenburg position on the other ventilatory parameters, such as $etCO_2$ and RR, were comparable. End tidal CO_2 pressure started to show a stepwise significant increase in both groups after the 30th minute of pneumoperitoneum and the

Trendelenburg position. After the first hour of pneumoperitoneum, the VCV group had a significantly higher $etCO_2$ than the PCV-VG group ($p = 0.016$). There were no statistically significant differences between the groups for RR at every time point ($p > 0.05$).

The PCV-VG group had a significantly higher TVe than the VCV group at every time point, which included pneumoperitoneum and the Trendelenburg position ($p < 0.05$) (Table 2).

Mean PaO_2 levels were significantly higher in the PCV-VG group than in the VCV group at every time point after pneumoperitoneum and the Trendelenburg position ($p < 0.05$). Arterial oxygenation decreased significantly from T1 to T4 in both groups ($p < 0.05$). Other gas exchange values such as $PaCO_2$ pH and SaO_2 did not show any significant differences between the groups. In both study groups $PaCO_2$ increased significantly at T3 and T4 compared to T1. For both groups, pH levels were compared at different time points and a significant reduction in pH levels was detected over time. Pulse oxygen saturation decreased significantly in both groups for time points, including pneumoperitoneum and the Trendelenburg position ($p < 0.01$) (Table 3).

Hemodynamic parameters did not show any significant differences between the two groups at any time point. Mean arterial pressure significantly increased compared to the baseline in both groups ($p < 0.001$), but the VCV group had no significant differences between T3 and T4. The heart rate increased in both groups at T2, T3, and T4 compared to the baseline ($p < 0.001$) but was stable after the 30th minute of pneumoperitoneum in the VCV group (Table 4).

Discussion

This study demonstrated the benefits of the PCV-VG mode compared to the VCV mode for obese patients who underwent laparoscopic hysterectomy in a 30° Trendelenburg position. The use of the PCV-VG mode was intended to counteract the higher PIP observed with pneumoperitoneum and the Trendelenburg position, and it achieved lower PIP, Pmean, Pplateau and Dp values as well as higher dynamic compliance and arterial oxygenation levels than the VCV mode.

The recommendations for the ventilatory management of obese patients include PIP levels below 30 cmH_2O.[5] The primary result of this study was that the PIP was significantly lower in the PCV-VG mode than in the VCV mode in all periods after pneumoperitoneum and Trendelenburg, which could be explained by the theory of how the PCV-VG mode operates. The PCV-VG mode combines the benefits of both the PCV and VCV modes of ventilation by delivering a prearranged tidal volume with the lowest possible pressure with a decelerating volume.[9] The first breath transferred to the patient is a volume control breath, and the patient's respiratory system compliance is calculated from this volume breath and readapts the inspiratory pressure level to reach the desired tidal volume preset by the clinician.[10] In theory, this type of operation leads to lower PIP and higher dynamic compliance than VCV mode, with a resultant decline in pulmonary shunt and advancement of oxygenation in obese adults.

Similar studies compared the VCV mode with Pressure-Regulated Volume-Controlled (PRVC) mode, which is the proprietary name of PCV-VG specifically for Maquet ventilators[10] or PCV-VG mode in One-Lung Ventilation (OLV).[9,11–13] Boules et al.[13] found advanced arterial oxygenation with PCV-VG mode during OLV. In the study by Dion et al.,[14] both the PCV-VG and PCV modes resulted in a lower PIP than VCV, but they did not find any significant differences in oxygenation between the three modes of ventilation during laparoscopic bariatric surgery. In the OLV studies mentioned above, there was a great consensus about decreased PIP levels with PCV-VG mode; however, the results about improvement of arterial oxygen are still debated.

