



# Brazilian Journal of ANESTHESIOLOGY



## CLINICAL RESEARCH

### Hemodynamic outcome of different ventilation modes in laparoscopic surgery with exaggerated trendelenburg: a randomised controlled trial

Hakan Yılmaz<sup>a</sup>, Baturay Kansu Kazbek<sup>a,\*</sup>, Ülkü Ceren Köksoy<sup>a</sup>, Ahmet Murat Gül<sup>a</sup>, Perihan Ekmekçi<sup>a</sup>, Gamze Sinem Çağlar<sup>b</sup>, Filiz Tüzüner<sup>a</sup>

<sup>a</sup> *Ufuk University Faculty of Medicine, Department of Anesthesiology and Reanimation, Ankara, Turkey*

<sup>b</sup> *Ufuk University Faculty of Medicine, Department of Obstetrics and Gynecology, Ankara, Turkey*

Received 9 December 2019; accepted 25 April 2021

#### KEYWORDS

Laparoscopic surgery;  
Mechanical ventilation;  
Hemodynamic monitoring

#### Abstract

**Purpose:** To compare hemodynamic effects of two different modes of ventilation (volume-controlled and pressure-controlled volume guaranteed) in patients undergoing laparoscopic gynecology surgeries with exaggerated Trendelenburg position.

**Methods:** Thirty patients undergoing laparoscopic gynecology operations were ventilated using either volume-controlled (Group VC) or pressure-controlled volume guaranteed mode (Group PCVG) (n = 15 for both groups). Hemodynamic variables were measured using Pressure Recording Analytical Method by radial artery cannulation in addition to peak and mean airway pressures and expired tidal volume.

**Results:** The only remarkable finding was a more stable cardiac index in Group PCVG, where other hemodynamic parameters were similar. Expired tidal volume increased in Group VC while peak airway pressure was lower in Group PCVG.

**Conclusion:** PCV-VG causes less hemodynamic perturbations as measured by Pressure Recording Analytical Method (PRAM) and allows better intraoperative hemodynamic control in exaggerated Trendelenburg position in laparoscopic surgery.

© 2021 Published by Elsevier Editora Ltda. on behalf of Sociedade Brasileira de Anestesiologia. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

\* Corresponding author.

E-mail: [bkkazbek@gmail.com](mailto:bkkazbek@gmail.com) (B.K. Kazbek).

<https://doi.org/10.1016/j.bjane.2021.04.028>

© 2021 Published by Elsevier Editora Ltda. on behalf of Sociedade Brasileira de Anestesiologia. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Please cite this article as: H. Yılmaz, B.K. Kazbek, Ü.C. Köksoy et al., Hemodynamic outcome of different ventilation modes in laparoscopic surgery with exaggerated trendelenburg: a randomised controlled trial, *Brazilian Journal of Anesthesiology*, <https://doi.org/10.1016/j.bjane.2021.04.028>

## Introduction

Modern gynecologic surgery by laparoscopy shortens length of stay, causes less postoperative pain, and allows faster recovery. In order to optimize surgical exposure, Trendelenburg position, defined as 30° head down tilt, is preferred. Exaggerated Trendelenburg (> 30°) ensures better access to the pelvis and lower abdomen.

The increase in intra-abdominal pressure caused by Carbon dioxide (CO<sub>2</sub>) insufflation and exaggerated Trendelenburg position causes adverse effects in the cardiovascular and other systems.<sup>1</sup> The CO<sub>2</sub> pneumoperitoneum utilized in laparoscopic surgeries increases systemic and pulmonary vascular resistance while lowering the Cardiac Index (CI), thus causing a major increase in the afterload and a decrease in cardiac output. The addition of Trendelenburg to pneumoperitoneum reverts the afterload to normal levels while increasing the preload and pulmonary wedge pressure.<sup>2</sup> Considering the necessity of exaggerated Trendelenburg position in laparoscopic gynecologic surgeries, cardiovascular management is of concern.

The Pressure Recording Analytical Method (PRAM) is the modern version of the pulse contour measurement methods, which was first utilized in 1800s.<sup>3</sup> This minimally invasive technique provides real time analysis of hemodynamic variables using the arterial pressure waveform obtained by cannulating radial, brachial, or femoral artery. This method allows beat-to-beat calculation of Systemic Vascular Resistance Index (SVRI), Stroke Volume Index (SVI), Cardiac Index (CI), Stroke Volume Variability (SVV), Cardiac Cycle Efficiency (CCE), and maximal pressure/time ( $dP/dt_{max}$ ).

Ventilator settings and modes need to be adjusted to minimize the adverse effects on respiratory mechanics caused by Trendelenburg position and pneumoperitoneum because functional residual capacity and lung compliance is decreased due to limitation of diaphragmatic movement.<sup>4</sup> Both Volume-Controlled Ventilation (VCV) and Pressure-Controlled Ventilation (PCV) can be utilized for this surgery. However, their advantages over each other are still a subject of debate. Volume-controlled mode uses a constant or decelerating flow to deliver the target tidal volume and aims to provide adequate minute ventilation.<sup>1</sup> On the other hand, pressure-controlled volume guaranteed (PCV-VG) mode encompasses both VCV and PCV modes and uses a constant inspiratory pressure and tidal volume, which result in a decelerating flow pattern.<sup>5</sup> PCV-VG mode can deliver a suitable tidal volume in the face of rapidly changing intra-abdominal pressure caused by changes in position and CO<sub>2</sub> insufflation in laparoscopic surgery.<sup>6</sup> This study was conducted due to the scarcity of studies comparing the cardiac and respiratory effects of VCV and PCV-VG modes in the exaggerated Trendelenburg position for laparoscopic gynecologic surgeries.

