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ORIGINAL RESEARCH **GENERAL ANESTHESIA**

Comparative study of the effects of volume-controlled ventilation vs. pressure-controlled volume guaranteed ventilation in patients with obesity during laparoscopic surgery

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ABSTRACT

Background & objective: The anesthetists have been experimenting with different modes of mechanical ventilation during general anesthesia. The objective of this study was to evaluate the efficacy of Pressure Controlled Ventilation-Volume Guaranteed (PCV-VG) mode in comparison to volume-controlled ventilation (VCV) mode in obese patients undergoing laparoscopic surgery in the Trendelenburg position, with a focus on their lung compliance and Oxygenation Index (OI).

Methodology: This randomized controlled clinical trial involved 64 obese patients of both sexes, with a Body Mass Index (BMI) of ≥30 kg/m², and classified as American Society of Anesthesiologists (ASA) class I or II. The participants were randomly assigned to one of the two groups: the study group (Group P) using PCV-VG and the control group (Group V) using VCV. Hemodynamic and respiratory parameters were monitored.

Results: The arterial oxygen partial pressure (PaO_2) and lung compliance were significantly higher in Group P compared to Group V ($P < 0.05$). Conversely, the peak pressure (P peak) and plateau pressure (Pplat) along with the mean pressure (P mean) as well as the OI were significantly lower in Group P compared to Group V ($P < 0.05$).

Conclusion: PCV-VG significantly improves lung compliance and oxygenation while maintaining lower peak and plateau pressures, with comparable hemodynamic stability and $PaCO_2$ levels.

Abbreviations: BMI: Body Mass Index, OI: Oxygenation Index, PCV-VG: Pressure Controlled Ventilation-Volume Guaranteed, PIP: Peak Inspiratory Pressure, PRVC- pressure-regulated volume-controlled, V_T: tidal volume, VCV: volume-controlled ventilation

Keywords: Volume-Controlled Ventilation; Pressure-Controlled Ventilation Volume-Guaranteed; Trendelenburg Position; Obesity; Airway Pressures

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1. INTRODUCTION

Obesity is characterized by elevated resistance to airflow, difficulty in breathing, and reduced respiratory system compliance, with a Body Mass Index (BMI) exceeding 30 kg/m^2.[1]

The combination of Carbon dioxide pneumoperitoneum with or without precipitous Trendelenburg positioning is typically necessary for assisted laparoscopic surgery to achieve an optimal surgical perspective. However, this approach can result in heightened airway pressure and adverse impacts on gas exchange. [2]

Elevated atelectasis and cranial displacement of the diaphragm are consequences of carbon dioxide pneumoperitoneum in conjunction with steep Trendelenburg positioning. This condition leads to a reduction in total lung volume, decreased lung compliance, and decreased functional residual capacity. Therefore, the primary objectives of anesthetic management during laparoscopic-assisted surgery are to mitigate elevated airway pressures, enhance oxygenation, and facilitate the removal of carbon dioxide.[3]

In the context of laparoscopic assisted surgery, elevation of intraabdominal pressure due to CO_2 pneumoperitoneum can lead to various complications. These complications may include deterioration in oxygenation, increase in airway pressure, reduction in lung volume and compliance, and elevated risk of atelectasis. Consequently, these factors can contribute to the development of hypercapnia, acidosis, and impaired oxygenation in patients.[4]

Volume-controlled ventilation (VCV) is the optimal method for general anesthesia administration. This mode of ventilation guarantees sufficient minute ventilation and delivers a target tidal volume (V_T) through a constant flow. However, this approach can result in increased airway pressure in situations like laparoscopic assisted surgery.[5]

To obtain the optimal V_T, the ventilator regulates the Peak Inspiratory Pressure (PIP) in Pressure-Controlled Ventilation Volume-Guaranteed (PCV-VG) mode. The ventilator parameters are consistently modified without altering the airway pressure to achieve the desired volume. Therefore, PCV-VG offers the benefits of both VCV and PCV in that it minimizes the occurrence of barotraumas while maintaining the target minute ventilation.[6]