As far as could be determined, there have been only two studies in the field of laparoscopic gynecologic surgery that compared the effects of different ventilation modes on respiratory ventilation parameters.[15,16] Ogurlu et al.[15] compared the PCV mode versus the VCV mode and reported similar results as earlier studies in terms of lower PIP, plateau pressure, and higher compliance in PCV mode during pneumoperitoneum and the Trendelenburg position. These results were consistent with the results of our study, as they were probably associated with the same decelerating inspiratory flow pattern of both PCV and PCV-VG. PCV-VG includes the advantages of PCV, the most important of which is sustained reductions in PIP because of its decelerating flow profile, as discussed in a meta-analysis about intraoperative mechanical ventilation strategies in OLV.[17] Assad et al. analyzed the effects of PCV-VG and VCV on airway pressures during laparoscopic surgery in the Trendelenburg position and showed that PCV-VG was superior to VCV in its ability to provide ventilation with lower PIP and greater dynamic compliance.[16] In contrast to our study, Assad et al. reported that PCV-VG had no advantage over VCV for improving oxygenation. The different oxygenation results of these two studies can be explained by a variation in the patient population. In the study by Assad et al. the mean body mass index of the population was $23.4\,kg.m^{-2}$ in the VCV group and $24.5\,kg.m^{-2}$ in the PCV-VG group; however, it was $32.8\,kg.m^{-2}$ in the VCV group and $33.1\,kg.m^{-2}$ in the PCV-VG group in this study. Thus, the current patients were more obese than Assad's study population. Cadi et al. compared PCV and VCV in morbidly obese patients undergoing laparoscopic gastric banding surgery and showed improvements in arterial oxygenation in favor of PCV.[18] They explained their results as an increase in oxygenation by means of the instantaneous acceleration flow profile of the pressure-controlled mode. Davis et al. studied PCV-VG mode in Acute Respiratory Distress Syndrome (ARDS) and, in agreement with our results, found that PCV-VG can improve oxygenation compared with VCV in patients with ARDS.[19] A recent meta-analysis by Aldenkortt et al. evaluated 13 trials that included 505 obese surgical patients and a variety of ventilation strategies in obese adults.[6] This meta-analysis closely examined 4 trials that included 100 patients and compared PCV with VCV. They concluded that there was no superiority of either the VCV or the PCV modes to improve oxygenation or ventilation in obese patients. However, considering the results of our study, in obese patients undergoing laparoscopic surgery in the Trendelenburg position, an assumption that the PCV-VG mode is more effective than VCV in increasing oxygenation can be made. The decelerating flow pattern of PCV-VG rapidly inflates the alveoli so that all alveoli

Table 2 Ventilation parameter determination among groups.

		T1	T2	T3	T4
PIP (cm H_2O)	PCV-VG	15.6 ± 2.8	24.6 ± 3.2[a,b]	24 ± 3.2[a,b]	25.04 ± 4.2[a,b]
	VCV	15.9 ± 2.9	29.1 ± 3.4[b]	28.5 ± 2.7[b]	29.3 ± 4.2[b]
Pmean (cm H_2O)	PCV-VG	8.1 ± 0.9	8.4 ± 1.6[a]	9.3 ± 2.1[b]	10 ± 1.9[a,b]
	VCV	8.2 ± 1.3	9.5 ± 1.5[b]	9.9 ± 1.8[b]	11.7 ± 1.2[b]
Pplateau (cm H_2O)	PCV-VG	13.2 ± 2.8	21.9 ± 3.2[a,b]	21.4 ± 3.3[a,b]	22.4 ± 4.4[a,b]
	VCV	13.6 ± 2.9	26.5 ± 3.5[b]	25.4 ± 2.8[b]	26.1 ± 4.4[b]
Dp (cm H_2O)	PCV-VG	8.2 ± 2.8	16.9 ± 3.2[a,b]	16.4 ± 3.2[a,b]	17.3 ± 4.4[a,b]
	VCV	8.6 ± 2.9	21.6 ± 3.6[a]	20.4 ± 2.8[a]	21.1 ± 4.4[a]
Compliance (mL. cm^{-1} H_2O)	PCV-VG	42.9 ± 6.1	23.9 ± 3.6[a,b]	22.7 ± 5.4[b,c]	22.6 ± 6.2[a,b]
	VCV	42.6 ± 6.5	18.8 ± 3.8[b]	20.6 ± 5.1[b]	17.8 ± 4.4[b]
RR (breath. min^{-1})	PCV-VG	11.3 ± 1.0	11.5 ± 0.8	12.3 ± 1.3	12.9 ± 2.4
	VCV	11.3 ± 1.0	11.6 ± 1.0	12.4 ± 1.5[b]	13.6 ± 2.9[b]
TVe (mL)	PCV-VG	457.3 ± 39.0	470.1 ± 26.3[c]	469.7 ± 30.1[c,f]	472.3 ± 24.3[c,d]
	VCV	448.9 ± 38.5	451.3 ± 42.6	452.73 ± 39.1	452.3 ± 50.8
$etCO_2$ (mmHg)	PCV-VG	35.28 ± 2.3	34.90 ± 2.3	37.66 ± 2.1[b]	37.40 ± 1.9[b,c]
	VCV	35.18 ± 2.0	35.12 ± 2.0	38.40 ± 2.2[b]	38.5 ± 2.4[b]

Data are presented as the mean ± SD.

