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The Influences of three Intraoperative Ventilatory Strategies on Arterial Oxygenation in Morbid Obese Patients Undergoing Laparoscopic Bariatric Surgery

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Background: Maintaining satisfactory ventilation for obese patients undergoing bariatric surgery frequently poses a challenge for anesthetists. The optimal ventilation strategy during pneumoperitoneum remains obscure in obese patients. In this study, we investigated the effect of conventional ventilation, inverse ratio ventilation (IRV) and alveolar recruitment maneuver (RM) on arterial oxygenation, lung mechanics and hemodynamics in morbid obese patients undergoing laparoscopic bariatric surgery.

Methods: 105 adult obese patients scheduled for elective laparoscopic bariatric surgery were randomly allocated into three groups: Conventional ratio ventilation (I:E ratio was 1:2, PEEP 5 cmH_2O and no RM), Inverse Ratio Group (IRVG) (I:E ratio was 2:1 and PEEP 5 cmH_2O and No RM) and Recruitment Maneuver Group (RMG) (RM was done and I:E ratio was 1:2). Arterial blood gases and respiratory mechanics were recorded after induction of anesthesia (T1), 5 minutes (T2), 30 minutes (T3), 60 minutes (T4) after the beginning of pneumoperitoneum and at the end of the surgery (T5). Cardiac output was recorded at (T1), (T2), (T3) and (T5).

Results: At T3, T4 and T5, arterial oxygen tension was higher in RMG than IRVG than CG (P <

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0.05). At T3, T4 and T5, the mean airway pressure and dynamic compliance (Cdyn) were significantly higher in IRVG and RMG compared with CG ($P < 0.05$) while at those times, the mean air way pressure and Cdyn in IRVG and RMG were comparable. Cardiac output result were comparable between all groups throughout the study period ($P > 0.05$).

Conclusions: RM and IRV had provided better arterial oxygenation and respiratory mechanics compared to conventional ventilation in morbid obese patients undergoing laparoscopic bariatric surgery. However, RM had better gas exchange than IRV.

Keywords: Laparoscopy; Bariatric surgery; ventilation.

1. INTRODUCTION

Since its beginning in the 1960s, bariatric surgery has gained growing popularity. For anesthetists, maintaining satisfactory ventilation for patients undergoing bariatric surgery frequently poses a challenge. Characteristic physiological abnormalities such as higher metabolic demand for oxygen, diminished pulmonary compliance, and altered ventilation-perfusion ratio may render ineffective commonly used ventilation methods as increasing fraction of inspired oxygen (FiO_2) and adjusting tidal volume [1, 2].

Laparoscopic surgery is commonly performed by intraabdominal insufflation of carbon dioxide (CO_2); this insufflation contributes to an increase in intraabdominal pressure. The increase in intraabdominal pressure can prompt shift of the diaphragm cranially and compression of basal lung regions. Consequently, the increase in intraabdominal pressure could emphasize the effects of atelectasis already predisposed to by general anesthesia, and therefore laparoscopic surgeries are associated with a frequent incidence of lung atelectasis [3].

Different strategies have been established to decrease atelectasis such as induction of anesthesia in the head-up position without [4] or with a continuous positive airway pressure (CPAP) [5] and use of intraoperative positive end-expiratory pressure (PEEP) [5, 6]. The alveolar recruitment maneuver (RM) appears to be an effective technique to reverse atelectasis [6] In morbid obese patients undergoing laparoscopic surgery, recruitment of lung volume during surgery enhances intraoperative respiratory mechanics and oxygenation [7, 8].

Prolonged inspiratory to expiratory (I:E) ratio ventilation, for example 1:1 or 2:1, was used to enhance arterial oxygenation in patients with lung injury [9]. Prolonged I:E ratio ventilation during laparoscopic surgery also informed favorable results in terms of oxygenation and respiratory mechanics [10]. Prolonged I:E ratio ventilation is reported to increase arterial oxygenation in morbid obese patients undergoing bariatric surgery [11].

In this study, we investigated the effect of conventional ventilation, inverse ratio ventilation (IRV) and alveolar RM on arterial oxygenation, lung mechanics and hemodynamics in morbid obese patients undergoing laparoscopic bariatric surgery.

2. METHODS

This prospective randomized study was carried out in Tanta University Hospitals, in General Surgery Department from July 2017 to July 2019 on patients scheduled for elective laparoscopic bariatric surgery. A written informed consent was obtained from all patients. Procedures were approved by the Institutional ethical committee with approval code: 31557/ 05/ 17.