PCV-VG is a type of controlled ventilation mode that integrates the characteristics of both Pressure Control Ventilation (PCV) and VCV. This mode functions as a pressure-regulated volume-controlled (PRVC) system employing autoflow ventilation. The design allows for a reduction in inspiratory pressure, which in turn, minimizes the risk of barotrauma.[3]

PCV-VG is a secure ventilation method without related deficiencies or even inferiority in maximal airway pressure, plateau pressure, and dynamic compliance, with the potential to offer advantages in terms of enhanced airway dynamics compared with VCV.[7]

Objective of the study

The study aimed to evaluate the efficacy of pressure-controlled ventilation volume-guaranteed (PCV-VG) and volume-controlled ventilation (VCV) modes in obese patients undergoing laparoscopic aided surgery in the Trendelenburg position with respect to lung compliance and Oxygenation Index (OI).

2. METHODOLOGY

This investigation was registered in an investigational study with registration number NCT06117748 as a randomized controlled trial. We enrolled 64 obese patients, 21-60 years old of both sexes with BMI ≥ 30 kg/m^2, ASA class I/ II and currently undergoing laparoscopic assisted surgery. The research was conducted over a span of one year following approval from our institutional ethics committee under reference number FMASU MD 280/2022. Written informed consent was obtained from all patients.

The criteria for exclusion were as follows: ASA III or IV, intraoperative hemodynamic instability, obese patients on home oxygen therapy, pneumoperitoneum with carbon dioxide with intra-abdominal pressure exceeding 14 mmHg, anti-Trendelenburg position, asthmatic patients, patients with advanced renal or liver disease, pulmonary hypertension and advanced malignancy. Pregnant ladies were also excluded.

The patients were divided into two equal categories: Group P (PCV-VG), representing the study group; and Group V (VCV), representing the control group. The use of a random number table and a closed envelope technique were implemented to randomly assign patients to one of the two categories.

Prior to surgery, a thorough medical history was obtained from each patient, followed by a comprehensive clinical examination. All pertinent investigations were reviewed, including complete blood count (CBC), coagulation profile, liver enzymes, kidney function tests, electrocardiogram (ECG), echocardiography (ECHO), pulmonary function tests, and arterial blood gas analysis (ABG). Subsequently, each patient was administered premedication ondansetron 8 mg and famotidine 20 mg intravenously. Monitoring included ECG, noninvasive blood pressure monitoring, and pulse oximetry. Following preoxygenation for 3-5 min, anesthesia was administered via fentanyl 1-2 µg/kg and propofol 2 mg/kg IV over a duration of 15 sec, and atracurium 0.5 mg/kg IV. Tracheal intubation was subsequently performed using a direct laryngoscopy. After confirming the endotracheal tube position through capnography, an arterial line was successfully inserted into the left radial artery using a 3-Fr Vygon catheter, after the performance of a modified Allen test.

The respiratory parameters were established as follows: V_T 8 mL/kg body weight, respiratory rate 12 breaths/min, PEEP 5 mmHg, oxygen flow 4 L/min, inspired oxygen (FiO_2) 0.6 %, and I:E ratio of 1:2. Anesthesia was maintained using 1.5-2.5 vol% end-tidal sevoflurane to regulate hemodynamic responses during the surgical procedure, keeping them within a 20% range of the preoperative values. The respiratory parameters were consistently monitored and maintained at a stable level with end-tidal carbon dioxide ($EtCO_2$) kept below 45 mmHg. The patient was positioned supine, pneumoperitoneum was executed with carbon dioxide at an intraabdominal pressure of 14 mmHg, and then inclined to achieve a 30° Trendelenburg position. Lactated Ringer's solution was administered continuously at a rate of 6-8 mL/kg/h throughout the study period.

