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54	Abstract	<p>Background: There are no guidelines on ventilation modes in morbidly obese patients. We investigated the effects of volume-controlled (VCV) and pressure-controlled ventilation (PCV) on gas exchange, respiratory mechanics, and cardiovascular responses in laparoscopic gastric banding procedures.</p> <p>Methods: After Institutional Review Board approval, 24 adult consenting patients scheduled for laparoscopic gastric banding were studied. Anesthesia was standardized using remifentanyl, propofol, rocuronium, and sevoflurane. All patients started with VCV with a tidal volume of 10 ml kg⁻¹ ideal body weight, respiratory rate adjusted to obtain an end-tidal carbon dioxide of 35–40 mmHg, positive end-expiratory pressure of 5 cmH₂O, an inspiratory pause of 10% and an inspiratory/expiratory ratio of 1:2. Fifteen minutes after pneumoperitoneum, the patients were randomly allocated to two groups. In Group VCV (<i>n</i> = 12), ventilation was with the same parameters. In Group PCV (<i>n</i> = 12), the airway pressure was set to provide a tidal volume of 10 ml kg⁻¹ ideal body weight without exceeding 35 cm H₂O. Respiratory rate was adjusted to keep an endtidal carbon dioxide of 35–40 mmHg. Arterial blood samples were drawn after surgical positioning and 15 min after allocation. Analysis of variance (ANOVA) was used for statistical analysis.</p> <p>Results: With constant minute ventilation, VCV generates equal airway pressures and cardiovascular effects with a lower Pa_{CO2} as compared to PCV (42.5 (5.2) mmHg versus 48.9 (4.3) mmHg, <i>p</i> < 0.01 ANOVA). Arterial oxygenation remained unchanged.</p> <p>Conclusions: VCV and PCV appear to be an equally suited ventilatory technique for laparoscopic procedures in morbidly obese patients. Carbon dioxide elimination is more efficient when using VCV.</p>	
55	Keywords separated by ' - '	Ventilation - Mechanics - Surgery - Laparoscopy - Partial pressure oxygen - Carbon dioxide - Elimination - Cardiovascular system - Effects	
56	Foot note information	<p>Performed at the University Hospital of Ghent, Department of Anesthesia, Gent Belgium.</p> <p>Preliminary results of this study were presented as poster discussion at the Euroanaesthesia meeting 2005 in Vienna, Austria.</p>	

Comparison of Volume-controlled and Pressure-controlled Ventilation during Laparoscopic Gastric Banding in Morbidly Obese Patients

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Abstract

Background There are no guidelines on ventilation modes in morbidly obese patients. We investigated the effects of volume-controlled (VCV) and pressure-controlled ventilation (PCV) on gas exchange, respiratory mechanics, and cardiovascular responses in laparoscopic gastric banding procedures. **Methods** After Institutional Review Board approval, 24 adult consenting patients scheduled for laparoscopic gastric banding were studied. Anesthesia was standardized using remifentanyl, propofol, rocuronium, and sevoflurane. All patients started with VCV with a tidal volume of 10 ml kg⁻¹ ideal body weight, respiratory rate adjusted to obtain an end-tidal carbon dioxide of 35–40 mmHg, positive end-expiratory pressure of 5 cmH₂O, an inspiratory pause of 10% and an inspiratory/expiratory ratio of 1:2. Fifteen minutes after pneumoperitoneum, the patients were randomly allocated to two groups. In Group VCV (n=12), ventilation was with the same parameters. In Group PCV (n=12), the airway pressure was set to provide a tidal volume of 10 ml kg⁻¹ ideal body weight without exceeding 35 cm H₂O. Respiratory rate was adjusted to keep an endtidal carbon dioxide of 35–40 mmHg. Arterial blood samples were drawn after surgical positioning and 15 min after allocation. Analysis of variance (ANOVA) was used for statistical analysis.