Every patient received an explanation of the purpose of the study and had a secret code number to ensure privacy of participants and confidentiality of data. Any unexpected risks were encountered during the course of the research were cleared to the participants as well as the Ethical Committee. Research results were only used for scientific purposes.

The study included one hundred and five patients who had the following criteria; American society of anesthesiology (ASA) classification II or III, aged between 20 and 40 years old, BMI more than 35 Kg/m^2 and scheduled elective laparoscopic bariatric surgery.

Exclusion criteria included; Congestive heart failure, valvular or ischemic heart diseases, uncontrolled respiratory morbidity such as sever bronchial asthma or COPD, renal or endocrine disorders, patients with hepatic dysfunction, patients with history of cerebrovascular disease or uncontrolled DM.

2.1 Randomization

Patients were randomized through a computer-generated randomization numbers into three groups by using sealed opaque envelope and each patient chose the envelope which determined his group.

105 patients were randomly assigned to group I (control group: 35 patients), group II (Inverse Ratio Group (IRVG): 35 patients) or group III (Recruitment Maneuver Group (RMG): 35 patients).

2.2 Intervention

Evaluation of patients were carried out through proper history taking, clinical examination and laboratory investigation included complete blood count, prothrombin time, liver function tests, renal function tests, blood glucose level, arterial blood gases, pulmonary function tests, chest radiography, electrocardiogram and echocardiography.

A 20 gauge peripheral cannula was inserted. All patients received IV pantoprazole (40 mg) and IV ondansterone (4mg) before induction of anesthesia. All patients were wearing elastic stocking before induction of anesthesia.

Heart rate (HR), mean arterial blood pressure (MAP), SPO_2 and end tidal CO_2 ($ETCO_2$) were monitored. Trans-esophageal echocardiography (TEE) probe and temperature probe were inserted after induction of anesthesia in all patients.

Adequate pre-oxygenation for 2-3 minutes was performed for all patients by spontaneous breathing of oxygen through the face mask. Induction was done by IV fentanyl 2µg/kg according to ideal body weight and propofol 2-mg/kg according to lean body weight (LBW). Cis-atracurium 0.15 mg/kg according to LBW was given after loss of consciousness. Then endotracheal tube was inserted.

The patient's lungs were ventilated with volume-controlled ventilation and initial ventilatory parameters were set as: tidal volume 6 mL/kg (IBW), respiratory rate 12 breaths/min, PEEP of 5 cmH_2O, and I:E ratio of 1:2 in the three groups. $ETCO_2$ was kept between 30-40 mmHg by changing the respiratory rate. The development of the intrinsic PEEP was identified by monitoring the time flow curve when the following inspiration begins before the expiration flow is zero.

After induction of anesthesia, arterial cannula was inserted for serial arterial blood samples which were needed for arterial blood gases analysis then TEE probe was inserted. Patients were randomly assigned to:

Group I: Control Group (CG)

This group received conventional ventilation (I:E= 1:2) and PEEP 5 cmH_2O and no RM was performed either before or after the pneumoperitoneum.

Group II: Inverse Ratio Group (IRVG)

Before creation of the pneumoperitoneum, the ventilatory setting was the same as group I. After pneumoperitoneum, the I:E ratio was adjusted to 2:1 and PEEP 5 cmH_2O. No RM was performed.

Group III: Recruitment Maneuver Group (RMG)

Before creation of the pneumoperitoneum, the ventilatory setting was the same as group I. Immediately after pneumoperitoneum, RM was performed as following: PEEP was increased from 5 to 10 cmH_2O for 10 breaths, then PEEP 15 cmH_2O for 10 breaths, then PEEP 20 cmH_2O for 10 breaths and then return to PEEP 10 cmH_2O till the end of the surgery with I:E ratio 1:2. If peak airway pressure (Ppeak) at any point during the RM exceeded 45 cmH_2O, the RM was stopped and the patient was excluded from the study.

Arterial oxygen tension (PaO_2) (mmHg) , arterial carbon dioxide tension ($PaCO_2$) (mmHg) and PF ratio, Ppeak (cm H_2O), plateau pressure (Pplat) (cm H_2O), mean airway pressure (cm H_2O), intrinsic PEEP (cm H_2O), and dynamic compliance of the respiratory system (Cdyn) (ml/cm H_2O) were recorded after induction of anesthesia (T1), 5 minutes after the beginning of pneumoperitonium (T2) which was coincide with the end of RM in the recruitment group, 30 minutes after pneumoperitonium (T3), 60 minutes after pneumoperitoneum (T4) and at the end of the surgery (T5).

Cardiac output (CO) and wall motion abnormality by TEE were recorded at (T1), (T2), (T3) and (T5).