Data collection

Mean arterial blood pressure (MAP) and heart rate (HR) were monitored for 10 min prior to anesthesia administration (T0), immediately after the onset of pneumoperitoneum, after every 10 min during the initial hour, and at the conclusion of surgery. The ABG's were recorded at T0 and every 10 min during the initial hour to assess metabolic and respiratory changes. Peak airway pressure (P peak), plateau pressure (P_{plat}), mean airway pressure (P mean), and compliance of the respiratory system were recorded at T0 and at every 10 min in the initial hour.

Primary outcome was the Oxygenation Index (computed as mean airway pressure × FiO_2 × 100/ PaO_2). Secondary outcomes were MAP, HR, SpO_2, $PaCO_2$, and lung compliance.

Sample size calculation

A sample of least 32 cases per category (a total of 64 cases) achieves a power of 80% to detect an effect size of 0.3 within as well as between the groups using Repeated measures ANOVA with in-between factor with level of significance of 0.05. A correlation of at the most 0.5 was assumed between the repeated measures and 20% excess cases were added to compensate for the potential of drop-outs.[8]

Statistical analysis

All statistical analyses were performed using SPSS v26 (IBM Inc., Chicago, IL, USA). The mean and standard

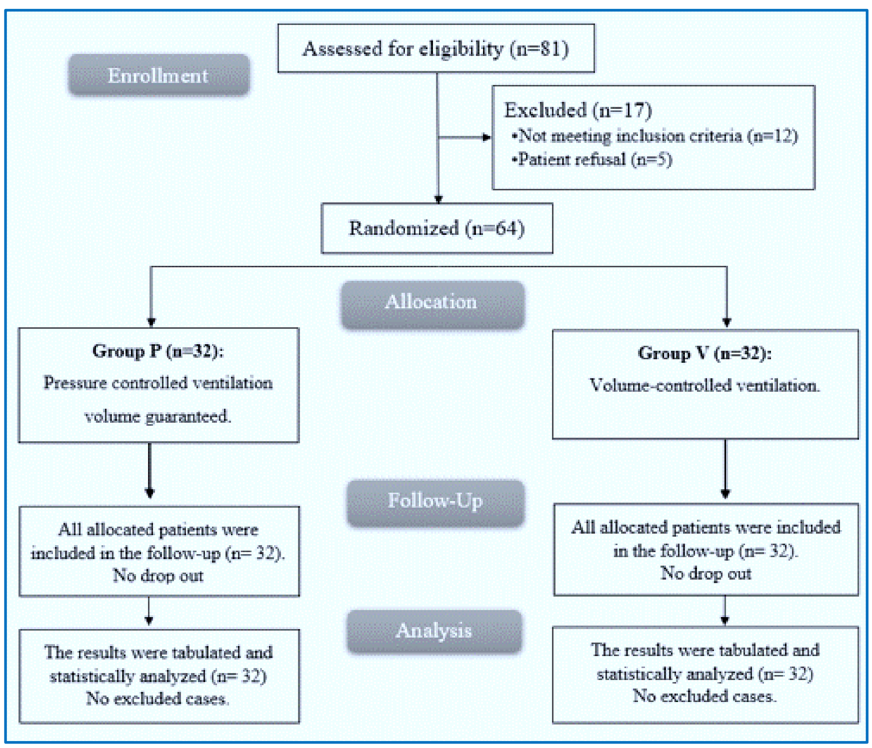

Figure 1: CONSORT flowchart of the study population

deviation (SD) of quantitative variables are presented. and contrasted between the two groups using an unpaired Student's t-test. Frequencies and percentages (%) are employed to represent qualitative variables. and analyzed using the Chi-square test. Statistical significance is characterized by a two-tailed P-value <0.05.