There is no study in the literature that compares PCV-VG and VCV in the exaggerated Trendelenburg position in laparoscopic surgery concerning hemodynamic parameters with PRAM method. The hypothesis of this study was that PCV-VG ventilation would cause less hemodynamic deterioration compared to VCV mode. Therefore, this study is designed to evaluate the hemodynamic effects of volume-controlled and pressure-controlled volume guaran-

teed modes on hemodynamic parameters using PRAM in a randomized design.

## Materials and methods

After obtaining ethical committee approval (Ethical committee approval n° 04012017-5, clinicaltrials.gov NCT03684291) and written informed consent from all patients, 30 ASA (American Society of Anesthesiologists) physical status I/II patients were randomized to groups VC (n = 15) and PCVG (n = 15) using closed envelope method. Patients scheduled to undergo elective surgery in a university hospital were included in the study. Patients refusing to participate, patients with severe systemic disease (history of myocardial infarction, chronic obstructive, or restrictive lung disease), obese patients (BMI > 30), heavy smokers (cigarette consumption > 20/day) and patients with known allergy to any of the study drugs and patients with neuromuscular diseases were excluded from the study. Conversion to laparotomy, desaturation (SpO<sub>2</sub> < 90%) and/or hemodynamic disturbance (more than 20% fall in systolic blood pressure and/or ±20% decline in heart rate) was defined as exclusion criteria.

The surgery was performed by the same surgeon (GSC) and all cases were laparoscopic gynecologic operations for benign conditions (laparoscopic myomectomy, hysterectomy and adnexial mass removal, or oophorectomy). The operating table was set to > 30° Trendelenburg position using a protractor and the intra-abdominal pressure was set to 10–12 mmHg using an automated endoflator during surgery.

## Anesthesia and monitorization

After arriving in the operation room, electrocardiography, peripheral pulse saturation (SpO<sub>2</sub>), and noninvasive blood pressure were monitored. Anesthesia induction was carried out using propofol 3 mg.kg<sup>-1</sup>, fentanyl 1 mcg.kg<sup>-1</sup>, and rocuronium 0.6 mg.kg<sup>-1</sup>. Sevoflurane 1 minimal alveolar concentration (MAC) and 50/50 mixture of oxygen and nitrous oxide (fresh gas flow 2 L.min<sup>-1</sup>) was used for maintenance. Neuromuscular blockade was monitored using Train Of Four (TOF). Additional neuromuscular blocker agent was administered when two twitches were observed on TOF. All patients were given 7 mL.kg<sup>-1</sup>.h<sup>-1</sup> Ringer's lactate solution. Patients were heated using a conductive system to keep the body temperature above 36 °C.

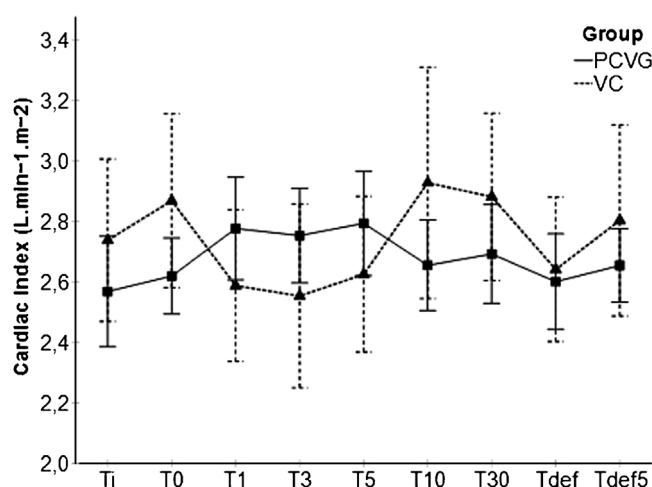
Mechanical ventilation settings were as follows: the patients in Group VC were mechanically ventilated using VCV while the patients in Group PCVG were ventilated using PCV-VG. Tidal volume 8–10 mL.kg<sup>-1</sup> (ideal body weight), I:E ratio 1:2, frequency target end-tidal CO<sub>2</sub> 38±2 mmHg for both groups. PEEP was not utilized. Radial artery cannulation was performed for all patients and PRAM monitorization was carried out using MostCareup® (Vygon, Italy) as described by Romagnoli et al.<sup>3</sup> Hemodynamic variables detected by PRAM monitorization (heart rate, mean arterial pressure, Systemic Vascular Resistance Index (SVRI), Stroke Volume Index (SVI), Cardiac Index (CI), stroke volume variation SVV, Cardiac Cycle Efficiency (CCE) and  $dP/dt_{max}$ ), and ventilator parameters (tidal volume expired, peak and mean airway pressures) were measured and recorded following induction

(Ti), at peritoneal insufflation (T<sub>0</sub>), 1 (T<sub>1</sub>), 3 (T<sub>3</sub>), 5 (T<sub>5</sub>), 10 (T<sub>10</sub>), and 30 (T<sub>30</sub>) minutes after pneumoperitoneum, following desufflation (Tdef), and 5 minutes following desufflation (Tdef<sub>5</sub>).

