COMPARISON OF PRESSURE-CONTROLLED AND VOLUME-CONTROLLED VENTILATION IN OBESE PATIENTS UNDERGOING LAPAROSCOPIC BARIATRIC SURGERY: A PROSPECTIVE CROSS-OVER COHORT STUDY

May Rady Helou[1], Maroun Badwi Ghabach[2], Jessica Tony Moussally[3], Antoine Pierre Daccache[3], Nada Hassan Saleh[3] and May Semaan Matta[4]

Abstract

Background: No specific guidelines on the optimal ventilatory settings for obese patients undergoing laparoscopic bariatric procedures has been recommended till now. The aim of this study was to evaluate volume-controlled ventilation (VCV) and pressure-controlled ventilation (PCV) during laparoscopic bariatric surgery using a cross-over cohort model in 4 different situations (supine and beach chair position, with and without intra-abdominal CO_2 insufflation).

Methods: 33 obese patients aged ≥15 years, with a body mass index (BMI) ≥40 kg/m^2 or BMI ≥35 kg/m^2 with at least one obesity-associated comorbid condition undergoing laparoscopic bariatric surgery were included. Patients were then randomly assigned to receive VCV and PCV in each of the following situations: the supine position without intra-abdominal CO_2 insufflation, the beach chair position without intra-abdominal CO_2 insufflation, the supine position after intra-abdominal CO_2 insufflation and in the beach chair position after the intra-abdominal CO_2 abdominal insufflation. Peak inspiratory pressure (PIP), plateau pressure, mean airway pressure (Pmean), total static compliance, expiratory tidal volume, end tidal CO_2 (TVexp), oxygen saturation, mean arterial pressure and heart rate were recorded.

Results: PIP was significantly lower during PCV when compared to VCV at all situations (p=0.000). Pmean was significantly higher during PCV than VCV in the beach chair position before intra-abdominal CO_2 insufflation. Hemodynamic variables and dynamic compliance were similar between the two modes.

Conclusion: In adult population undergoing laparoscopic bariatric surgery, PCV was found to be superior to VCV in providing the lowest PIP for the same inspiratory tidal volume delivered at all time-points and the highest TVexp at the supine and beach chair positions before intra-abdominal CO_2 insufflation.

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1 Associate Professor, Chairman Department of Anesthesia and Reanimation, Lebanese University, Faculty of Medical Sciences, Beirut, Lebanon.
2 Associate Professor, Department of Anesthesia and Reanimation, Lebanese University, Faculty of Medical Sciences, Beirut, Lebanon. Chairman of anesthesia Department, Rosary Hospital.
3 Resident of Anesthesia, Department of Anesthesia and Reanimation, Lebanese University, Faculty of Medical Sciences, Beirut, Lebanon.
4 Anesthesiologist, Department of Anesthesia, Rosary Hospital, Beirut, Lebanon.
Corresponding Author: Maroun Badwi Ghabach, M.D, Associate Professor, Department of Anesthesia and Reanimation, Chairman of Anesthesia Department, Rosary Hospital, Gemayze, Beirut-Lebanon, P.O. Box: 175-272, Tel: 00961-(0)-581140. E-mail: maroun_ghabash@yahoo.com

Introduction

The anatomical effects of obesity on lung function has been the subject of intense investigation over the last 50 years. The most consistently reported effects are a reduction in functional residual capacity[1], a reduction in lung compliance[2] and abnormalities in ventilation distribution[3]. Furthermore, the respiratory physiologic derangements are aggravated under general anesthesia and with intra-abdominal CO_2 insufflation during laparoscopic bariatric surgery[4]; the most common deleterious effects encountered during ventilation under general anesthesia are high-pressure levels leading to barotrauma and impaired alveolar ventilation leading to atelectasis[5].

The use of volume-controlled ventilation (VCV) is common, as this has been the only available mode on ventilators for a long time. This mode utilizes a constant flow to deliver a target tidal volume (Vt) and thus insures a satisfactory minute ventilation (MV) despite frequently seen high-pressure levels in obese patients[6]. Pressure-controlled ventilation (PCV) utilizes a decelerating flow pattern and thus facilitates recruitment of unstable alveoli, reduces ventilatory inhomogeneities and improves arterial oxygenation despite putting the patient at risk of hypoventilation and pulmonary over-distention[6]. However, in obese patients undergoing bariatric laparoscopic surgery, studies failed to prove any significant difference in airway pressures and compliance between PCV and VCV modes[7] and no guidelines regarding the preferred mode of ventilation are recommended till now[8]. In practice, appropriate strategy of ventilation is based on the anesthesiologist's preference.