Results With constant minute ventilation, VCV generates equal airway pressures and cardiovascular effects with a lower PaCO₂ as compared to PCV (42.5 (5.2) mmHg versus 48.9 (4.3) mmHg, p<0.01 ANOVA). Arterial oxygenation remained unchanged. **Conclusions** VCV and PCV appear to be an equally suited ventilatory technique for laparoscopic procedures in morbidly obese patients. Carbon dioxide elimination is more efficient when using VCV.

Keywords Ventilation · Mechanics · Surgery · Laparoscopy · Partial pressure oxygen · Carbon dioxide · Elimination · Cardiovascular system · Effects

Introduction

Bariatric surgery has become very popular as long-term treatment of morbid obesity caused by the fact that long-term weight loss is better sustained in surgically treated patients compared to conventional treatment [1]. Laparoscopic bariatric procedures are the preferred technique [2]. In mechanically ventilated and sedated obese patients, derangements in lung and chest wall mechanics have been well documented and include: reduced respiratory system compliance, increased respiratory system resistance, severely reduced FRC and impaired arterial oxygenation [3]. The reduced lung volumes, decreased functional residual capacity, and high closing capacity eventually lead to a ventilation perfusion mismatch and increased physiological intrapulmonary shunt [4]. Maintenance of adequate oxygenation and avoiding ventilation induced lung injury is often a serious problem in morbidly obese patients. The optimal ventilation mode to

Performed at the University Hospital of Ghent, Department of Anesthesia, Gent Belgium.
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achieve these goals in morbidly obese patients is still under debate.

When ventilating morbidly obese patients, positive end expiratory pressure (PEEP) is known to improve oxygenation [5]. The use of large tidal volume ventilation does not improve oxygenation [6], nor does high or low respiratory rate [7]. In their response to a letter to the editor, Ogunnaike and coworkers reported their use of pressure-controlled ventilation with inspiratory pressures of up to 50 cmH₂O and vigilant monitoring of tidal volumes during bariatric laparoscopy without adverse pulmonary events [8].

There are no studies exploring the application of volume-controlled ventilation (VCV) or pressure-controlled ventilation (PCV) during laparoscopic surgery in morbidly obese patients. Our hypothesis was that during laparoscopy in morbidly obese patients, VCV would generate lower PaO₂ with higher airway pressures and less favorable cardiovascular readings compared to PCV.

In view of these problems, we investigated the effects of VCV and PCV on gas exchange, respiratory mechanics, and cardiovascular responses in morbidly obese patients undergoing laparoscopic gastric banding.

Materials and Methods

After the Institutional Review Board approval and written informed consent, 24 ASA I–II adult patients, scheduled for laparoscopic gastric banding were studied. Inclusion criteria were BMI > 35 kg m⁻². Patients with cardiopulmonary or hepato-renal disease were excluded. Ideal body weight (IBW) was defined as body length in cm—100 for men—and body length in cm—105 for women.

All patients were premedicated with 1 mg midazolam IV 10 min before arrival in the operating room. Upon arrival in the operating room, monitoring consisted of five-lead ECG, noninvasive blood pressure, pulse-oximetry, bispectral EEG (BIS), capnometry, and spirometry using the Datex S5 monitor (Datex-Ohmeda, Helsinki, Finland). An arterial cannula was inserted in the radial artery under local anesthesia and a blood gas sample was drawn with the patient breathing room air. After 5 min of facemask preoxygenation in supine position, anesthesia was induced with a target-controlled infusion (TCI) of remifentanyl [9] set at an initial plasma concentration of 4 ng ml⁻¹, and a bolus of propofol 2 mg kg⁻¹ IBW. One minute after a 0.9-mg kg⁻¹ IBW bolus of rocuronium, a direct laryngoscopy was performed and the trachea was intubated with a cuffed endotracheal tube. Endotracheal intubation was confirmed by capnography and auscultation. Mechanical ventilation was with the Datex ADU ventilator (GE Healthcare, Helsinki, Finland). Anesthesia was maintained with sevoflurane in 50% oxygen/air, adjusted to keep BIS values

between 45 and 55 and remifentanyl TCI adjusted to maintain adequate analgesia. Throughout the study period, neuromuscular block was assured with administration of rocuronium as evidenced by lack of train of four response to neuromuscular stimulation.