Heamodynamic parameters including HR and MAP were recorded before induction of general anesthesia, after induction of general anesthesia, 5 minutes after beginning of pneumoperitoneum then every 30 minutes till the end of the surgery.

CO_2 pneumoperitoneum tension was set at 15 mmHg. After CO_2 insufflation, patient was positioned in a 30° reverse Trendelenburg position.

If O_2 Saturation decreased below 92%, FiO_2 was increased and if patient was still hypoxic, conventional ventilatory parameter was resumed and the patient was excluded from the study. Intra-operative hypotension is defined as systolic blood pressure decreases more than 25% of the base line and was treated with a bolus of normal saline 0.9 % (250 mL) and incremental doses IV ephedrine (5 mg).

Paracetamol 1 g IV infusion was given about 20 minutes before the end of the surgery and then 1 g/6h was given for postoperative analgesia for 48 hours.

At the end of surgery, muscle relaxant was reversed according to the neuromuscular monitoring by neostigmine (50 µg/kg) and atropine sulfate (0.015 mg/kg). Awake extubation was done in a semisitting position after reaching satisfactory criteria for extubation including return of airway reflex, breathing of adequate tidal volume (>5 mL/kg), full reversal of the muscle relaxant and the patient is fully awake and hemdynamically stable.

Patients were shifted to PACU and were placed in upright position about 40^o and oxygen was given via a non-rebreathing facemask. Morphine (3 mg) IV was given as rescue analgesia. Patients received paracetamol 1 gm/6 hours and ketorolac 30 mg/6 hours regularly as postoperative analgesia. The patient was admitted to the ICU if there was hemodynamic instability or post-operative hypoxia (O_2 saturation below 92 % on room air).

2.3 Outcomes

The primary outcome was the influence of the three ventilatory strategies on arterial oxygenation, while the secondary outcomes were the lung mechanics, hemodynamic changes, cardiac output changes, wall motion abnormalities and intra and postoperative complications.

2.4 Statistical Analysis

SPSS Version 24 (IBM Corporation, Armonk, NY) was used for data processing and statistical analysis. The sample size calculation estimated at N>32 in each group so we enrolled 35 patients per group, based on the following criteria:

95% confidence limit, 80% power of study, ratio of Group 1 to Group 2 to Group 3 is 1:1:1, The expected change in primary outcome: represented by arterial oxygen tension (PaO_2) among the three groups which is based on previous studies [8, 10].

The statistical analysis was performed using the statistical software SPSS 16 (SPSS Inc., Chicago, IL). The Kolmogorov-Smirnov test and the visualization of the histogram were utilized to verify the assumption of normality. The quantitative parameters with normal distribution were expressed as mean ± SD and analyzed utilizing one-way analysis of variance with post hoc Turkey's honestly significant difference test. The parameters that did not follow the normal distribution were expressed as median with interquartile range and analyzed among the studied groups using the Kruskal-Walls test followed by Dunn's multiple comparisons test for post hoc analysis. Categorical data were presented as patients' number or frequencies (%) and were analyzed utilizing the $\chi 2$ test. P-value <0.05 was considered significant and the nature of the hypothesis testing was 2-sided.

3. RESULTS

One hundred and thirteen patients were evaluated for enrollment in the study. Five patients didn't meet the inclusion criteria and three patient refused to participate in the study. The remaining one hundred and five were equally and randomly allocated in three groups (35 patient each). Data of all patients were successfully collected Fig. 1.

Demographic data including age, gender and BMI were comparable among the three groups (p value = 0.107, 0.738, and 0.587 respectively) Table 1.

There was no statistically significant difference in the mean values of PaO_2 and PF ratio among the three groups at T1 and T2 ($p > 0.05$). At T3, T4 and T5, the mean values of PaO_2 and PF ratio in IRVG and RMG were significantly higher than CG ($p < 0.05$). The comparison between IRVG and RMG showed that PaO_2 and PF ratio were higher in RMG ($P < 0.05$) Table 2.

At T1, the mean values of Ppeak were insignificantly different among the three groups ($p > 0.05$). At T2, T3, T4 and T5, they were significantly lower in IRVG compared with CG and RMG ($p < 0.05$). At the same times, mean values of Ppeak were significantly higher in RMG than group CG ($P < 0.05$) Table 3.

