The dual mode of ventilation 'pressure-controlled ventilation–volume guaranteed' does not provide anymore benefit in obese anesthetized patients

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Background
Ventilatory strategies aim at the prevention of atelectasis and the improvement of oxygenation, but yet none is optimal. On comparing pressure-controlled ventilation (PCV) with volume-controlled ventilation (VCV) with the same tidal volume and inspiratory time, PCV tends to produce higher mean airway pressures, and thereby improves oxygenation. However, volume-targeted ventilators (VTV) allow to set the tidal volume directly. In order to deliver that volume. We compared PCV and pressure-controlled ventilation volume guaranteed (PCV–VG) with regard to the airway pressures produced when aiming to achieve the same tidal volume.
Patients and methods
Thirty obese ASA I–III patients scheduled for abdominal surgery were ventilated with PCV for 45 min; then, the PCV–VG mode was applied to all patients with the same parameters, targeting the same tidal volume of conventional PCV during the first phase. The plateau pressure and the mean airway pressure were recorded and compared between both modes. Vital signs, $EtCO_2$, SpO_2, arterial blood gases, and the oxygenation index were compared.
Results
No difference was observed between both modes of ventilation in terms of the plateau airway pressure (34.2 ± 1.8 vs. 34.1 ± 2.9 cmH_2O, $P = 0.484$) and the mean airway pressure (13.4 ± 1.6 vs. 13.2 ± 1.8 cmH_2O, $P = 0.326$). No significant difference was observed between PCV and PCV–VG with regard to the hemodynamics, $EtCO_2$, and SpO_2. No significant change was observed in the arterial blood gas analysis including pH (7.39 ± 0.3 versus 7.4 ± 0.2 with *P* value 0.204), $PaCO_2$ (30.8e 0.204) change in 0.2 with *P* value 0.06), PaO_2 (155.8 0.06)) change in0.2 with blood *P* value 0.316) and oxygenation index (4.34 oxygenation index.2 with b*P* value 0.176).
Conclusion
No significant difference was observed between both modes of ventilation (PCV vs. PCV–VG) in obese patients.

Keywords:
dual mode ventilation, obese, pressure-controlled ventilation, pressure-controlled volume guarantee ventilation

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Introduction

Difficulties in pulmonary ventilation are frequently encountered in morbidly obese patients during general anesthesia. Derangements in ventilation during surgery have been well documented, which include reduced respiratory system compliance, increased respiratory system resistance, a severely reduced functional residual capacity, and impaired arterial oxygenation [1,2]. The reduced lung volumes, the decreased functional residual capacity, and the high closing capacity eventually lead to a ventilation–perfusion mismatch, and increase the physiological intrapulmonary shunt, leading to an impairment of gas exchange and eventually intraoperative hypoxemia [3].

Different ventilatory modalities have been proposed to prevent atelectasis and improve arterial oxygenation, but the optimal ventilatory mode to achieve these goals is still under debate. Pressure-controlled ventilation (PCV) is one of the strategies proposed to improve gas exchange in hypoxic patients. This mode provides a maximal pressure gradient between the proximal airway and the alveoli at the beginning of the inspiration, and most of the tidal volume is delivered early during the inspiratory phase. These actions lead to the recruitment of unstable alveoli [4]. Moreover, compared with volume-controlled ventilation (VCV) with the same tidal volume and inspiratory time, PCV tends to produce higher mean airway pressures [5] and thereby can improve arterial oxygenation [6]. Finally, keeping the inspiratory pressure constant reduces ventilatory nonhomogeneities by allowing the redistribution of the tidal volume from alveoli with a low time constant to alveoli with a longer time constant [7].