Our aim in this paper was to compare VCV and PCV modes in obese patients undergoing laparoscopic bariatric surgery under general anesthesia before and after intra-abdominal CO_2 insufflation at different intraoperative positions using a prospective cross-over cohort model of study.

Methods

This prospective study was approved by the Institutional Review Board and a written informed consent was obtained from all patients.

33 obese patients undergoing laparoscopic bariatric surgery (sleeve or bypass) were included. Inclusion criteria were age ≥15 years, a body mass index (BMI) ≥40 kg/m^2 or BMI ≥35 kg/m^2 with at least one obesity-associated comorbid condition. Preoperative exclusion criteria were patient refusal and patients with ASA score >III.

Age, sex, total body weight (TBW), height (H), ideal body weight (IBW), BMI and the presence of comorbidities (pulmonary or cardiac) were registered preoperatively. BMI was defined as TBW/H^2 (kg/m^2) and IBW was calculated using Lorentz's formula: IBW=H (cm)-100-[H (cm)-150]/2 in females and IBW=H (cm)-100-[H (cm)-150]/4 in males.

In the induction room, anesthesia monitoring was standardized in all patients: ECG, non-invasive arterial blood pressure, pulse oximetry, anesthetic gas analyzer, capnography, bispectral index (BIS) and a train-of-four monitor (TOF). After 5 min of pre-oxygenation with 100% oxygen and continuous positive airway pressure (CPAP) of 6 cmH_2O using the table RAMP system (Rapid Airway Management Positioner), induction of anesthesia was performed with midazolam (1mg), propofol (2.5 mg/kg) and sufentanyl (0.2µg/kg). Tracheal intubation at an appropriate TOF of 0 twitch was facilitated with rocuronium 1.2 mg/kg. Endotracheal tube size 8 was used in males and 7.5 in females. Anesthesia was maintained to a BIS level 40-60 with sevoflurane 1.5-2% and remifentanil 0.05-0.3 µg/kg/min. Rocuronium 0.15 mg/kg was given intermittently to maintain TOF at 0 twitch at the adductor pollicis muscle. The dosages of all medications used were calculated based on the IBW.

All patients underwent mechanical ventilation intraoperatively with Aisys ventilator (GE healthcare, Madison, USA) with 2 liters of oxygen-air mixture (FiO_2=0.4) using semi-closed circuit. Patients were then randomly assigned to start ventilation with VCV for 20 min followed by PCV for another 20-min period or to the opposite sequence of these modes of ventilation. Randomization was performed using the online randomizer (Graphpad software, San Diego, CA, USA). Both modes were applied to all patients in each of the following situations: the supine position without intra-abdominal CO_2 insufflation (T1), the beach chair position without intra-abdominal CO_2 insufflation (T2), the supine position after intra-abdominal CO_2 insufflation (T3) and in the beach chair position after the intra-abdominal CO_2 insufflation (T4). The set CO_2 insufflation pressure was 15 mmHg for an optimal intra-abdominal exposure and a suitable operating field.

Set parameters for VCV mode were: an inspiratory tidal volume of 8 mL/kg of IBW, respiratory rate of 12 breath/min, inspiratory time over the expiratory time ratio (I/E ratio) of 1:2 and a positive end expiratory pressure (PEEP) of 8 cm H_2O. An inspiratory pause equal to 5% of the inspiratory time was used to measure plateau pressure (Pplateau). Set parameters for PCV mode were: peak inspiratory pressure (PIP) adjusted to deliver inspiratory tidal volume of 8 mL/kg of IBW, respiratory rate of 12 breath/min, inspiratory time over the expiratory time ratio (I/E ratio) of 1:2 and a positive end expiratory pressure (PEEP) of 8 cm H_2O. A drop to zero inspiratory flow was checked on the flow-time to record Pplateau. In both modes, absence of auto-PEEP was ensured by a drop to zero expiratory flow on the flow-time curve.