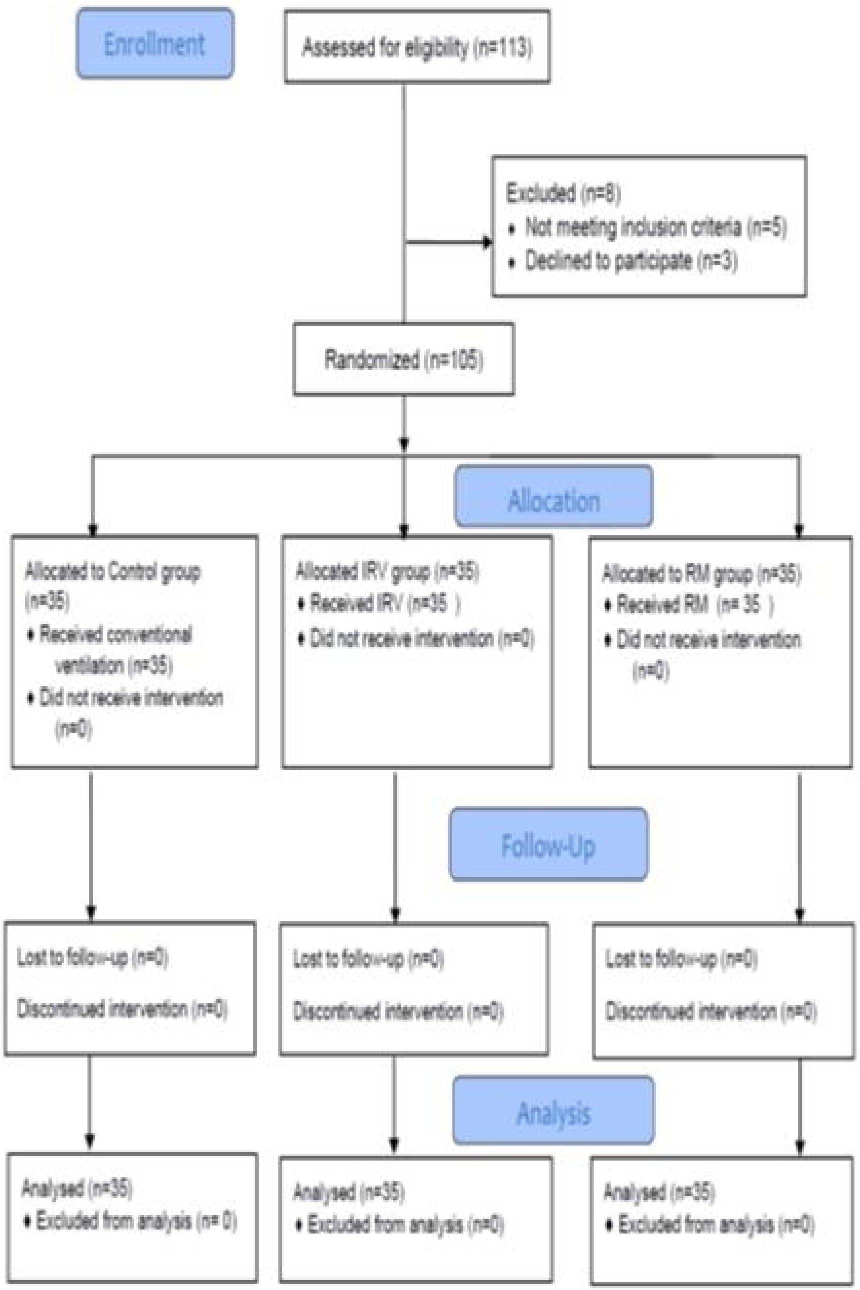

Fig. 1. CONSORT flow diagram of the participants through each stage of the randomized trial

There was no statistically significant difference in the mean values of mean airway pressure among the three groups at T1 and T2 ($p > 0.05$). At T3, T4 and T5, the mean values of mean airway pressure were significantly higher in IRVG and RMG compared with CG ($P < 0.05$). At the same times, the mean values of mean air way pressure in IRVG and RMG were comparable ($p > 0.05$) Table 3.

The mean values of Pplat were not significantly different among the three groups at T1 and T2 (p value > 0.05). At T3 and T4, Pplat was significantly lower in IRVG compared with CG and RMG. At the same times, Pplat was significantly higher in RMG than CG ($P < 0.05$). At T5, Pplat was higher in RMG than CG and IRVG (p value < 0.05) without significant difference between CG and IRVG ($P > 0.05$) Table 3.

At T1 and T2, the mean values of Cdyn were comparable among the three groups (p value > 0.05). At T3, T4 and T5, mean values of Cdyn was significantly higher in IRVG and RMG compared with the CG (p value < 0.05) while at those times there was no statistically significant difference between IRVG and RMG in the mean values of Cdyn. ($P > 0.05$) Table 3.