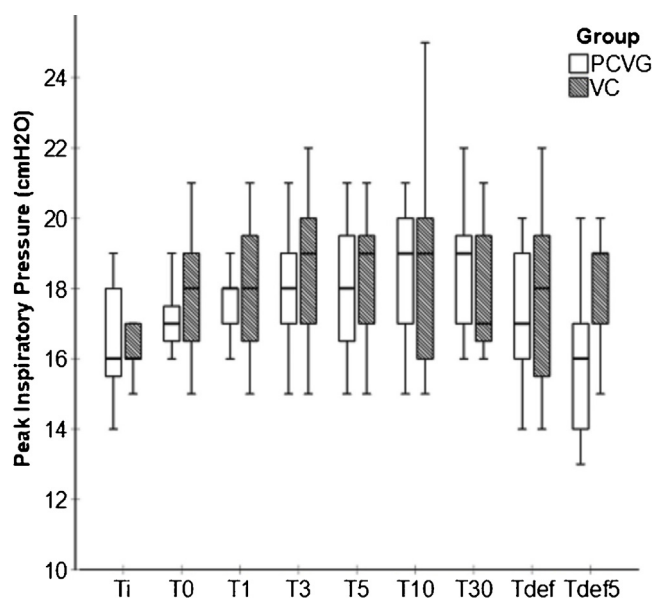
Statistical analyses were performed with SPSS version 12.0 software (SPSS Inc., Chicago, IL, USA). Data are expressed as means ± Standard Deviation (SD) or numbers of patients. The sample size is calculated in a similar fashion to a previous study,<sup>7</sup> in which AP<sub>peak</sub> in PCV patients was 6 cmH<sub>2</sub>O lower than with VCV, with a standard deviation of 6 cmH<sub>2</sub>O in the Trendelenburg position. The parameters used in this study are AP<sub>peak</sub> in PCVG patients as 5 cmH<sub>2</sub>O lower than with VCV, with a standard deviation of 5 cm H<sub>2</sub>O in the Trendelenburg position. Accordingly, these parameters suggest 14 patients per group for a test with an alpha error of 0.05 and power of 80%. X<sup>2</sup>-test or Fisher's exact test was performed to compare patient characteristics. To compare variables between the two groups, the Kolmogorov-Smirnov test was used to identify variables with normal distribution. Independent *t*-test was used to compare variables with normal distribution, and those without normal distribution were compared by Mann-Whitney *U* test. A *p*-value < 0.05 was considered statistically significant.

## Results

During the study period 15 patients not fulfilling the criteria were excluded from the study. After randomization, 3 cases were dropped out due to conversion to laparotomy. Finally, the study was concluded with 30 patients (15 cases for Group PCVG and 15 for Group VC). The age and BMI of the groups were similar (for age 32.7 ± 6.5 vs. 29.7 ± 5.9, *p* = 0.190 and for BMI 26.6 ± 5.1 vs. 24.6 ± 2.7, *p* = 0.204; Group PCVG and Group VC respectively). Demographical data is presented in Table 1. No significant difference was found in the duration of surgery, anesthesia, and pneumoperitoneum (*p* > 0.05). After induction of anesthesia, until desufflation, the recorded hemodynamic values by PRAM monitorization are given at Table 2. There was no statistically significant difference concerning heart rate and MAP values between two groups. SVRI values were lower in Group PCVG at T<sub>0</sub> point without statistical significance (2484 ± 244 dyne·s·m<sup>-2</sup>·cm<sup>-5</sup> in Group PCVG 2675 ± 417 dyne·s·m<sup>-2</sup>·cm<sup>-5</sup> in Group VC). These values have remained higher in Group VC throughout pneumoperitoneum without significance however, the difference had a statistical significance at T<sub>3</sub> and T<sub>5</sub> time points (*p* = 0.023 in T<sub>3</sub> and *p* = 0.023 in T<sub>5</sub>). SVI values were significantly lower in Group VC at peritoneal insufflation and desufflation (*p* = 0.001 and *p* = 0.004, respectively.) In Group VC, SVI significantly decreased in T<sub>0</sub> compared to Ti (*p* = 0.034), significantly increased in T<sub>1</sub> compared to T<sub>0</sub> (*p* = 0.007) and remained constant throughout the study period but decreased at desufflation compared to Group PCVG. The only remarkable parameter was detected at CI which was more stable in Group PCVG at all time points (Group PCVG vs Group VC, *p* = 0.025) (Fig. 1). There were no significant differences in SVV, dP/dt<sub>max</sub> and CCE values throughout the study period. Peak airway pressure values were lower in Group PCVG (Fig. 2) while expiratory tidal volumes were increased in Group VC (Fig. 3).