PIP, Peak Inspiratory Pressure; Pmean, Mean Inspiratory Pressure; RR, Respiratory Rate; Pplateau, Plateau Pressure; Dp, Driving Pressure; TVe, Exhaled Tidal Volume; $etCO_2$, End Tidal CO_2; VCV, Volume-Controlled Ventilation; PCV-VG, Pressure-Controlled Ventilation-Volume Guaranteed.

[a] $p < 0.01$ vs. the VCV group at the same time point.

[b] $p < 0.01$ vs. T1 in each group.

[c] $p < 0.05$ vs. the VCV at the same time point.

[d] $p < 0.05$ vs. T1 in each group.

Table 3 Gas exchange value determination among groups.

		T1	T2	T3	T4
PaO_2 (mmHg)	PCV-VG	180.3 ± 30.3	176.3 ± 23.5[a]	165.5 ± 20.3[a,b]	165.2 ± 23.5[b,c]
	VCV	180.7 ± 51.5	163.7 ± 24.9	155.9 ± 24.6[b]	149.4 ± 27[b]
$PaCO_2$ (mmHg)	PCV-VG	36.7 ± 3.1	36.4 ± 3.6	39.4 ± 3.3[b]	39.9 ± 4[b]
	VCV	37.2 ± 2.5	36.6 ± 3.2	39.5 ± 4.1[b]	40.60 ± 5.2[b]
pH	PCV-VG	7.5 ± 0.1	7.4 ± 0.1[b]	7.4 ± 0.1[b]	7.4 ± 0.1[b]
	VCV	7.4 ± 0.1	7.4 ± 0.1[b]	7.4 ± 0.6[b]	7.3 ± 0.1[b]
SaO_2	PCV-VG	99.5 ± 0.9	99.5 ± 0.7	99 ± 0.8[b]	98.7 ± 1.2[b]
	VCV	99.5 ± 0.6	99.1 ± 1.1	98.7 ± 1.2[b]	98.7 ± 1.3[b]

Data are presented as the mean ± SD.

PaO_2, partial arterial oxygen tension; $PaCO_2$, partial arterial carbon dioxide tension; VCV, volume-controlled ventilation; PCV-VG, pressure-controlled ventilation-volume guaranteed.

[a] $p < 0.05$ vs. the VCV at the same time point.

[b] $p < 0.01$ vs. T1 in each group.

[c] $p < 0.01$ vs. the VCV group at the same time point.

reach a more uniform distribution of the tidal volume, which diminishes the amount of atelectasis via improved alveolar recruitment. It seems apparent that the pressure-controlled mode and the flow profile of PCV-VG allow better alveolar recruitment before pneumoperitoneum in the obese population.

Mean airway pressure is associated with alveolar ventilation, and higher Pmean values increase arterial oxygenation.[20] In the situation of improved oxygenation, higher mean pressures might have been anticipated, but PCV-VG achieved lower Pmean values than VCV at every time point after pneumoperitoneum. For the same adjusted volume, decelerating inspiratory flow arrives at more advanced values with PCV-VG than with VCV. Despite the fact that the mean pressure was low in the PCV-VG group, the high tidal volume of pneumoperitoneum in all lungs indicates that the alveoli that become atelectatic after pneumoperitoneum and the Trendelenburg position also participate in ventilation. When more alveoli participate in ventilation, the ventilation/perfusion ratio is better preserved using PCV-VG.

Another important result of this study was that the dynamic compliance of the PCV-VG group was statistically significant at all time points after pneumoperitoneum. In

Table 4 Hemodynamic parameters.

		T1	T2	T3	T4
HR	PCV-VG	66.2 ± 2.3	62.2 ± 1.9[a]	75.7 ± 5.2[a]	74.2 ± 3.3[a]
	VCV	66.5 ± 2.4	62.4 ± 2.3[a]	75.9 ± 2.7[a]	74.9 ± 3.6[a]
MAP	PCV-VG	68 ± 2.6	75.3 ± 3.2[a]	78.6 ± 4.5[a]	82.7 ± 4[a]
	VCV	67.7 ± 2.8	75.9 ± 3.1[a]	79.3 ± 11.5[a]	83.5 ± 4.5[a]

Data are presented as the mean ± SD.

HR, Heart Rate; MAP, Mean Arterial Pressure; VCV, Volume-Controlled Ventilation; PCV-VG, Pressure-Controlled Ventilation-Volume Guaranteed.