Baseline ventilation of the lungs in all patients (baseline control group) was with volume-controlled ventilation (VCV) with constant flow and a tidal volume of 10 ml kg⁻¹ IBW. The initial respiratory rate of 12 breaths per minute was adjusted during laparoscopy to maintain an end-tidal carbon dioxide of 35–40 mmHg. An inspiratory/expiratory ratio of 1:2 was used with an end-inspiratory pause of 10% of the inspiration time, and a positive end-expiratory pressure of 5 cmH₂O. Patients were put in a semirecumbent position. A second blood gas was sampled and peritoneal insufflation was initiated. In all patients, carbon dioxide pneumoperitoneum was induced with an initial intra abdominal pressure (IAP) of 20 mmHg. After a few minutes, IAP was reduced to approximately 15–17 mmHg according to institutional surgical standards for laparoscopic obesity surgery.

Fifteen minutes after peritoneal insufflation, the patients were randomly allocated to one of two groups. In group VCV (*n*=12) ventilation mode was maintained, whereas in group PCV (*n*=12) ventilation mode was switched to pressure-controlled ventilation. Pressure was initiated to provide a tidal volume of 10 ml kg⁻¹ IBW with an upper pressure limit of 35 cmH₂O and was adjusted to maintain a constant minute volume targeting an end-tidal carbon dioxide (CO₂) of 35–40 mmHg. Fifteen minutes after group allocation, a third blood gas analysis was done. In all patients, FIO₂ was maintained at 50%. End-tidal CO₂, peak inspiratory airway pressure (P_{peak}), plateau inspiratory airway pressure where applicable (P_{plateau}), mean airway pressure, compliance, airway resistance and arterial

Table 1 Patient characteristics and arterial blood gases while breathing room air

	Group VCV (<i>n</i> =12)	Group PCV (<i>n</i> =12)	
Age (yrs)	34 (20–54)	40(32–57)	t1.3
Male/female	9/3	8/4	t1.4
Bodyweight (kg)	117.4 (22.3)	111.7 (19.2)	t1.5
Height (m)	1.68 (0.10)	1.70 (0.12)	t1.6
BMI (kg m ⁻²)	41.4 (4.5)	38.6 (3.6)	t1.7
pH room air	7.36 (0.04)	7.35 (0.04)	t1.8
PaO ₂ (mmHg) room air	79.3 (9.6)	81.9 (7.3)	t1.9
PaCO ₂ (mmHg) room air	40.5 (3.2)	40.4 (3.0)	t1.10

Data are median (range), means (SD) or number of patients. BMI=body mass index, PaO₂=partial pressure of oxygen in the arterial blood, PaCO₂=partial pressure of carbon dioxide in the arterial blood, VCV=volume-controlled ventilation, PCV=pressure-controlled ventilation

t2.1 **Table 2** Cardiovascular responses at different time points

t2.2	Time point	T1		T2		T3	
		VCV	PCV	VCV	PCV	VCV	PCV
t2.3	Group (n=12)						
t2.4	Heart rate (bpm)	60(9)	61(10)	71(12)	70(9)	71(16)	71(12)
t2.5	Systolic blood pressure (mmHg)	97(10)	104(9)	124(17) ^a	130(9) ^a	115(13)	120(13) ^a
t2.6	Diastolic blood pressure (mmHg)	57(12)	60(9)	71(14) ^a	80(8) ^a	73(12)	74(9)
t2.7	Mean arterial pressure (mmHg)	70(11)	74(9)	95(15) ^a	97(8) ^a	89(13) ^a	91(12) ^a

t2.8 Data are mean (SD).
T1=baseline after positioning, T2=15 min after insufflation, T3=15 min after group allocation, VCV=volume controlled ventilation, PCV=pressure controlled ventilation
^a*p*<0.05 compared to T1 value within group

oxygen saturation were continuously monitored during the procedure. All parameters were recorded with Rugloop software (RUGLOOP II[®], Demed, Temse, Belgium). The arterial blood samples were analyzed immediately after they were drawn with the GEM blood gas analyzer (GEM Premier 3000, Instrumentation Laboratories, Lexington, MA, USA) and corrected to the patients temperature.