**Fig. 1** Cardiac index variations measured by Pressure Recording Analytical Method in both groups. Data (means ± SD) are the same as those shown in Table 2. Ti, anesthesia induction; T<sub>0</sub>, peritoneal insufflation; T<sub>1</sub>, T<sub>3</sub>, T<sub>5</sub>, T<sub>10</sub>, and T<sub>30</sub>, 1, 3, 5, 10, and 30 minutes after CO<sub>2</sub> pneumoperitoneum respectively; Tdef, desufflation; T<sub>5def</sub>, termination of pneumoperitoneum (5 minutes after desufflation). PCVG, Pressure-Controlled Volume-Guaranteed ventilation; VCV, Volume-Controlled Ventilation. Figure 1 indicates that there is more variation in group VC compared to group PCVG (*p* = 0.025).



**Fig. 2** Peak inspiratory pressures at different time points in both groups. Boxplot graphic, middle line of box; median value, upper-lower line of box; 25–75%, upper-lower line of whisker; min-max value excluding outliers. Ti, anesthesia induction; T<sub>0</sub>, peritoneal insufflation; T<sub>1</sub>, T<sub>3</sub>, T<sub>5</sub>, T<sub>10</sub>, and T<sub>30</sub>, 1, 3, 5, 10, and 30 minutes after CO<sub>2</sub> pneumoperitoneum, respectively; Tdef, desufflation; T<sub>5def</sub>, termination of pneumoperitoneum (5 minutes after desufflation). PCVG, Pressure-Controlled Volume-Guaranteed ventilation; VCV, Volume-Controlled Ventilation.

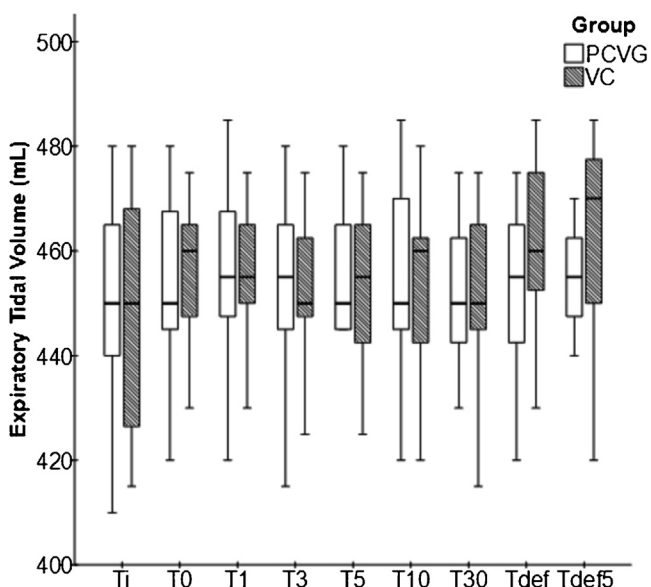
**Table 1** Patient characteristics and operative data.

	Group PCVG (n = 15)	Group VC (n = 15)	p
Age (yr)	32.7 ± 6.5	29.7 ± 5.9	0.190
Weight (kg)	78 ± 15.6	78.3 ± 10.4	0.956
Height (m)	161.2 ± 8.1	162.6 ± 7.6	0.628
BMI (kg.m <sup>-2</sup> )	26.6 ± 5.1	24.6 ± 2.7	0.204
Duration of anesthesia (min)	88.3 ± 14.6	88 ± 13.9	0.949
Duration of surgery (min)	76 ± 15.7	74.7 ± 14.1	0.808
Duration of pneumoperitoneum (min)	64.3 ± 15	64 ± 12.4	0.948

Data are expressed as mean ± SD.

PCVG, Pressure-Controlled Volume Guaranteed ventilation; VCV, Volume Controlled Ventilation; BMI, Body Mass Index.

No significant differences were noted between the two groups.



**Fig. 3** Expiratory tidal volumes at different time points in both groups. Boxplot graphic, middle line of box; median value, upper-lower line of box; 25–75% percentile, upper-lower line of whisker; min-max value excluding outliers. Ti, anesthesia induction; T0, peritoneal insufflation; T1, T3, T5, T10, and T30, 1, 3, 5, 10, and 30 minutes after CO<sub>2</sub> pneumoperitoneum, respectively; Tdef, desufflation; T5def, termination of pneumoperitoneum (5 minutes after desufflation). PCVG, Pressure-Controlled Volume-Guaranteed ventilation; VCV, Volume-Controlled Ventilation.

## Discussion

In this study, two different ventilation modes PCV-VG and VCV were compared in hemodynamically stable women undergoing laparoscopy in exaggerated Trendelenburg position. The data shows that PCV-VG causes less hemodynamic perturbations as measured by PRAM and allows better intraoperative hemodynamic control in exaggerated Trendelenburg position in laparoscopic surgery.

The studies investigating the cardiac and respiratory effects of exaggerated Trendelenburg position in laparoscopic surgery are mostly performed in gynecologic and urological procedures. It can be seen that both have similar

positional hemodynamic effects. Among these, the number of studies comparing the effects of different ventilation modes (volume vs. pressure modes) is limited.