3. RESULTS

In this investigation, eligibility assessment was conducted for 81 patients, 12 patients did not satisfy the criteria, and 5 patients declined to participate in the investigation. The remaining patients were randomly assigned into one of the two equal groups (32 patients in each). The statistical analyses and follow-up of all allocated patients were conducted (Figure 1).

There were no significant differences between the two groups with respect to demographic data and duration of surgery (Table 1).

Table 1: Comparative demographic data and surgery duration in the groups

Parameter		Group P (n = 32)	Group V (n = 32)	P value
Age (years)		42.38 ± 10.64	45.5 ± 11.29	0.259
Sex	**Male**	15 (46.88%)	11 (34.38%)	0.309
	Female	17 (53.13%)	21 (65.63%)	
Weight (kg)		98.97 ± 14.63	104.09 ± 10.6	0.114
Height (cm)		164.34 ± 6.3	166.97 ± 5.23	0.074
BMI (kg/m^2)		36.65 ± 5.1	37.47 ± 4.7	0.508
ASA physical status	**I**	20 (62.5%)	22 (68.75%)	0.599
	II	12 (37.5%)	10 (31.25%)	
Duration of surgery (min)		55.31 ± 16.99	59.69 ± 16.65	0.302

Data presented as mean ± SD or frequency (%). BMI: Body mass index

There was no significant difference in the values of mean HR, and MAP before induction, immediately after pneumoperitoneum, at 10 min after intubation, and at 10 min intervals between both groups (Table 2).

Table 2: Comparative hemodynamic data of the studied groups

Parameter	Time	Group P (n = 32)	Group V (n = 32)	P value
HR (bpm)	**Before induction (T0)**	77.09 ± 9.72	79.38 ± 8.54	0.323
	After pneumoperitoneum	74.63 ± 9.69	77.72 ± 9.09	0.193
	10 min	75.03 ± 9.65	77.91 ± 8.61	0.213
	20 min	73.69 ± 9.82	76.81 ± 8.62	0.181
	30 min	71.81 ± 9.78	75.34 ± 8.63	0.131
	40 min	73.59 ± 10.03	72.66 ± 8.83	0.693
	50 min	71.47 ± 9.76	75.44 ± 8.56	0.089
	60 min	70.66 ± 9.48	74.31 ± 8.48	0.109
	End of surgery	72.56 ± 9.64	75.78 ± 8.85	0.169
MAP (mmHg)	**Before induction (T0)**	93.5 ± 12.33	93.78 ± 10.96	0.923
	After pneumoperitoneum	89.19 ± 12.24	92.03 ± 11.61	0.344
	10 min	89.34 ± 12.49	92.13 ± 10.92	0.347
	20 min	87.97 ± 12.28	91.41 ± 10.81	0.239
	30 min	89.44 ± 12.39	87.66 ± 11.09	0.547
	40 min	86.13 ± 12.44	89.41 ± 11.07	0.269
	50 min	86.44 ± 12.91	89.78 ± 10.91	0.267
	60 min	84.94 ± 12.46	88.66 ± 10.81	0.207
	End of surgery	87.19 ± 12.12	90.25 ± 11.33	0.300

*Data are presented as mean ± SD; *Significant as P ≤ 0.05.*
MAP: Mean arterial blood pressure. HR: heart rate

PaO_2 at 20, 30, 40, 50 and 60 min was significantly increased in Group P than in Group V (P < 0.05). P peak at (20, 30, 40, 50 and 60 min and end of surgery) was significantly lower in Group P than in Group V (P < 0.05) (Table 3).