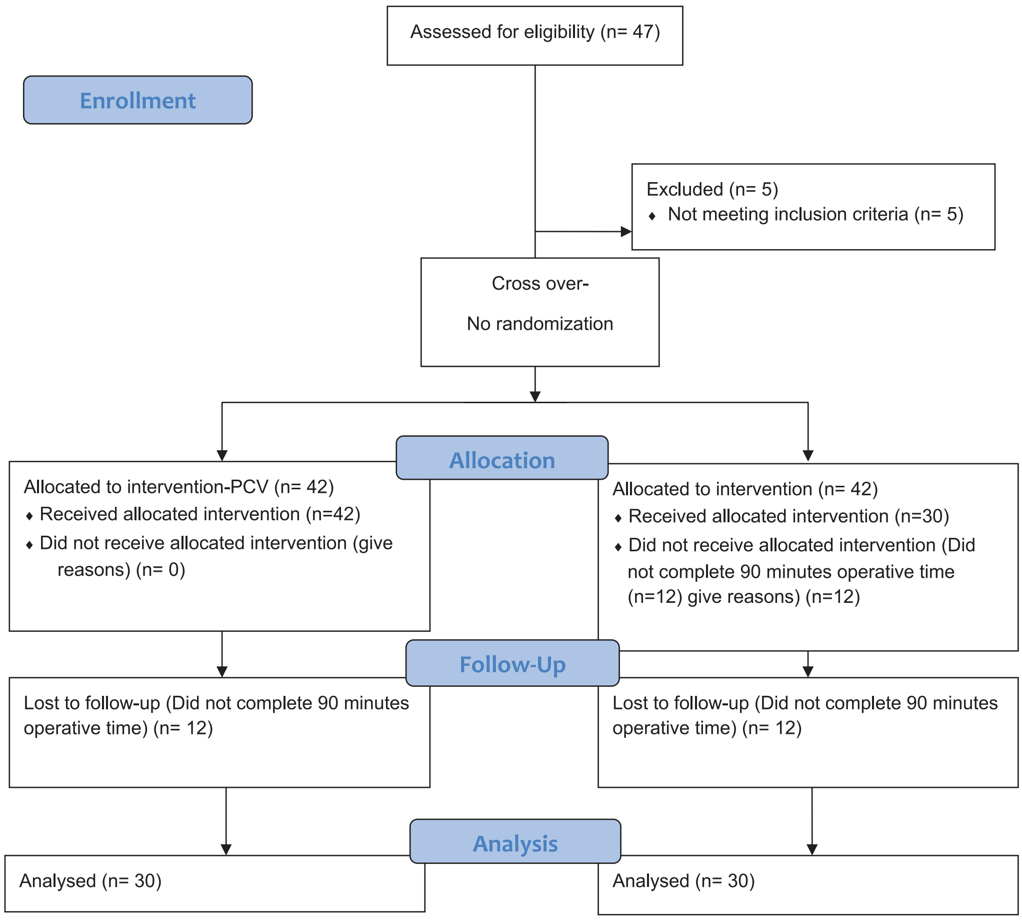
Volume-targeted ventilators (VTV) allow the clinician to set the tidal volume directly, the ventilator's internal computer makes adjustments to peak inspiratory pressure or inflation times from inflation to inflation in a trial to deliver that volume. VTVs are either volume supported (volume cycled) or volume guaranteed (time cycled). Volume-guaranteed ventilation is a form of time-cycled, pressure-limited ventilation. The preset inspiratory time, the expiratory tidal volume, and the maximum pressure set by the clinician limit the maximum peak inspiratory pressure (PIP). It uses a flow sensor placed at the endotracheal tube to measure the inspired and the expired tidal volumes (VTe) of each breath. The operator sets a target expiratory tidal volume. The ventilator then adjusts the peak inflating pressure to try and maintain the set VTe for the next inflation. When the measured tidal volume is less than the value selected by the clinician, it makes small stepwise increases in the PIP from breath to breath (<3 cmH_2O) until the set VTe is reached. If the measured volume exceeds that set, it reduces the inflating pressure in similar decrements [8].

This study examined the hypothesis that the dual mode of ventilation 'pressure-controlled ventilation–volume-guaranteed mode' reduces the variability in plateau pressure and the mean airway pressure better than traditional PCV in the short-term cross-over study.