Oğurlu et al. have noninvasively compared the cardiac and respiratory effects of PCV and VCV modes in ASA I/II patients in laparoscopic gynecologic surgeries. The authors stated that two modes have similar hemodynamic effects but PCV mode provided lower peak airway pressure and higher compliance than VCV mode.<sup>4</sup> Moreover, in another study by Assad et al where PCV-VG and VCV is compared, PCV-VG provided lower peak inspiratory pressure and better compliance in 30° Trendelenburg in laparoscopy.<sup>8</sup> In the study of Kim et al, PCV-VG is compared to Equal Ratio Ventilation (ERV), which is a variation of VCV, and inspirium to expirium ratio was set at 1:1 in 30° of exaggerated Trendelenburg.<sup>5</sup> Our results are in accordance with the previous studies documenting lower peak airway pressures with PCV-VG.<sup>8,9</sup> The advantages of PCV-VG over VCV mode in laparoscopic surgery in exaggerated Trendelenburg position can be explained by avoiding barotrauma in PCV-VG mode, which in turn causes lower inspiratory pressures and decelerating airflow where laparoscopic surgery is concerned as this ventilation mode has a predetermined high pressure limit to prevent barotrauma.<sup>9</sup> Thus, PCV-VG is considered a time-cycled pressure-regulated mode. Changes in anesthesia depth, degree of muscle relaxation, and surgical manipulations can cause fluctuations in intra-abdominal pressure. The ventilator compensates for these changes when PCV-VG mode is used.<sup>8</sup> As a result, as previously suggested, PCV-VG is a better alternative in terms of oxygenation and could be a better choice in patients with low cardiac reserve because it provided a lower mean airway pressure compared to VCV.<sup>5</sup>

The utilization of N<sub>2</sub>O does not have any significant hemodynamic effects other than in patients with pulmonary hypertension.<sup>10</sup> One of the foremost concerns about the utilization of N<sub>2</sub>O is its diffusion into the abdominal cavity and bowels causing suboptimal surgical conditions. Fifty percent N<sub>2</sub>O was used in this study as suggested by the ENIGMA II study that N<sub>2</sub>O has “a clean bill of health”.<sup>11</sup> The effects mentioned above were not observed in this study because the surgeries were pelvic and deep Trendelenburg position was used.

Another critical point to be discussed about anesthesia management in this study is lack of PEEP utilization.

**Table 2** Hemodynamic changes measured by pressure recording analytical method.

Variable	Group	Ti	T0	T1	T3	T5	T10	T30	Tdef	Tdef5	p
HR (bpm)	PCVG	75 ± 9	79 ± 9	82 ± 8	75 ± 10	78 ± 8	77 ± 10	76 ± 8	80 ± 10	83 ± 9	0.093
	VC	86 ± 14	80 ± 15	79 ± 13	78 ± 15	83 ± 10	86 ± 13	85 ± 14	82 ± 9	81 ± 10	
MAP (mmHg)	PCVG	77 ± 13	78 ± 8	77 ± 11	78 ± 11	76 ± 11	77 ± 11	78 ± 11	76 ± 10	76 ± 11	0.916
	VC	77 ± 16	78 ± 14	76 ± 14	74 ± 12	74 ± 11	77 ± 13	78 ± 11	75 ± 13	77 ± 18	
SVRI dyne.s.m <sup>-2</sup> .cm <sup>-5</sup>	PCVG	2687 ± 288	2484 ± 244	2548 ± 364	2530 ± 246 <sup>a</sup>	2454 ± 184 <sup>a</sup>	2566 ± 172	2464 ± 245 <sup>b</sup>	2499 ± 246	2506 ± 257	0.317
	VC	2669 ± 418	2675 ± 417	2799 ± 541	2852 ± 453	2770 ± 474	2784 ± 597	2668 ± 316	2558 ± 349	2542 ± 527	
SVI mL.m <sup>-2</sup>	PCVG	35 ± 9	34.2 ± 7.5 <sup>a</sup>	38.2 ± 7.8	37.6 ± 5.9	34.1 ± 7.7	37.3 ± 9.7	38.9 ± 7.9	39.3 ± 7.7 <sup>a</sup>	37.5 ± 8.6	0.438
	VC	30.7 ± 10	24.6 ± 5.8 <sup>b</sup>	31.3 ± 7.1 <sup>c</sup>	32.4 ± 9.2 <sup>c</sup>	32.8 ± 8.8 <sup>c</sup>	33.7 ± 8.9 <sup>c</sup>	34.7 ± 9.1 <sup>c</sup>	30.1 ± 8.5 <sup>c</sup>	32.2 ± 8.3 <sup>c</sup>	
CI L.min <sup>-1</sup> .m <sup>-2</sup>	PCVG	2.56 ± 0.32	2.61 ± 0.22	2.77 ± 0.30	2.75 ± 0.28	2.79 ± 0.31	2.65 ± 0.26	2.69 ± 0.29	2.60 ± 0.28	2.65 ± 0.21	0.025
	VC	2.73 ± 0.48	2.86 ± 0.51	2.58 ± 0.45	2.55 ± 0.54	2.62 ± 0.46	2.92 ± 0.69	2.88 ± 0.49	2.64 ± 0.43	2.80 ± 0.57	
SVV (%)	PCVG	24 ± 21	23 ± 23	23 ± 17	17 ± 8	18 ± 9	19 ± 12	21 ± 18	19 ± 10	19 ± 15	0.144
	VC	23 ± 9	21 ± 9 <sup>b</sup>	18 ± 8 <sup>b</sup>	20 ± 8	23 ± 19	32 ± 25	22 ± 11	20 ± 6	18 ± 7 <sup>b</sup>	
dP/dt mmHg.s <sup>-1</sup>	PCVG	0.57 ± 0.24	0.55 ± 0.37	0.49 ± 0.34	0.62 ± 0.28	0.62 ± 0.27	0.72 ± 0.25 <sup>c</sup>	0.60 ± 0.35	0.60 ± 0.32	0.68 ± 0.33	0.347
	VC	0.51 ± 0.28	0.35 ± 0.27	0.57 ± 0.35	0.58 ± 0.28 <sup>c</sup>	0.48 ± 0.34	0.61 ± 0.29 <sup>c</sup>	0.54 ± 0.29	0.73 ± 0.26 <sup>b,c</sup>	0.62 ± 0.26 <sup>c</sup>	
CCE	PCVG	0.154 ± 0.79	0.171 ± 0.83	0.169 ± 0.72	0.169 ± 0.71	0.072 ± 0.66	0.084 ± 0.69	0.164 ± 0.81	0.265 ± 0.43	0.305 ± 0.48	0.554
	VC	0.039 ± 0.56	-0.131 ± 0.59	0.010 ± 0.52	-0.117 ± 0.66	-0.104 ± 0.47	0.140 ± 0.46	-0.081 ± 0.38	0.238 ± 0.49	-0.041 ± 0.55	