P_{plat} at T0 and 10 min, Pmean after intubation, lung compliance after intubation, and OI (after intubation, at

Table 3: Comparative PaO_2, $PaCO_2$ and P_{peak} of the studied groups

Parameter	Time	Group P (n = 32)	Group V (n = 32)	P value
PaO_2 (mmHg)	**10 min**	181.75 ± 18.44	177.13 ± 18.92	0.326
	20 min	181.25 ± 18.66	166 ± 19.28	**0.002***
	30 min	176.59 ± 18.97	163.75 ± 19.87	**0.010***
	40 min	173.28 ± 18.82	160.47 ± 20.2	**0.011***
	50 min	177.88 ± 18.41	168.09 ± 18.89	**0.040***
	60 min	181.13 ± 18.56	170.81 ± 19.16	**0.033***
	End of surgery	182.06 ± 18.64	174.28 ± 19.62	0.109
$PaCO_2$ (mmHg)	**10 min**	35.84 ± 4.33	36.69 ± 4.43	0.444
	20 min	35.88 ± 4.27	36.59 ± 4.32	0.506
	30 min	35.03 ± 4.45	36.03 ± 4.4	0.369
	40 min	36.78 ± 4.3	37.91 ± 4.28	0.298
	50 min	37.28 ± 4.56	38 ± 4.43	0.525
	60 min	38.31 ± 4.23	39.97 ± 4.75	0.146
	End of surgery	39.19 ± 4.4	40.31 ± 4.34	0.307
P_{peak} (cmH2O)	**After intubation(T0)**	15.38 ± 3.52	16.91 ± 4.31	0.124
	10 min	17.72 ± 3.4	18.84 ± 4.3	0.250
	20 min	21.63 ± 4.01	24.56 ± 4.13	**0.005***
	30 min	23.84 ± 4.21	27.06 ± 4.6	**0.005***
	40 min	24.91 ± 3.4	28.13 ± 4.34	**0.002***
	50 min	24.28 ± 3.67	27.56 ± 4.34	**0.002***
	60 min	24.75 ± 3.95	29.06 ± 4.92	**< 0.001***
	End of surgery	23.59 ± 3.26	26.81 ± 4.5	**0.002***

*Data are presented as mean ± SD, PaO2: partial oxygen pressure. MAP: Mean arterial blood pressure. HR: heart rate *Significant as P ≤ 0.05.*

10 min and end of surgery) were not significantly different between both groups (Table 4).

Lung compliance at 10, 20, 30, 40, 50 and 60 min and at the end of surgery were significantly higher in Group P than in Group V ($P < 0.05$).

P_{plat} at 20, 30, 40, 50 and at 60 min and at the end of surgery, P_{mean} at 10, 20, 30, 40, 50 and 60 min and OI at (20, 30, 40, 50 and 60 min, were significantly lower in Group P than in Group V ($P < 0.05$) (Table 4).

4. DISCUSSION

CO_2 pneumoperitoneum is frequently used in conjunction with the Trendelenburg position during laparoscopic interventions to ensure appropriate surgical viewing and space.[9]

These methods significantly affect cardiovascular and pulmonary systems. These conditions lead to increased mean arterial pressure, higher P peak, reduced pulmonary compliance, and increased risk of barotrauma or atelectasis.[15]

The objective minute ventilation can be ensured through the application of VCV in anesthesia; Nevertheless, a constant flow rate may lead to a greater PIP, which can exacerbate the risk of barotrauma and cause an imbalanced distribution of pulmonary gases.[6]

In our study, the MAP was not significantly different at all time points between both groups. Consistent with our results, Civraz et al. exhibited that there was no significant difference in MAP between VCV and PCV-VG in patients undergoing laparoscopic cholecystectomy.[10]

In the present study, PaO_2 was statistically equivalent at 10 min and at the end of surgery between both groups and was significantly higher at 20, 30, 40, 50, and 60 min in Group P than in Group V ($P < 0.05$). Nevertheless, Civraz et al. showed no significant difference between VCV and PCV-VG in cases undergoing laparoscopic cholecystectomy regarding PaO_2 at all measurement points. This finding may be attributable to the positional disparity and the time frame of the arterial blood gas analysis in the two investigations.[10] Toker et al. found a significantly greater PaO_2 in the PCV-VG mode employed in the Trendelenburg position in obese patients.[5]

In the current investigation, the P peak was insignificantly different after intubation and at 10 min between both groups and was significantly lower at 20, 30, 40, 50, and 60 min and the at the end of surgery in Group P than in Group V ($P < 0.05$). Ahmed et al.