Table 1. Demographic data

		CG	IRVG	RMG	Test of sig.	P
Age	**Range**	26-38	25-37	29-39	F=2.287	0.107
	Mean ±SD	32.17 ± 5.38	31.10 ± 6.10	33.9 ± 5.05		
BMI	**Range**	40-51	40-50	41-49	F=0.535	0.587
	Mean ±SD	45.57 ± 5.32	44.73 ± 4.55	44.87 ± 4.07		
Gender M/F		10/25	11/24	13/22	χ^2=0.609	0.738

Data was expressed as Mean ± SD or patient numbers. BMI; body mass index.
χ^2: Chi square test, F: F for ANOVA test
p: p value for comparing between the three studied groups.

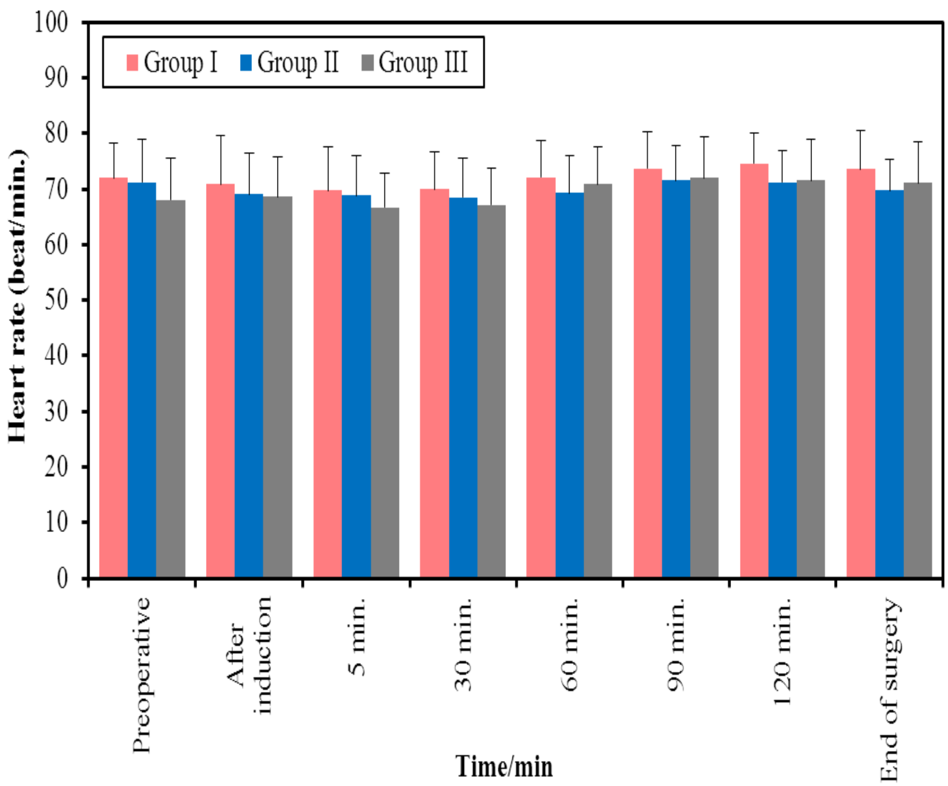

Fig. 2. Comparison of heart rate changes in studied groups (b/ min)

Table 2. Arterial blood gases in the three studied groups

		CG	IRVG	RMG	F	P	Post Hoc Test (Tukey)		
							P1	**P2**	**P3**
PaO_2 (mmHg)	**T1**	195.97±10.30	195.40±9.64	191.60±7.05	2.384	0.097			
	T2	199.71±7.31	203.63±8.51	202.11±6.59	2.415	0.094			
	T3	183.97±10.72	219.29±6.27	225.37±7.77	244.557*	<0.001*	<0.001*	<0.001*	0.009*
	T4	181.71±11.17	221.09±6.90	226.54±8.91	249.486*	<0.001*	<0.001*	<0.001*	0.038*
	T5	184.40±10.45	220.97±9.29	229.0±8.13	226.724*	<0.001*	<0.001*	<0.001*	0.001*
PF ratio	**T1**	391.94±20.59	390.80±19.2	383.20±14.1	2.384	0.097			
	T2	399.43±14.62	407.26±17.0	404.23±13.1	2.415	0.094			
	T3	367.94±21.44	438.57±12.5	450.74±15.5	244.557*	<0.001*	<0.001*	<0.001*	0.009*
	T4	363.43±22.34	442.17±13.8	453.09±17.8	249.486*	<0.001*	<0.001*	<0.001*	0.038*
	T5	368.80±20.91	441.94±18.5	458.0±16.2	226.724*	<0.001*	<0.001*	<0.001*	0.001*
$PaCO_2$ (mmHg)	**T1**	37.74±1.80	37.94±1.76	38.23±1.75	0.663	0.517			
	T2	41.54±1.04	42.26±1.87	42.06±1.28	2.295	0.106			
	T3	42.26±1.24	42.91±1.50	42.94±1.80	2.245	0.111			
	T4	42.37±1.11	43.20±2.01	42.57±1.82	2.283	0.107			
	T5	39.60±1.73	40.17±1.01	40.46±1.42	2.698	0.072			