Patients and methods

This cross-over study was approved by the ethical committee of the National Cancer Institute, Cairo University. All patients were asked for a signed and informed consent. We enrolled 30 obese ASA I–III patients (Fig. 1) scheduled for abdominal surgery

Figure 1



A consort flowchart for the study (cross-over design).

during the period from 18 December 2014 to 30 April 2015. The inclusion criteria were morbid obesity, and aged 18–60 years. Morbid obesity is defined by a BMI of 35 kg/m^2 or more (obesity class 2). Preoperative exclusion criteria were patient refusal, a lack of understanding by the patient of the purpose of the study, pulmonary function less than 70% of that predicted, $PaCO_2$ 50 mmHg or more, and patients with obstructive sleep apnea. Intraoperative exclusion criteria were failure of tracheal intubation, and an inability to maintain stable mechanical ventilation settings for 30 min (defined as an inability to maintain an appropriate $EtCO_2$ from 35 to 40 mmHg).

The preoperative evaluation included a physical examination. All patients underwent pulmonary function tests and blood gases. Cardiac evaluation may proceed for cardiological consultation and echocardiography should they be deemed necessary. The primary outcome was the appreciation of the plateau pressure 45 min after ventilation by the two different modes: PCV and pressure-controlled ventilation volume-guaranteed (PCV–VG) dual mode of ventilation. The primary outcome was the comparison of the plateau pressure between the two ventilation modes (PCV vs. PCV–VG). Secondary outcomes were vital signs, $EtCO_2$, SpO_2, arterial blood gases, and the oxygenation index after 45 min of ventilation.

A standardized anesthetic protocol was used. ECG, noninvasive blood pressure, pulse oximetry, and a CO_2 analyzer were used throughout the procedure. Preoxygenation was applied before induction. Induction was performed with propofol 2 mg/kg and fentanyl 5–10 mcg/kg and maintained with sevoflurane (0.5–1 expired MAC) in 50% oxygen in air. Intraoperative muscle relaxation was achieved with cisatracurium 0.15 mg/kg followed by a continuous infusion of 2 μg kg^{-1} min^{-1}; full muscle relaxation (no response to train of four stimulation) was maintained during surgery to avoid any possible effect on airway pressure due to inadequate relaxation. Patients with operations lasting less than 90 minutes were excluded from the study.

The Datex–Ohmeda ventilator (S/5 Avance–Aisys, General Electric, Madison, Wisconsin, USA) was used, starting with PCV. The $EtCO_2$ was maintained between 35 and 40 mmHg, and the plateau pressure was maintained at an upper limit of 40 cm because in obese patients, the plateau pressure may be a poor indication of the transpulmonary pressure, and because of impaired chest compliance in these patients, a limit of 30 cmH_2O was considered low for these patients [2,9].

A respiratory rate of 12/min and an *I*/*E* ratio of 1 : 2 were set. After 45 min, PCV–VG was applied to all patients. The same parameters were used, targeting the same tidal volume of conventional PCV during the first phase. No recruitment maneuvers were performed after tracheal intubation. After surgery, neostigmine 0.05 mg/kg (estimated lean body weight) and atropine 0.02 mg/kg (estimated lean body weight) were given if the train-of-four ratio was more than two switches.

Parameters

The blood pressure was measured every 5 min. The heart rate, $EtCO_2$, and SpO_2 were monitored continuously. Plateau and mean inspiratory airway pressures were measured at each ventilatory cycle. All these parameters were recorded every 5 min during the study period. Arterial blood samples were drawn to measure $PaCO_2$ and PaO_2 after 45 min of ventilation by each mode, with the calculation of the oxygenation index ($FiO_2 \times 100 \times P_{mean}/PaO_2$).

Statistical analysis

Data were computerized and analyzed using the statistical package for the social sciences (SPSS 22.0; SPSS Inc., Chicago, Illinois, USA) software. Normality of the distribution of data was assessed by the Kolmogorov–Smirnov test. Continuous variables were expressed as the mean ± SD. Numerical data were compared using paired Student's *t*-test. Hemodynamic changes were analyzed using the repeated-measures analysis of variance, followed by the Schaffer test, as appropriate. A *P* value of 0.05 or less was considered statistically significant.