At the end of each mode of ventilation (VCV and PCV) at T1, T2, T3 and T4 the following parameters were recorded: PIP, Pplateau, Mean airway Pressure (Pmean), total static compliance (C), expiratory tidal volume (TVexp), end tidal CO_2 ($EtCO_2$), oxygen saturation (SaO_2), mean arterial pressure (MAP) and heart rate (HR). All pressures are expressed in cm H_2O.

All patients underwent uneventful surgery by the same surgical team and no perioperative adverse events were noted. Sugammadex at recommended doses was used to reverse muscle relaxant effect.

Data were computerized and analyzed using the SPSS 15.0 software (Statistical Packages for Social Science; SPSS Inc., Chicago, Illinois, USA). Normality of the distribution of data was assessed using the Kolmogorov–Smirnov test. We expressed continuous variables as mean ± standard deviation (SD). Means were compared using ANOVA test, P <0.05 was considered statistically significant.

Results

33 patients were enrolled in the Study. The mean ± SD of age, TBW, H, IBW and BMI are shown in Table 1, as well as male to female ratio (M/F) and ASA physical status.

Table 1

Demographic and Anesthetic Characteristics

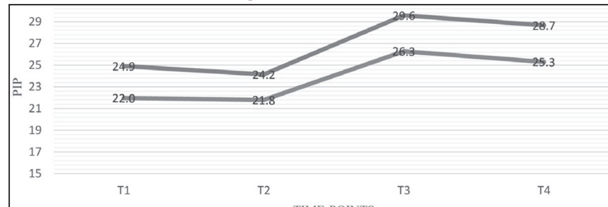
N	33
Age (years)	39.2 ± 13.2
TBW (Kg)	117.3 ± 19.6
H (cm)	166.9 ± 8.7
IBW (Kg)	60.9 ± 7.5
BMI (Kg/m²)	41.9 ± 4.4
F/M	22/11
ASA Status II/III	13/20
Data are mean ± SDs or numbers. SD=Standard deviations	

n=number, TBW=Total Body weight, H=height, IBW=ideal body weight, BMI=Body Mass Index, F=Female, M=Male.

Measured respiratory mechanics (PIP, Pmean, Pplateau and C) are shown in Table 2. PIP was significantly higher during VCV mode when compared to PCV mode at T1 (24.9 ± 3.6 vs 22.0 ± 3.5, p=0.000), at T2 (24.2 ± 2.8 vs 21.8 ± 2.7, p=0.000), at T3 (29.6 ± 5.5 vs 26.3 ± 4.8, p=0.000) and at T4 (28.7 ± 4.1 vs 25.3 ± 3.9, p=0.000) (figure 1). Pmean was significantly higher during PCV mode at T1 (12.8 ±1.1 vs 13.4 ±1.3, p=0.014) and T2 (12.6 ± 1.5 vs 13.3 ±

Fig. 1

Mean PIP values during VCV and PCV at T1, T2, T3 and T4



VCV=Volume Controlled Ventilation, PCV=Volume Controlled Ventilation, PIP=Peak inspiratory Pessure in cmH_2O. T1: Supine position, T2: Beach chair position, T3: Supine position after intra-abdominal CO_2 insufflation, T4: Beach chair position after the intra-abdominal CO_2 insufflation.

Table 2
Respiratory Mechanics Characteristics

		PIP			**P Mean**			**P Plateau**			**C**		
Mean		STD	p	Mean	STD	p	Mean	STD	p	Mean	STD	p	
T1	VCV	24.9	3.6	.000	12.8	1.1	.014	21.7	3.9	.503	35.8	11.0	.104
	PCV	22.0	3.5		13.4	1.3		22.0	3.5		34.3	8.4	
T2	VCV	24.2	2.8	.000	12.6	1.5	.025	21.0	2.9	.183	37.2	8.8	.107
	PCV	21.8	2.7		13.3	1.0		21.8	2.7		36.3	6.4	
T3	VCV	29.6	5.5	.000	14.0	1.4	.083	26.4	5.0	.901	24.9	6.4	.079
	PCV	26.3	4.8		14.4	1.5		26.3	4.8		23.6	6.5	
T4 VCV		28.7	4.1	.000	14.1	2.2	.529	24.6	4.1	.263	27.8	6.0	.315
	PCV	25.3	3.9		14.3	1.2		25.3	3.9		27.2	6.0	
SD=Standard deviations. P=p value, p <0.05 is considered significant													