Table 4: Comparative ventilation and oxygenation indices

Parameter	Time	Group P (n = 32)	Group V (n = 32)	P value
P plateau (cmH_2O)	**After intubation(T0)**	15.25 ± 3.39	13.91 ± 4.31	0.170
	10 min	17.53 ± 3.41	15.84 ± 4.3	0.087
	20 min	21.38 ± 4	23.56 ± 4.13	**0.035***
	30 min	23.72 ± 3.98	26.06 ± 4.6	**0.033***
	40 min	24.88 ± 3.46	27.16 ± 5.02	**0.038***
	50 min	24.13 ± 3.37	26.91 ± 4.79	**0.009***
	60 min	24.56 ± 3.96	28.06 ± 4.63	**0.002***
	End of surgery	23.41 ± 3.39	25.94 ± 4.89	**0.019***
P_{Mean} (cmH_2O)	**After intubation(T0)**	8.19 ± 1.38	8.91 ± 2.1	0.111
	10 min	8.56 ± 1.54	10.47 ± 2.24	**< 0.001***
	20 min	9.81 ± 1.57	11.53 ± 2.26	**0.001***
	30 min	9.69 ± 1.49	11.22 ± 2.2	**0.002***
	40 min	9.78 ± 1.5	11.28 ± 2.26	**0.003***
	50 min	9.63 ± 1.45	11.38 ± 2.12	**< 0.001***
	60minP	9.97 ± 1.67	11.78 ± 2.14	**< 0.001***
	End of surgery	10.69 ± 1.35	12.53 ± 2.08	**< 0.001***
Lung Compliance (mL/cmH_2O)	**After intubation(T0)**	42.72 ± 6.69	40.5 ± 8.2	0.240
	10 min	37.75 ± 7.22	30.75 ± 8.61	**0.001***
	20 min	32.22 ± 7.16	27.53 ± 8.89	**0.023***
	30 min	27.69 ± 6.78	23.69 ± 8.71	**0.045***
	40 min	25.84 ± 6.65	21.94 ± 8.31	**0.042***
	50 min	24.41 ± 6.63	17.16 ± 8.25	**< 0.001***
	60 min	22.06 ± 7.09	17.38 ± 8.51	**0.020***
	End of surgery	21.38 ± 7.38	17 ± 8.46	**0.031***
Oxygenation index (OI)	**After intubation(T0)**	18.16 ± 1.27	18.38 ± 1.52	0.535
	10 min	13.31 ± 3.27	14.69 ± 2.9	0.080
	20 min	13.66 ± 2.77	15.38 ± 2.54	**0.012***
	30 min	12.94 ± 2.56	14.94 ± 2.65	**0.003***
	40 min	13 ± 2.49	14.94 ± 2.35	**0.002***
	50 min	13.13 ± 2.18	14.59 ± 2.84	**0.024***
	60 min	13.81 ± 2.64	15.38 ± 2.46	**0.017***
	End of surgery	13.81 ± 2.68	15.06 ± 2.71	0.068

*Data are presented as mean ± SD, *Significant as P ≤ 0.05.*

showed that there was a significantly higher P peak in the VCV group in contrast to PCV-VG at T1 (prior to pneumoperitoneum), T2 (15 min following pneumoperitoneum), and T3 (5 min following desufflation).[11]

In our study, P_{plat} was insignificantly different at T0 and at 10 min between the two groups and was significantly lower at all other time points of measurement in the Group P than in Group V ($P < 0.001$). In this context, Civraz et al. demonstrated that the P_{plat} results were significantly higher in the VCV group than in the PCV-VG group in patients undergoing laparoscopic cholecystectomy.[10]