Data was expressed as Mean ± SD.
F: F for ANOVA test, Pairwise comparison bet. each 2 groups was done using Post Hoc Test (Tukey)
p: p value for comparing between the three studied groups.
p_1: p value for comparing between group I and group II.
p_2: p value for comparing between group I and group III.
p_3: p value for comparing between group II and group III
**: Statistically significant at $p \leq 0.05$*
PaO2; partial pressure of arterial oxygen, , PaCO2; arterial partial pressure of carbon dioxide, T1; after induction of anesthesia ,T2; 5 minutes,T3; 30 minutes, T4; 60 minutes after the beginning of pneumoperitoneum and T5; at the end of the surgery.

Table 3. Respiratory mechanics changes in both groups

		CG	IRVG	RMG	F	P	Post Hoc Test (Tukey)		
							P1	P2	P3
Ppeak (cmH2O)	**T1**	18.80 ± 2.15	19.29 ± 1.95	19.31 ± 1.92	0.723	0.488	0.572	0.535	0.998
	T2	22.97 ± 2.02	21.54 ± 1.82	28.60 ± 1.94	130.763*	<0.001*	0.007*	<0.001*	<0.001*
	T3	23.37 ± 1.59	21.94 ± 1.43	26.09 ± 2.03	53.268*	<0.001*	0.002*	<0.001*	<0.001*
	T4	23.29 ± 1.95	21.66 ± 1.70	26.09 ± 1.87	51.804*	<0.001*	0.001*	<0.001*	<0.001*
	T5	19.17 ± 1.71	18.66 ± 1.47	24.34 ± 1.89	119.781*	<0.001*	0.418	<0.001*	<0.001*
Pmean (cmH2O)	**T1**	10.77 ± 2.20	11.37 ± 2.30	11.23 ± 2.30	0.669	0.515	0.512	0.677	0.962
	T2	12.40 ± 2.32	13.09 ± 1.99	19.49 ± 1.56	136.35*	<0.001*	0.320	<0.001*	<0.001*
	T3	15.0 ± 2.06	15.14 ± 1.48	17.40 ± 1.70	20.433*	<0.001*	0.939	<0.001*	<0.001*
	T4	15.14 ± 2.0	15.26 ± 1.12	18.06 ± 1.80	33.670*	<0.001*	0.957	<0.001*	<0.001*
	T5	12.40 ± 2.09	12.14 ± 1.99	16.03 ± 1.81	42.822*	<0.001*	0.848	<0.001*	<0.001*
Pplat (cmH2O)	**T1**	14.0 ± 2.13	14.34 ± 1.91	14.66 ± 1.92	0.955	0.388	0.752	0.354	0.787
	T2	17.71 ± 1.87	16.60 ± 1.80	23.74 ± 1.82	154.05*	<0.001*	0.033*	<0.001*	<0.001*
	T3	18.43 ± 1.61	17.20 ± 1.43	21.49 ± 2.08	57.025*	<0.001*	0.010*	<0.001*	<0.001*
	T4	18.17 ± 1.87	16.80 ± 1.66	21.29 ± 1.90	56.185*	<0.001*	0.006*	<0.001*	<0.001*
	T5	14.20 ± 1.69	14.20 ± 1.45	19.26 ± 1.84	107.21*	<0.001*	1.000	<0.001*	<0.001*
Cdyn (ml/ cmH2O)	**T1**	34.83 ± 3.28	32.06 ± 2.59	32.29 ± 2.84	9.733*	<0.001*	<0.001*	0.001*	0.943
	T2	30.14 ± 2.93	33.14 ± 2.56	34.66 ± 3.22	21.749*	<0.001*	<0.001*	<0.001*	0.081
	T3	26.54 ± 2.48	35.37 ± 2.21	39.57 ± 3.68	188.97*	<0.001*	<0.001*	<0.001*	<0.001*
	T4	26.29 ± 2.41	34.91 ± 2.28	38.26 ± 3.15	191.71*	<0.001*	<0.001*	<0.001*	<0.001*
	T5	31.43 ± 3.34	37.37 ± 2.22	42.89 ± 3.94	109.11*	<0.001*	<0.001*	<0.001*	<0.001*

Data was expressed as Mean ± SD.