All operations were performed by the same surgical team using the same operating techniques (Swedish Adjustable Gastric Band, Obtech Medical, Baar, Switzerland). All patients were in the reverse Trendlenburg position throughout the operation. At the end of the procedure, the surgeons were probed for quality of anesthesia and for their subjective evaluation of surgical working conditions during pneumoperitoneum.

Given the fact that there are no similar studies in the literature, power analysis was based on the study of Davis and coworkers [10], comparing the difference in arterial oxygen partial pressure when using VCV or PCV in critically ill patients. They found a PaO₂ of 74±11 mmHg in the VCV group versus 89±12 mmHg in the PCV group. Based on these data, statistical difference in arterial oxygen partial pressure between groups could be predicted with a β

error=0.2 and a α error=0.05 when including 10 patients in each group. Twelve patients per group were randomized to compensate for possible dropouts.

Statistical analysis was performed with the GraphPad Instat software package version 3.05 for Windows 95/NT.

First, the assumption that data are sampled from populations with identical standard deviations (SD) was tested using the method of Bartlett. The assumption that the differences are sampled from populations that follow Gaussian distribution was verified using the method of Kolmogorov-Smirnov. Thereafter, differences between and within the groups were analyzed with the One-way Analysis of Variance (ANOVA) with the Tukey–Kramer multiple comparisons posttest.

Values of *p*<0.05 were accepted as statistically significant. Data are presented as mean (SD).

Results

No differences were found in the patient characteristics of the two groups nor in the blood gas values at room air (Table 1). Gender distribution was statistically not different.

t3.1 **Table 3** Lung mechanics

t3.2	Time point	T1		T2		T3	
		VCV	PCV	VCV	PCV	VCV	PCV
t3.3	Group (n=12)						
t3.4	Peak airway pressure (cmH ₂ O)	22.4(2.3)	21.7(1.9)	29.4(3.9) ^a	29.9(3.6) ^a	28.9(4.2) ^a	25.8(1.6)
t3.5	Plateau pressure (cmH ₂ O)	18.9(2.1)	18.4(1.9)	25.8(3.7) ^a	26.1(3.3) ^a	25.1(3.7) ^a	N.A.
t3.6	Mean airway pressure (cmH ₂ O)	10.4(0.7)	10.0(0.5)	12.1(1.1) ^a	12.1(1.0) ^a	12.0(1.2) ^a	11.6(0.6) ^a
t3.7	Compliance (ml cmH ₂ O ⁻¹)	47.3(9.9)	51.4(17.3)	31.0(8.1) ^a	31.0(8.3) ^a	32.0(8.2) ^a	29.8(7.4) ^a
t3.8	Airway resistance(cmH ₂ O L ⁻¹ s ⁻¹)	11.1(1.6)	10.5(1.9)	13.2(4.6)	12.6(2.4)	12.2(2.4)	12.0(3.0)
t3.9	Respiratory rate (breaths min ⁻¹)	11.4(1.3)	11.0(0.8)	11.3(1.4)	11.3(1.4)	11.7(1.2)	11.8(1.8)
t3.10	Expiratory tidal volume (ml)	630(124)	650(165)	622(125)	643(157)	645(138)	612(170)
t3.11	Minute volume (L)	7.8(1.7)	7.6(1.7)	7.5(1.2)	7.4(1.3)	7.7(1.2)	7.7(1.7)

t3.12 Data are mean (SD).
T1=after positioning, T2=15 min after insufflation, T3=15 min after group allocation, VCV=volume controlled ventilation, PCV=pressure controlled ventilation, N.A.=not applicable
^a*p*<0.05 compared to T1 value within group