[a] $p < 0.01$ versus T1 in each group.

the PCV-VG group, a 44% decline in compliance was observed at T2, in contrast to a 55% decline in the VCV group at T2. Hirvonen et al. who evaluated the ventilatory effects of prolonged CO_2 pneumoperitoneum and Trendelenburg position showed that dynamic compliance was reduced by 20% in the head down position and reduced by an additional 30% with pneumoperitoneum, reaching a total 50% decrease.[21] Considering Hirvonen's study result, this study found that the PCV-VG mode resulted in a lesser reduction in dynamic compliance. The higher compliance achieved with PCV-VG may be beneficial during laparoscopic gynecologic surgeries.

In our study, the driving pressure and the plateau pressures of the VCV group after the start of pneumoperitoneum and Trendelenburg position significantly increased compared to baseline, and at the same time points, they were higher than those of the PCV-VG group. Better ventilation mode selection in obese patients has been previously evaluated.[22] The administration of the volume mode carries the risk of increased positive inspiratory pressures to achieve the preset tidal volume. Thus checking the end inspiratory alveolar pressure defined as plateau pressure is crucial to prevent barotrauma. In our study, significantly higher levels of plateau pressure in the VCV group predicted the possibility of barotrauma. The Dp is the difference between plateau pressure and PEEP; in other words, Dp is the quotient between the tidal volume and respiratory system compliance.[23] Both the compliance of the lungs and the plateau pressure affect the driving pressure. Mechanical ventilation strategies that favor lower plateau pressures, lower driving pressures, higher PEEP levels and lower tidal volumes have been associated with increased survival rates in acute respiratory distress syndrome.[24] Therefore, an increase in driving pressure will show a nonrecruitable lung in which the distention exceeds recruitment. Bugedo et al. suggested 15 cm H_2O as the safety limit for Dp.[25] In our study, the Dp levels exceeded 15 cm H2O after the start of pneumoperitoneum and Trendelenburg position in both groups. However our results suggest that the PCV-VG mode reduces the Dp in the presence of the same PEEP values in both groups. Thus, setting the ventilatory mode to PCV-VG in a patient who undergoes surgery in the Trendelenburg position will decrease the Dp. The decline in Dp may improve respiratory outcomes after surgery.

Obese patients are likely to develop atelectasis due to the loads to lung mechanics aggravated by excessive adiposity and the common presence of additional respiratory morbidities.[5] Thus, PEEP is a crucial method to improve respiratory mechanics. In our study, we applied PEEP in 5 mmHg to all patients as is the current clinical practice.

There were two randomized controlled studies that found better oxygenation levels favoring the PCV-VG mode over the VCV mode in the field of thoracic surgery and OLV.[9,13] We also found that arterial oxygenation was higher in the PCV-VG group than in the VCV group at all 3 time points after starting pneumoperitoneum and Trendelenburg position. Although this finding was significant, the measured levels of partial oxygen pressures were both higher from targeted thresholds for oxygenation during mechanical ventilation. In our opinion, these higher levels did not affect arterial oxygen saturation; thus, the values of arterial oxygen saturation stayed above 98%. Therefore, this finding does not have a great impact on favoring one ventilation mode to another in terms of oxygenation.

In our study, after 30 minutes of starting pneumoperitoneum and the Trendelenburg position, increased $etCO_2$ levels were found in both groups. However, the adjustment of the respiratory rate to keep the $etCO_2$ value between 35 and 40 mmHg resulted in the normalized range $PaCO_2$ levels. These results regarding $PaCO_2$ levels suggest that there is no superiority between the two ventilation techniques for CO_2 removal.

One limitation of this study was that it evaluated only one type of surgery using the Trendelenburg position. Other types of surgeries, such as robotic surgeries, may need steeper Trendelenburg positions, which could modify the results. Another limitation was that only patients with no concomitant lung disease were included. Therefore these results cannot be generalized to include patients with obstructive or restrictive pulmonary diseases. Additionally, no lung atelectasis assessment was performed postoperatively.

Conclusion

The results of this trial indicate that the PCV-VG mode of ventilation limited peak inspiratory pressure decreased driving pressure and increased dynamic compliance compared to VCV in obese patients undergoing laparoscopic hysterectomy with 14 mmHg pneumoperitoneum pressure and a 30° Trendelenburg position. PCV-VG may be a preferable modality to prevent barotrauma during laparoscopic surgeries in obese patients.

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Conflicts of interest

The authors declare no conflicts of interest.

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