Sample size estimation

Sample size calculation depended on previous studies with similar modes of ventilation [10,11], we anticipated that the plateau pressure would be ~15 ± 4 in both modes of ventilation. Using a Probability of type 1 error of 0.05 and desired power of 90%, we estimated that 25 patients will be needed to demonstrate a statistically significant difference. In addition, from previous study with similar modes of ventilation [4], we anticipated that the oxygenation index would be ~40 ± 5 in both modes of ventilation. Using a Probability of type 1 error of 0.05 and desired power of 90%, we estimated that 20 patients will be needed to demonstrate a statistically significant difference (effect size *d* = 20).

Results

Patients included 13 males and 17 females with mean age 38.2 ± 11.8 years and mean body mass index (BMI) is 36.2 ± 0.9.

Our study revealed no statistically significant difference between the two modes of ventilation (PCV vs. PCV–VG) (Table 1) with regard to the plateau airway

Table 1 Comparison between pressure-controlled ventilation and pressure-controlled volume-guaranteed ventilation

Parameters	PCV	PCV–VG	*P* value
Systolic pressure (mmHg)	133.5 ± 2.5	133 ± 1.5	0.834
Diastolic pressure (mmHg)	78.6 ± 1.2	78.7 ± 0.9	0.809
Heart rate (bpm)	77.4 ± 3.6	77.1 ± 2.9	0.708
End tidal CO_2 (mmHg)	32.6 ± 2.4	32.3 ± 1.7	0.213
SpO_2 (%)	96.8	97.2	0.424
Plateau pressure (cmH_2O)	34.2 ± 1.8	34.1 ± 2.9	0.484
Mean airway pressure (cmH_2O)	13.4 ± 1.6	13.2 ± 1.8	0.326
PO_2	155.8 ± 17.3	157 ± 18.1	0.316
$PaCO_2$	30.8 ± 1.5	30.4 ± 1.3	0.06
pH	7.39 ± 0.3	7.4 ± 0.2	0.204
OI	4.34 ± 0.45	4.24 ± 0.49	0.176

Data are presented as mean ± SD; $P < 0.05$ is considered statistically significant; OI, oxygenation index; $PaCO_2$, arterial partial pressure of carbon dioxide; PCV, pressure-controlled ventilation; PCV–VG, pressure-controlled volume guaranteed ventilation; PO_2, arterial partial pressure of oxygen; SpO_2, oxygen saturation.

pressure (34.2 ± 1.8 vs. 34.1 ± 2.9 cmH_2O, $P = 0.484$) and the mean airway pressure (13.4 vs. 13.2 cmH_2O, $P = 0.326$).

Systolic blood pressure (133.5 ± 2.5 mmHg versus 133 ± 1.5 mmHg with *P* value 0.834), diastolic blood pressure (78.6 ± 1.2 mmHg versus 78.7 ± 0.9 mmHg with *P* value 0.809), heart rate (77.4 ± 3.6 bpm versus 77.1 ± 2.9 bpm *P* value 0.708), EtCO2 (32.6 ± 2.4 mmHg versus 32.3 ± 1.7 mmHg with *P* value 0.213) and oxygen saturation (96.8% versus 97.2% *P* value 0.424).

Both modes of ventilation did not produce any significant change in arterial blood gas analysis including pH (7.39 ± 0.3 versus 7.4 ± 0.2 with *P* value 0.204), PaCO2 (30.8 ± 1.5 versus 30.4 ± 1.3 with *P* value 0.06), PaO2 (155.8 ± 17.3 mmHg versus 157 ± 18.1 with *P* value 0.316) and oxygenation index (4.34 ± 0.45 versus 4.24 ± 0.49 with *P* value 0.176).

Discussion

Our study concluded that by comparing PCV with PCV–VG, the dual mode of ventilation (PCV–VG) does not add anymore to the PCV in obese patients with regard to the plateau pressure, the mean airway pressure, vital signs, $EtCO_2$, SpO_2, arterial blood gases, and the oxygenation index.

Obese patients are characterized by a heterogeneous population of alveoli with different time constants. Consequently, alveoli with a short time constant may be initially overinflated, but then a more homogeneous distribution of the tidal volume in all the ventilated alveoli could follow, reducing the amount of atelectasis by an improved alveolar recruitment [12]. The plateau pressure reflects the average peak alveolar pressure [13]; that was why we decided to use it. Although the goals of the ARDS Network trial correlate better outcomes with a lower VTe along with a lower plateau pressure [14] and have determined an upper limit of plateau pressure by 30 cmH_2O, we used the upper limit of 40 cmH_2O for the plateau pressure in our study similar to Dion *et al.* [15], who also conducted their study on obese patients with less compliance requiring higher pressure for adequate recruitment and ventilation.