Data are expressed as mean ± SD.

Hemodynamic data were measured at anesthesia induction (Ti), at peritoneal insufflation (T0), 1 (T1), 3 (T3), 5 (T5), 10 (T10), and 30 (T30) minutes after CO<sub>2</sub> pneumoperitoneum, at desufflation (Tdef) and at termination of pneumoperitoneum (5 minutes after desufflation) (T5def).

HR, Heart Rate; MAP, Mean Arterial Pressure; SVRI, Systemic Vascular Resistance Index; SVI, Stroke Volume Index; CI, Cardiac Index; SVV, Stroke Volume Variation; dP/dt, Aortic pressure variation over time; CCE, Cardiac Cycle Efficiency.

Comparison between the study groups was done using Student *t*-test for independent samples while within group comparison between the different time points was done using paired sample *t*-test. Comparison of the different variables over the study time points was done using repeated measure analysis of variance through General Linear Model regression analysis with repeated measure and the paired *t*-test was done as a post hoc test and are given in the right column of the table. *p* < 0.05 was considered statistically significant.

<sup>a</sup> *p* < 0.05 between groups at the same time points.

<sup>b</sup> *p* < 0.05 compared with anesthesia induction (Ti).

<sup>c</sup> *p* < 0.05 compared with peritoneal insufflation (T0).

There are controversial data on PEEP utilization under Trendelenburg position and pneumoperitoneum. Even though utilization of PEEP is a widely accepted intraoperative mechanical ventilation technique for the prevention of atelectasis and better oxygenation in laparoscopic surgeries with Trendelenburg position, neither 5 nor 10 cmH<sub>2</sub>O PEEP significantly affects oxygenation.<sup>12,13</sup> The only effective technique reported for better oxygenation was active recruitment maneuvers.<sup>13</sup> Supporting this data, others reported that 5 cmH<sub>2</sub>O PEEP may increase intra-alveolar pressure and consequently the shunt fraction, thus failing to improve oxygenation.<sup>14</sup> Additionally, deep Trendelenburg position is known to cause auto PEEP and adding extrinsic PEEP can worsen the hemodynamic status.<sup>15</sup> Considering all, no benefit from PEEP utilization was expected in this study. Moreover, the possibility of a significant decrease in cardiac output as a result of increased intrathoracic pressure and decreased right ventricular venous return was avoided by not using PEEP.

Although thermodilution method is the standard technique for cardiac output measurement, the invasiveness of this technique limits its use.<sup>16</sup> In the recent years, less invasive techniques which allow monitorization of cardiac output and various hemodynamic parameters have been developed. Among these techniques, the PRAM method continuously analyses the pressure waveform at 1000 Hz without the need of internal or external calibration. The system needs femoral or radial artery cannulation in order to analyze the pressure waveform.<sup>17</sup> The fact that its validity has been proven in various clinical and experimental settings and it allows noninvasive beat-to-beat analysis increases its popularity.<sup>18,19</sup> Therefore, in this study we used PRAM method, which provided beat-to-beat analysis. Moreover, PRAM method has been used in laparoscopic surgery in obese patients undergoing laparoscopic gastric bypass in reverse Trendelenburg position.<sup>20</sup> Likewise, in this study, the quality of the pressure and the ability to detect a pressure signal was not affected by Trendelenburg position. To our knowledge, this is the first study using PRAM method in laparoscopic surgeries performed under Trendelenburg position.