Table 4 Data on gas exchange

Time point	T1		T3	
Group	VCV (n=12)	PCV (n=12)	VCV (n=12)	PCV (n=12)
pH	7.42(0.06)	7.40(0.04)	7.36(0.03) ^a	7.30(0.03) ^a
SaO ₂ (%)	99.5(0.7)	99.1(1.0)	99.6(0.5)	98.6(1.3)
PaO ₂ (mmHg)	189.4(58.4)	162.9(45.5)	189.9(53.8)	143.4(47.8)
PaCO ₂ (mmHg)	37(6.5)	39.9(5.0)	42.5 (5.2) ^{a,b}	48.9(4.3) ^{a,b}
Et CO ₂ (mmHg)	31.6(4.8)	32.5(3.2)	36.2(3.2)	38.2(2.7) ^a
P(a-Et)CO ₂ (mmHg)	3.6(1.8)	3.6(2.0)	5.2(4.3)	6.4(5.1)

Data are mean (SD).

T1=baseline after positioning, T3=15 min after group allocation, PaO₂=partial pressure of oxygen in the arterial blood, PaCO₂=partial pressure of carbon dioxide in the arterial blood, SaO₂=arterial oxygen saturation, Et CO₂=end-tidal carbon dioxide, P(a-ET)CO₂=arterial to end-tidal carbon dioxide partial pressure difference, VCV=volume controlled ventilation, PCV=pressure controlled ventilation

^ap<0.01 compared to baseline value within group ANOVA

^bp<0.05 compared to value between group ANOVA

In both groups, the pneumoperitoneum caused significant increases in blood pressures but not in heart rate compared to the respective baseline values before peritoneal insufflation (Table 2). However, these changes were not statistically different between the groups.

Pulmonary mechanics are shown in Table 3. The airway pressures generated by insufflation of a tidal volume of 10 ml kg⁻¹ IBW were statistically not different in group VCV compared to group PCV. Airway pressures increased significantly compared to the baseline values in both groups. Compliance decreased in both groups after pneumoperitoneum. Comparison of VCV and PCV modes did not reveal any significant differences in oxygenation (Table 4). The alveolar-to-arterial oxygen partial pressure difference

was 73.9 (53.9) mmHg in VCV versus 81.7 (64.7) mmHg in PCV ($p=0.29$ with ANOVA).

The pH decreased and the arterial partial pressure of carbon dioxide (PaCO₂) increased in both groups after surgical insufflation. As shown in Table 4 and Fig. 1, in group VCV, this increase was lower as compared to group PCV (42.5 (5.2) mmHg versus 48.9 (4.3) mmHg, $p<0.01$ with ANOVA). End-tidal CO₂ values did not differ between groups, but the end-tidal CO₂ 15 min after group allocation was significantly higher compared to the baseline value in the group PCV. The arterial to end-tidal carbon dioxide partial pressure difference (P(a-ET)CO₂) was lower in group VCV compared to PCV without reaching statistical significance.

Fig. 1 Arterial carbon dioxide partial pressure changes in the two groups. T1=baseline after positioning; T3=15 minutes after group allocation

** p<0.01 with ANOVA

* p<0.05 with ANOVA

The surgical team did not remark any difference in operating conditions and could not distinguish any difference between both ventilation modes.

Discussion

This is the first study comparing the effects of VCV and PCV during laparoscopic bariatric surgery. With constant minute ventilation, we observed that VCV generates equal airway pressures and equal hemodynamic effects with a lower PaCO₂ as compared to PCV. Arterial oxygenation remained unchanged.

In the literature, there are no clear guidelines on the use of VCV or PCV in morbidly obese patients. There are only personal preferences guiding the choice between VCV and PCV, or the choice is based on institutional tradition and experience with ventilation in critically ill patients.

The selection of the optimal ventilation mode or the optimal control variable of ventilation for the obese patient is of interest to most of the anesthesiologists. According to Campbell and colleagues [11], VCV and PCV are not different ventilatory modes, but are different control variables within a mode. During VCV, airway pressure increases in response to reduced compliance, increased resistance, or active exhalation and may increase the risk of ventilator-induced lung injury. During PCV, the inspiratory flow and flow waveform are determined by the ventilator as it attempts to maintain an inspiratory pressure profile. The clinician should titrate the inspiratory pressure to the measured tidal volume [11].