During the use of the PCV mode, there is no difference between the peak and the plateau pressures as the operator sets up the inspiratory pressure, and the ventilator increases the pressure till it reaches the set inspiratory pressure and maintains this pressure during the inspiratory phase through change in the flow; that is why all pressure modes have a decelerating flow and a constant pressure. Hence, in the PCV mode, there is no difference between peak, plateau, or inspiratory pressures; in our study, we chose to mention it as a plateau pressure to make it clear that it is the pressure maintained throughout the inspiratory phase that will be more related to pulmonary mechanics and compliance, especially because our study group consisted of obese patients. A study [16] similar to ours used the same anesthesia machine with the same mode; the author similarly used the term plateau pressure to indicate the pressure during the whole inspiratory phase to reflect the effect of pulmonary mechanics on the airway pressure during the whole inspiratory phase and not during the initiation of the inspiratory phase only.

This study compared two modes of the same pattern. The flow pattern is considered as the most influential factor in ventilation. The decelerating flow used in PCV generates higher instantaneous flow peaks and may allow a better alveolar recruitment and oxygenation when compared with constant flow [4].

Baker *et al.* [17,18] compared decelerating flow with constant flow in anaesthetized dogs, where the VTe and the respiratory frequency were kept constant. $PaCO_2$ and the shunt fraction decreased, whereas PaO_2 and the mean airway pressure increased using the decelerating flow.

Al-Saady and Bennett [12] concluded the same on comparing a decelerating flow with a constant flow in 14 patients ventilated for respiratory failure. Even if the inspiratory flow is very low at the end of inspiration in PCV, it does not reach zero as in constant flow.

This explains our results [PaCO2 (30.8 ± 1.5 versus 30.4 ± 1.3 with *P* value 0.06), PaO2 (155.8 ± 17.3 mmHg versus 157 ± 18.1 with *P* value 0.316) and oxygenation index (4.34 ± 0.45 versus 4.24 ± 0.49 with *P* value 0.176)]. As long as both modes utilize the same flow pattern, it is not anticipated that oxygenation and carbon dioxide would differ. Consequently, no difference was detected.

However, the flow pattern itself interacts with some ventilator parameters to be influential on oxygenation. PCV is proved not to be sufficient alone to increase the arterial oxygen tension in morbidly obese patients undergoing abdominal surgery. It might need to be associated with the prolonged *I/E* ratio to improve gas exchange.

Accordingly, studies reporting better arterial oxygen tension during PCV used prolonged inspiratory times [7,19]. Consequently, monitoring the flow curve is helpful in determining the insufflation time to allow the end-inspiratory flow to reach zero [20].

Accordingly, our hypothesis suggested that the dual mode of ventilation may adjust the flow pattern to achieve better oxygenation. In contrast, this assumption was contradicted by this study results.

Our findings [plateau airway pressure (34.2 ± 1.8 vs. 34.1 ± 2.9 cmH_2O, $P = 0.484$) and mean airway pressure (13.4 ± 1.6 vs. 13.2 ± 1.8 cmH_2O, $P = 0.326$)] do not concur with those of Herrera *et al.* [21] who suggested that volume-targeted ventilation reduces the variability in tidal volume delivery and provides ventilation at lower mean airway pressures compared with traditional PCV. However, they performed this research on preterm infants and utilized it as a weaning mode, whereas our study group consisted of adult obese paralyzed patients.

Herrera *et al.* [21] conducted a short-term study, but four trials [22,23,24,25] reported mortality to hospital discharge as an outcome measure, and failed to demonstrate a difference in the mortality between the volume-targeted and the 'PCV' groups.