VCV=Volume Controlled Ventilation, PCV=Volume Controlled Ventilation, PIP=Peak inspiratory Pressure, Pmean=Mean airway Pressure, C=total static compliance, SD=Standard deviations, p=p value. T1: Supine position, T2: Beach chair position, T3: Supine position after intra-abdominal CO_2 insufflation, T4: Beach chair position after the intra-abdominal CO_2 insufflation.

1.0, p=0.025). At T3 and T4 the difference in Pmean between VCV and PCV was not significantly different (p=0.083 and p=0.529 respectively). At T1, T2, T3 and T4, Pplateau did not show any significant difference between the two modes of ventilation (p=0.503, p=0.183, p=0.901 and p=0.263 respectively). C did not differ significantly between PCV and VCV modes at T1, T2, T3 and T4 (p=0.104, p=0.107, p=0.079 and p=0.315 respectively).

Measured ventilation characteristics (TVexp and $EtCO_2$) are shown in table 3. TVexp was significantly lower during VCV when compared to PCV at T1 (454.0 ± 78.2 vs 482.7 ± 86.1, p=0.000) and at T2 (455.9 ± 78.7 vs 491.4 ± 91.4, p=0.000). At T3 and T4 the difference in TVexp between VC ventilation and PC ventilation was not significantly different (p=0.605 and p=0.409 respectively). $EtCO_2$ did not differ significantly between PCV and VCV modes at T1, T2, T3 and T4 (p=0.586, p=0.106, p=0.203 and p=0.553 respectively). Measured hemodynamic characteristics (SaO_2, MAP and HR) are shown in table 4. SaO_2, MAP and HR were not significantly different between VC and PC modes at T1, T2, T3 and T4 (p >0.05).

Table 3
Ventilation Characteristics

		TVexp			**$EtCO_2$**		
Mean		SD	p	Mean	SD	p	
T1	VCV	454.0	78.2	.000	37.1	3.9	.586
	PCV	482.7	86.1		36.9	4.4	
T2	VCV	455.9	78.7	.000	37.0	4.5	.106
	PCV	491.4	91.4		36.4	5.0	
T3	VCV	454.2	87.4	.605	37.7	5.2	.203
	PCV	446.5	99.3		39.4	5.3	
T4	VCV	453.5	79.1	.409	40.7	4.5	.553
	PCV	461.8	85.3		40.8	4.8	
SD=Standard deviations. P=p value, p<0.05 is considered significant							

VCV=Volume Controlled Ventilation, PCV=Volume Controlled Ventilation, TVexp=Expiratory Tidal Volume, $EtCO_2$=End tidal CO_2, SD=Standard deviations, p=p value. T1: Supine position, T2: Beach chair position, T3: Supine position after intra-abdominal CO_2 insufflation, T4: Beach chair position after the intra-abdominal CO_2 insufflation.

Discussion

This is the first prospective study that evaluates PCV and VCV modes during laparoscopic bariatric surgery in the adult population using a cross-over cohort model in 4 different situations (supine, beach chair position, with and without intra-abdominal CO_2 insufflation).

In the last published meta-analysis in 2012[7]

Table 4
Hemodynamic Characteristics

		SaO2			**MAP**			**HR**		
Mean		SD	p	Mean	SD	p	Mean	SD	p	
T1	VCV	97.8	1.8	.108	88.9	16.8	.203	79.5	15.7	.505
	PCV	97.5	1.9		77.5	12.9		76.7	15.1	
T2	VCV	95.3	10.1	.226	72.4	11.9	.422	73.2	12.9	.805
	PCV	95.5	10.1		73.9	13.1		73.4	14.4	
T3	VCV	93.5	15.0	.219	90.5	15.6	.159	70.4	12.5	.056
	PCV	96.8	2.1		94.6	15.9		72.1	13.2	
T4	VCV	97.0	1.8	.160	95.2	15.4	.542	71.6	11.7	.582
	PCV	97.3	1.6		94.5	16.6		71.9	12.1	
SD=Standard deviations. P=p value, p <0.05 is considered significant										