Interest in PCV was initially aimed at limiting pressure related lung injury in ARDS patients [12–14]. Most anesthesiologists are still convinced that PCV generates lower airway pressures during laparoscopy and thus is better for the patient. In this study, on obese patients undergoing laparoscopic gastric banding, no differences in respiratory mechanics were found when using VCV with a constant square wave flow and PCV (Tables 2 and 3). The results of our study suggest that the reported advantages in respiratory mechanics of PCV over VCV with a square wave flow do not apply in morbidly obese patients undergoing laparoscopic gastric banding.

In terms of gas exchange, early studies reported improvements in oxygenation with PCV. Many of those studies used different inspiration: expiration ratios with prolonged inspiratory time and often inversed ratio ventilation. The improved oxygenation might have resulted from alveolar recruitment through buildup of intrinsic PEEP. Subsequent studies with control of mean airway pressure, I–E ratio, and total PEEP did not provide evidence of improved oxygenation nor of hemodynamic variables when comparing VCV versus PCV [15–18]. These results on

oxygenation are similar to our findings in obese patients when using VCV with square wave flow.

In this study, we have found that there is more significant carbon dioxide elimination when using VCV. This observation must be because of either differences in minute ventilation, physiological dead space, or CO₂ production. Another explanation could be the higher EtCO₂ value in group PCV found 15 min after group allocation. End-tidal CO₂ may not reflect changes in PaCO₂ during insufflation because of changes in alveolar dead space, consequent to reduced cardiac output, increased ventilation–perfusion mismatching, or both [19]. Not all of these influences were measured; however, minute ventilation is not different, nor is P(a-Et)CO₂, implying that dead space is not different [20]. The conclusion could be that this observation is a little bit of both dead space and “production”.

Is maintenance of normal PaCO₂ necessary in morbidly obese patients? Recent work by Fleischmann and Hager [21, 22] advocates mild hypercapnia to improve subcutaneous and intestinal tissue oxygenation resulting in improved outcome after bariatric surgery in morbidly obese patients. Anastomotic leaks are potentially lethal complications in bariatric surgery and are every surgeon’s nightmare.

At this point, we have to formulate some limitations concerning our study. This study was a pure clinical study. According to institutional structures, monitoring and measurement were limited. For example, a pulmonary artery catheter could not be inserted so we could not measure cardiac output (CO) nor mixed venous oxygen saturation to calculate shunt fraction. The alternative of CO measurement by TEE is made impossible by the type of procedure.

Given the absence of data on the subject, only patients with mild degrees of morbid obesity were studied.

Our results could have been influenced by a time factor. Measurements were done within the first 60 min of the procedure. The effects of VCV and PCV on pulmonary mechanics, hemodynamics, and gas exchange beyond this time point were not studied in this protocol. There were no differences in operating and anesthesia time between both groups.

Although somewhat unlikely, this study protocol leaves the possibility that the observed CO₂ difference occurred after peritoneal insufflation with subcutaneous leakage. However, peritoneal insufflation parameters were the same in both groups and none of the patients had manifest subcutaneous emphysema.

For obvious reasons, gastric banding procedures are only performed in the obese, thus patients served as their own control.

In conclusion, VCV or PCV is probably just a fragment of the respiratory puzzle in morbidly obese patients. A multimodal approach of ventilatory care in obese patients

345 seems to be more appropriate: preoperative use of incentive
 346 spirometry, prevention of aspiration, correct preoxygenation
 347 techniques with continuous positive airway pressure, use of
 348 optimal FIO₂ during maintenance and emergence, the use
 349 of PEEP and alveolar recruitment maneuvers.

350 Regarding oxygenation, respiratory mechanics, and
 351 cardiovascular responses, both VCV and PCV appear to
 352 be equally suited in morbidly obese patients undergoing
 353 laparoscopic gastric banding. Further studies are required to
 354 explore the effects of VCV and PCV on gas exchange,
 355 ventilatory mechanics, and carbon dioxide elimination in
 356 the extreme obese patients (BMI>50 kg m⁻²) undergoing
 357 laparoscopic bariatric procedures of longer duration.

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