P: p value for comparing between the three studied groups. P_1: p value for comparing between group I and group II. P_2: p value for comparing between group I and group III. P_3: p value for comparing between group II and group III

**: Statistically significant at $p \le 0.05$*

Ppeak; peak inspiratory pressure, Pmean; mean airway pressure, Pplat; plateau pressure, Cdyn; dynamic compliance,, T1; after induction of anesthesia ,T2; 5 minutes,T3; 30 minutes, T4; 60 minutes after the beginning of pneumoperitoneum and T5; at the end of the surgery.

Table 4. Comparison between the three studied groups according to intrinsic PEEP

	CG	IRVG	RMG	H	P	Post Hoc Test (Dunn's)		
						p_1	p_2	p_3
T1	0 (0 – 0)	0 (0 – 0)	0 (0– 0)	0.0	1.000	–	–	–
T2	0 (0 – 0)	0 (0 – 0)	0(0 – 3)	2.0	0.368	–	–	–
T3	0 (0 – 0)	0 (0 – 4)	0(0 – 0)	4.038	0.133	–	–	–
T4	0(0 – 0)	0 (0 – 4)	0 (0 – 0)	8.234*	0.016*	0.013*	1.000	0.013*
T5	0(0 – 0)	0 (0 – 3)	0 (0 – 0)	2.0	0.368	–	–	–

*Data was expressed by using **Median (Min. – Max.)***
***H: H for Kruskal Wallis test**, Pairwise comparison bet. each 2 groups was done using Post Hoc Test (Dunn's for multiple comparisons test)*
p: p value for comparing between the three studied groups
*p_1: p value for comparing between **group I** and **group II***
*p_2: p value for comparing between **group I** and **group III***
*p_3: p value for comparing between **group II** and **group III***
**: Statistically significant at $p \leq 0.05$*
PaO2; partial pressure of arterial oxygen, , PaCO2; arterial partial pressure of carbon dioxide, T1; after induction of anesthesia ,T2; 5 minutes,T3; 30 minutes, T4; 60 minutes after the beginning of pneumoperitoneum and T5; at the end of the surgery.

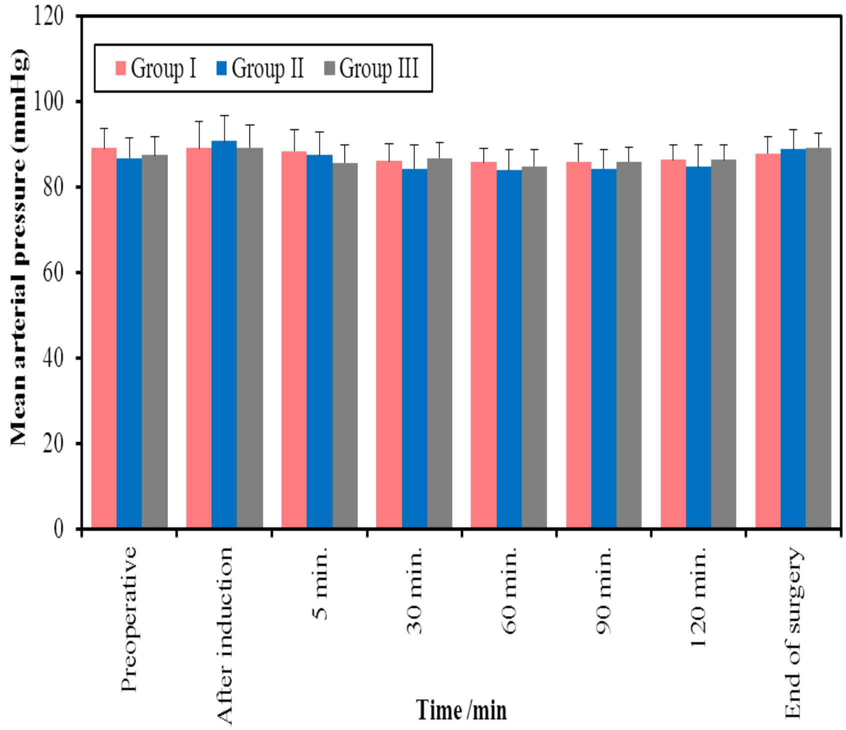

Fig. 3. Comparison of mean arterial pressure changes in studied groups (mmHg)