In contradiction to other studies, hemodynamic variables are documented in this study by PRAM method in exaggerated Trendelenburg position in laparoscopy. On the other hand, other studies<sup>4,5,8</sup> focused largely on the respiratory effects of the ventilation modes, and the hemodynamic monitorization was limited to MAP, heart rate and CVP. All these parameters (MAP, CVP, and heart rate) were similar in previous studies.<sup>4,8</sup> The study of Kim et al. also documented similar outcomes in MAP, and heart rate when VCV and PCV-VG were compared.

Pneumoperitoneum is expected to increase systematic vascular resistance secondary to increased intraabdominal pressure and vasoactive substances released as a result of CO<sub>2</sub> absorption.<sup>20</sup> Systemic vascular resistance was higher in Group VC compared to Group PCVG, which was statistically significant in T<sub>3</sub> and T<sub>5</sub>. In Group PCVG, the less pronounced effect of pneumoperitoneum on SVRI is striking. This may be caused by lower peak inspiratory pressures of PCV-VG mode and the minimalization of the hemodynamic effects of pneumoperitoneum by better adaptation to the rise in the intraabdominal pressure.

In this study, the trend observed in SVI values were similar to the findings obtained by Nguyen et al.<sup>21</sup> There was a transient decrease in SVI values following pneumoperitoneum induction followed by a progressive increase above baseline values. However, in this study, the significant fall in SVI in Group VC at insufflation and desufflation compared to Group PCVG may be due to sudden decreases in cardiac preload due to desufflation and increases in afterload due to insufflation. This remarkable finding might indicate the possibility that PCV-VG provides an advantage in adapting to changes caused by intra-abdominal pressure related cardiac filling and outflow pressures.

In this study, in a healthy female population with PCV-VG mode, the decline in cardiac output was minimal when compared with VCV. In PCVG group, a more stable cardiac index throughout the operation in PCV-VG group can be explained by the lower intrathoracic pressure in PCV-VG than VCV mode, which provides a better preload. We infer that PCV-VG might be a better option in patients with low cardiac reserve. However, in a patient population without cardiac comorbidities, the more stable CI values in the PCV-VG group will not change the clinical management. On the other hand, in patients with poor ventricular function, PCV-VG mode might overcome the hemodynamic disturbances caused by pneumoperitoneum and Trendelenburg position. Nevertheless, further studies on patients with cardiac dysfunction are required in order to test this thesis.

The maximal rate of rise of the left ventricular pressure is  $dP/dt_{max}$  and is determined by the left ventricle contractility and arterial impedance. It is used for the estimation of the left ventricle volumetric contractility. It is less dependent on the influence of afterload although it remains a preload-dependent variable. However, if it is measured using a peripheral artery catheter as in this study, during the LV ejection phase following the opening of the aortic valve, which is different from echocardiography, it can be affected by the vascular tone. Thus, changes in afterload may cause over- or underestimation of the left ventricular  $dP/dt_{max}$ .<sup>22</sup> Peritoneal insufflation increases the afterload, which in turn increases the arterial impedance. The fact that  $dP/dt_{max}$  decreases at insufflation in Group VC compared to Group PCVG, although without statistical significance, can be explained by suboptimal preload causing a decrease in myocardial isovolumetric contraction in Group VC.

CCE is an indirect index of arterioventricular coupling. It represents the dynamic equilibrium between arterial elastance, preload, and myocardial contractility. CCE indicates the sum of energy necessary to generate the stroke volume and is dependent on the relationship between the pump function of the heart and the arterial system. CCE is the ratio of systolic energy to total energy expenditure and can change between a positive (+1) or negative (-1) value.<sup>20</sup> CCE values have stayed positive (between 0–1) throughout the study period but have become negative with insufflation and remained mostly negative. This can be explained by the better filling pressures provided by the PCV-VG mode in the face of increased afterload caused by the rise in intra-abdominal pressure due to peritoneal insufflation and systemic vascular resistance, thus protecting the cardiac cycle efficiency.

As a limitation of this study, sample size is relatively small. Moreover, the arterial blood gas analysis and detailed measurement of ventilatory parameters are lacking, and

exclusion of patients with comorbidities limits the generalization of these results. Additionally, the PRAM method itself has some limitations such as over- and under-damping of arterial waveforms which are technical limitations and inappropriate signal acquisition or abnormalities of the peripheral arteries which are patient-related limitations.<sup>23</sup> Regarding this, the SVV values were unexpectedly high in this study. These results can be explained by miscalculations due to the effect of Trendelenburg position and increased intra-abdominal pressure and the limited diaphragmatic descent during pneumoperitoneum.<sup>24</sup>

## Conclusion

Our data shows that PCV-VG provides a lower peak airway pressure and more stable CI compared to VCV in gynecologic laparoscopic operations performed with exaggerated Trendelenburg position. Finally, future studies on cases with low cardiac reserve are needed to confirm the advantages of PCV-VG mode over VCV mode in laparoscopy with Trendelenburg position.

## Conflicts of interest

The authors declare no conflicts of interest.