In our study, lung compliance was insignificantly different after intubation between the two groups and was significantly higher at all other time points of measurement in Group P than in Group V ($P < 0.05$). Consistent with our findings, Civraz et al. found that compliance measures were significantly lower. in the VCV group than in the PCV-VG group ($p < 0.05$).[10] Recently, a meta-analysis by Schick et al. comparing VCV and PCV-VG showed higher dynamic compliance of the lung in PCV-VG mode.[12]

In our study, the OI was insignificantly different after intubation, at 10 min, and at the end of surgery between both groups and was significantly lower at 20, 30, 40, 50,

Table 5: Factors associated with time to full recovery of neuromuscular function

Variables		n (%) (n = 59)	Time to reach TOF ratio ≥ 0.9	P-value
Sugammadex dose (mg/kg)	4	37 (62.7)	4.2 ± 1.8	0.255
	2	22 (37.4)	3.7 ± 1.8	
BMI (kg/cm²)	< 18.5	9 (15.3)	4.8 ± 1.9	0.491
	18.5 – 22.99	29 (49.2)	4.0 ± 1.9	
	23 – 24.99	11 (18.6)	3.7 ± 2.1	
	≥ 25	10 (16.9)	3.6 ± 1.4	
ASA classification	I	6 (10.2)	3.0 ± 1.2	**0.042**
	II	44 (74.6)	3.9 ± 1.6	
	III	9 (15.3)	5.3 ± 2.8	
Age (y)	< 65	36 (61)	3.4 ± 1.3	**< 0.001**
	≥ 65	23 (39)	4.9 ± 2.2	
Gender	Male	32 (54.2)	4.25 ± 2.2	0.291
	Female	27 (45.8)	3.74 ± 1.3	
Time between the last administration of rocuronium and the administration of sugammadex (min)	< 42	37 (62.7)	4.0 ±1.6	0.743
	≥ 42	22 (37.3)	4.1 ± 2.3	
Duration of anesthesia (min)	< 120	6 (10.2)	5.0 ± 2.2	0.327
	120 – 180	15 (25.4)	3.7 ± 1.6	
	>180	38 (64.4)	4.0 ± 1.8	
Total rocuronium used (mg)	< 83	33 (55.9)	4.1 ± 1.6	0.832
	≥ 83	26 (44.1)	4.0 ± 2.1	
Total fentanyl used (µg)	< 218	40 (67.8)	3.9 ± 1.7	0.397
	≥ 218	19 (32.2)	4.3 ± 2.0	

Values are given as frequency (percentage) or mean ± SD

and 60 min in Group P than in Group V ($P < 0.05$). In line with our results, Toker et al. compared the VCV and PCV-VG modes in laparoscopic gynecologic surgery. In his study, he observed an increase in oxygenation in addition to the PCV-VG ventilation parameters.[5] Some studies have noted a significantly high oxygenation (high PaO_2) as well as improved ventilation with PCV mode; in contrast, other researchers did not observe any significant difference in relation to oxygenation and ventilation.[13,14]

5. LIMITATIONS

The limitations of this investigation were the relatively small sample size and the single-center investigation.

6. CONCLUSION

PCV-VG is a superior strategy for ventilation compared with VCV in obese patients who undergo laparoscopic surgery in the Trendelenburg position. PCV-VG significantly enhances lung compliance and oxygenation while maintaining lower peak and plateau pressures with comparable hemodynamic stability and PaCO2.

7. Data availability

The numerical data generated during this research is available with the authors, and can be requested

8. Funding

The study utilized the hospital resources only, and no external or industry funding was involved.

9. Conflict of interest

All authors declare that there was no conflict of interests in the conduct of this study.

10. Authors' contribution

AMS: Conduction of the study work

MES: Manuscript editing

SST, AMY: Literature search

AEG: Statistical analysis and review

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