VCV=Volume Controlled Ventilation, PCV=Volume Controlled Ventilation, SaO_2=Oxygen Saturation, MAP=Mean Arterial Pressure, HR=Heart Rate, SD=Standard deviations, p=p value. T1: Supine position, T2: Beach chair position, T3: Supine position after intra-abdominal CO_2 insufflation, T4: Beach chair position after the intra-abdominal CO_2 insufflation.

that included 13 randomized trials evaluating the ventilation strategy in obese patients undergoing laparoscopic surgery there was no evidence of any difference between PCV and VCV modes in terms of intraoperative PaO_2/FIO_2 ratio, intraoperative tidal volume, or Pmean. There was no evidence either of any difference in MAP or mean HR. In all mentioned trials in this meta-analysis, PCV was compared to VCV mode at the beach chair position with intra-abdominal CO_2 insufflation. Also to note that there was not enough data on other outcomes like PIP, Pplateau and compliance to draw more meaningful conclusions. Finding an ideal ventilation strategy that minimizes the degree of raised PIP while maintaining satisfactory Pmean is of major importance since obesity poses particular challenges to adequate mechanical ventilation primarily by restricted lung mechanics, decreased lung volumes and greater susceptibility to barotrauma and ventilator-induced lung injury[9]. Two more recent studies further evaluated the respiratory mechanics and have noted that PCV was able to significantly reduce PIP in obese adults undergoing intra-abdominal laparoscopic procedures[10,11]. In our study we found similar results, we demonstrated that PIP was significantly lower during PCV mode when compared to VCV mode at all time points (T1, T2, T3 and T4). This resulted from the different insufflation flow patterns specific for each of these modes of ventilation: VCV delivers a constant flow pattern that may allow high PIP during the inspiratory cycle to deliver a preset tidal volume while PCV delivers a decelerating flow pattern at a preset pressure.

Pmean, which closely reflects mean alveolar pressure, is a major determinant of oxygenation[12]. In our study, Pmean was significantly higher during PCV mode when compared to VCV mode at T1 and T2. This result has not been reported before and it demonstrates clearly the advantageous use of PCV mode over VCV mode in those situations ie supine position and beach chair position without intra-abdominal CO_2 insufflation. However, at T3 and T4, Pmean was not significantly different between the two modes of ventilation. Previous studies[13,14,15] comparing Pmean between VCV and PCV after intra-abdominal CO_2 insufflation in the beach chair position reported similar results. This deleterious effect of pneumoperitoneum on lung mechanics can be diminished by increasing I/E ratio to 2:1 or 3:1 as demonstrated by Lessard et al[16].

Pplateau does not seem to significantly differ between PCV and VCV at T1 (in the supine position before intra-abdominal CO_2 insufflation), at T2 (in the supine position after intra-abdominal CO_2 insufflation), at T3 (in the supine position after intra-abdominal CO_2 insufflation) and at T4 (in the beach chair position after intra-abdominal CO_2 insufflation). Data in the literature compared Pplateau between PCV and VCV modes in the beach chair position after intra-abdominal CO2 insufflation (set as T2 in our study) and they found similar results[13,14,15].

TVexp was found to be significantly higher in PCV mode than in VCV mode before pneumoperitoneum at T1 and T2. The pneumoperitoneum increases intra-abdominal pressure and displaces the diaphragm cephalad which decreases the volume of the chest cavity[17]. Consequently at T3 and T4 after intra-abdominal CO_2 insufflation, TVexp decreased and there was no significant difference in TVexp between PCV and VCV.

Compliance was not significantly different between the two modes of ventilation as demonstrated by all previous studies[13,14]. Hemodynamics variables were not significantly different between the 2 modes of ventilation as well. In fact, flow pattern does not affect HR, MAP or SaO2 in obese patients undergoing laparoscopic procedures.

As a conclusion, use of PCV mode in obese patients undergoing laparoscopic bariatric surgery is advantageous over VCV mode. It provides ventilation with a lower PIP as compared to VCV mode at the supine position, the beach chair position with and without intra-abdominal CO_2 insufflation. It also provides a higher TVexp at the supine and beach chair positions before intra-abdominal CO_2 insufflation.

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