Interestingly, Sinha *et al.* [23] and Lista *et al.* [25] studied the duration of intermittent positive pressure ventilation. Pooled analyses showed a statistically significant reduction in the number of days of intermittent positive pressure ventilation (IPPV) in the volume-targeted group. Again, volume-targeted ventilation seems to be superior as a weaning mode rather than a ventilating mode during anesthesia. Meanwhile, Keszler *et al.* [22] found a reduced rate of hypocarbia in blood gases from the volume-targeted group. There were no significant differences in rates of acidosis or hypercarbia. In another term, this mode may guard against hyperinflation that accompanies lung improvement with treatment. In contrast, volume-targeted ventilation failed to provide the same tidal volume with a lower airway pressure. The later finding agrees with our results.

Pressure-regulated volume control (PRVC) was compared with PCV as another example of comparing the two modes of the same flow pattern after on-pump coronary artery bypass graft (CABG) surgery. They appeared to be similar for atelectasis-induced perfusion mismatch, utilizing the oxygenation index as an indicator [11,26,27].

Oxygenation index assessment is a more sensitive indicator of oxygenation than the widely used PaO_2/FiO_2 ratio as the lung volume is affected by different techniques of mechanical ventilation [28,29]. In contrast to our study, PRVC results in a significantly lower mean airway pressure in the later stages of ventilation [11,27,30]. Again, the dual mode is proved to be superior as a weaning mode.

Another example of dual control is adaptive pressure control that is claimed to alter both the VTe and the flow, and guarantees a minimum delivered VTe, which is a feature not available with PCV. This mode was compared with traditional PCV, and no differences were found. Adaptive pressure ventilation can guarantee a minimum tidal volume, but it cannot guarantee a constant tidal volume. The authors confirmed that the ventilator could control only the pressure or the volume during a breath, and not both [31].

Alvarez *et al.* [32] compared volume-controlled ventilation (VCV), PCV, and PRVC in 10 adult patients with acute respiratory failure. Not surprisingly, the PIP was the highest with the constant-flow waveform, and there were no differences between PCV and PRVC.

Waveform monitoring revealed that dual control does not guarantee a set tidal volume. Moreover, the dual mode results in a more variable tidal volume than the pressure control mode [33]. The dual-control mode can deliver a consistent VTe when there is no patient effort. These data are applied to our work as anesthetized patients are paralyzed. Accordingly, the tidal volume attained during the first phase was the input (preset VTe) during the second phase. However, in a patient with a variable respiratory rate, the dual control mode may result in variable VTe delivery and air trapping.

Volume support ventilation (VSV) is claimed to change the pressure support level according to the changes in thoracopulmonary mechanical properties and the patient's inspiratory effort. It correlates the observed tidal volume to the tidal volume target selected by the physician, taking into account a minimal calculated minute ventilation. The patient controls the respiratory rate, the inspiratory time, and the flow [34,35]. VSV was compared with PSV in terms of the ventilator response when dead space was added to the circuit. More effort was exerted by the patient with VSV, as assessed by the work of breathing and the pressure–time product as compared with pressure support ventilation (PSV) [36]. Clearly, the dual mode of ventilation is debated for its role as a weaning mode. Our study aimed at verifying the role of the dual mode in obese anesthetized patients.

It seems that starting all the procedures with the same mode is a violation of randomization. However, this design permitted the standardization of the *I/E* ratio and the respiratory rate throughout the study. In contrast, Dion *et al.* [15] performed a cross-over study that allowed the randomization of the starting mode at the expense of different respiratory rates and *I/E* ratios that could affect the results. Clearly, a high rate of ventilation may result in auto-PEEP and subsequent high airway pressure. Interestingly, the former study [15] concluded the same results as ours regarding the equality of PCV to PCV–VG in terms of PIP and oxygenation.

Lin *et al.* [16] had chosen old patients undergoing chest surgery and one-lung ventilation to compare PCV and PCV–VG and also concluded that PCV has the same effect on PIP as PCV–VG.

Finally, our study concluded that on comparing PCV with PCV–VG, the dual mode of ventilation (PCV–VG) does not add anymore to PCV in obese patients with regard to the plateau pressure, the mean airway pressure, vital signs, $EtCO_2$, SpO_2, arterial blood gases, and the oxygenation index.

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Conflicts of interest
There are no conflicts of interest.

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