## References

1. Wang JP, Wang HB, Liu YJ, et al. Comparison of pressure- and volume-controlled ventilation in laparoscopic surgery: A meta-analysis of randomized controlled trial. *Clin Invest Med*. 2015;38:e119-41.
2. Patil S, Koyyalamudi P, Robertson C, et al. Physiologic effects of pneumoperitoneum and positioning. In: Kaye A, Urman R, editors. *Perioperative management in robotic surgery*. Cambridge: Cambridge University Press; 2017. p. 20-8.
3. Romagnoli S, Franchi F, Ricci Z, et al. The pressure recording analytical method (PRAM): Technical concepts and literature review. *J Cardiothorac Vasc Anesth*. 2017;31:1460-70.
4. Oğurlu M, Küçük M, Bilgin F, et al. Pressure-controlled vs volume-controlled ventilation during laparoscopic gynecologic surgery. *J Minim Invasive Gynecol*. 2010;17:295-300.
5. Kim MS, Soh S, Kim MY, et al. Comparisons of pressure-controlled ventilation with volume guarantee and volume-controlled 1:1 equal ratio ventilation on oxygenation and respiratory mechanics during robot-assisted laparoscopic radical prostatectomy: A randomized-controlled trial. *Int J Med Sci*. 2018;15:1522-9.
6. Dion JM, McKee C, Tobias JD, et al. Carbon dioxide monitoring during laparoscopic-assisted bariatric surgery in severely obese patients: transcutaneous versus end-tidal techniques. *J Clin Monit Comput*. 2015;29:183-6.
7. Choi EM, Na S, Choi SH, et al. Comparison of volume-controlled and pressure-controlled ventilation in steep trendelenburg position for robot-assisted laparoscopic radical prostatectomy. *J Clin Anesth*. 2011;23:183-8.
8. Assad OM, El Sayed AA, Khalil MA. Comparison of volume-controlled ventilation and pressure-controlled ventilation volume guaranteed during laparoscopic surgery in trendelenburg position. *J Clin Anesth*. 2016;34:55-61.
9. Dion JM, McKee C, Tobias JD, et al. Ventilation during laparoscopic-assisted bariatric surgery: volume-controlled, pressure-controlled or volume-guaranteed pressure-regulated modes. *Int J Clin Exp Med*. 2014;7:2242-7.
10. Hendrickx J, Peyton P, Carette R, et al. Inhaled anaesthetics and nitrous oxide: Complexities overlooked: things may not be what they seem. *Eur J Anaesthesiol*. 2016;33:611-9.
11. Li ECK, Balbuena LD, Gamble JJ. Evaluation of nitrous oxide in the gas mixture for anesthesia II (ENIGMA II) revisited: Patients still vomiting. *Anesthesiology*. 2017;127:204-5.
12. Sen O, Erdogan Doventas Y. Effects of different levels of end-expiratory pressure on hemodynamic, respiratory mechanics and systemic stress response during laparoscopic cholecystectomy. *Braz J Anesthesiol*. 2017;67:28-34.
13. Ukere A, Marz A, Wodack KH, et al. Perioperative assessment of regional ventilation during changing body positions and ventilation conditions by electrical impedance tomography. *Br J Anaesth*. 2016;117:228-35.
14. Sprung J, Whalley DG, Falcone T, et al. The effects of tidal volume and respiratory rate on oxygenation and respiratory mechanics during laparoscopy in morbidly obese patients. *Anesth Analg*. 2003;97:268-74.
15. Oksar M, Akbulut Z, Ocal H, et al. Anesthetic considerations for robotic cystectomy: a prospective study. *Braz J Anesthesiol*. 2014;64:109-15.
16. Donati A, Carsetti A, Tondi S, et al. Thermodilution vs pressure recording analytical method in hemodynamic stabilized patients. *J Crit Care*. 2014;29:260-4.
17. Romano SM, Pistolesi M. Assessment of cardiac output from systemic arterial pressure in humans. *Crit Care Med*. 2002;30:1834-41.
18. Franchi F, Falciani E, Donadello K, et al. Echocardiography and pulse contour analysis to assess cardiac output in trauma patients. *Minerva Anesthesiol*. 2013;79:137-46.
19. Franchi F, Silvestri R, Cubattoli L, et al. Comparison between an uncalibrated pulse contour method and thermodilution technique for cardiac output estimation in septic patients. *Br J Anaesth*. 2011;107:202-8.
20. Balderi T, Forfori F, Marra V, et al. Continuous hemodynamic monitoring during laparoscopic gastric bypass in superobese patients by pressure recording analytical method. *Obes Surg*. 2008;18:1007-14.
21. Nguyen NT, Ho HS, Fleming NW, et al. Cardiac function during laparoscopic vs open gastric bypass. *Surg Endosc*. 2002;16:78-83.
22. Scolletta S, Bodson L, Donadello K, et al. Assessment of left ventricular function by pulse wave analysis in critically ill patients. *Intensive Care Med*. 2013;39:1025-33.
23. Sangkum L, Liu GL, Yu L, et al. Minimally invasive or non-invasive cardiac output measurement: an update. *J Anesth*. 2016;30:461-80.
24. Pinsky MR. Cardiopulmonary interactions: Physiologic basis and clinical applications. *Ann Am Thorac Soc*. 2018;15:45-8.