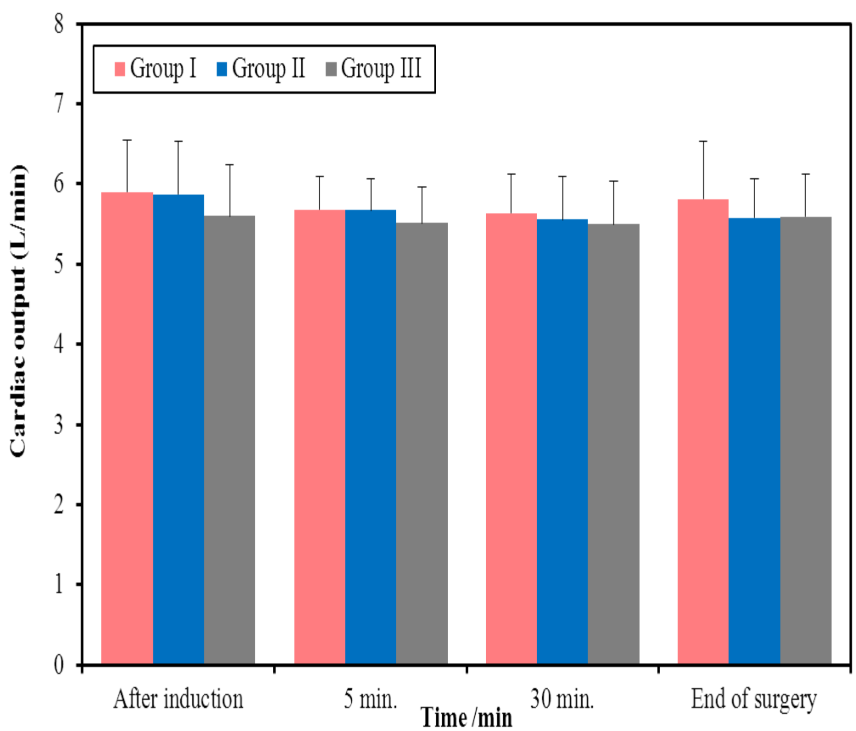

Fig. 4. Comparison of Cardiac output changes in studied groups (L/min)

There was no statistically significant difference in median values of intrinsic PEEP among the three groups at T1 and T2 (p value > 0.05). At T3, T4 and T5, median values of intrinsic PEEP were significantly higher in IRVG compared with CG and RMG (p value < 0.05) while at the same times, there was no significant difference between CG and RMG (p value > 0.05) Table 4.

There was no statistically significant differences in the measured hemodynamic variables (HR, MAP and CO) among the three groups (p > 0.05). There was no evidence of wall motion abnormality in all patients included in the study. Figs. 2,3, 4.

No intraoperative hypoxia nor hypotension was reported in the three studied groups. As regard postoperative hypoxia, there was only one case of postoperative hypoxia in the control group.

4. DISCUSSION

The results of our study showed that RM and IRV resulted in increasing PaO_2, Pmean and Cdyn without significant difference in the measured hemodynamic parameters as compared to the conventional ventilation. RM had higher PaO_2 compared to IRV. Ppeak and Pplatue were significantly higher in RMG than CG than IRVG.

Several ventilatory strategies have been proposed to improve gas exchange and outcome in obese patient [12]. The RM "a strategy of reopening atelectatic lung areas present during anesthesia" is recommended to reverse anesthesia induced atelectasis in the healthy lungs [13]. To prevent atelectasis from recurring after RM, a strategy consisting of RM followed by PEEP has been suggested in anesthetized patients. [14].

Our result showed that RMG had better arterial oxygenation than IRVG than CG., our results were in agreement with Whalen et al. [8] who compared the effects of RM and conventional ventilation on arterial oxygenation and respiratory mechanics in morbidly obese patients undergoing laparoscopic bariatric surgeries. They revealed that RM effectively improved the arterial oxygenation and increased intraoperative PaO_2 and PF ratio compared to the conventional ventilation.

Also, Chalhoub et al. [15] evaluated the effect of RM followed by PEEP on arterial oxygenation in morbidly obese patients undergoing bariatric surgeries. They reported that RM has a significantly higher PaO_2 than control group and improved the intraoperative arterial oxygenation. Moreover, Wei et al. [16] assessed the effects of repeated RM with or without additional PEEP on the arterial oxygenation of morbid obese patients who were undergoing laparoscopic sleeve gastrectomy. They revealed that the two RM groups had better arterial oxygenation with significantly higher PaO_2 and PF ratio compared to control group.

Many studies, in accordance with our results, demonstrated the benficial effects of RM on arterial oxygenation [6,7,17-22].

It has been cleared that reduction in lung compliance and formation of atelectasis after induction of general anesthesia are significant causes of regional ventilation and gas exchange abnormalities [23]. Also, it has been proven that RM opens the atelectatic alveoli, thus increasing end expiratory lung volume, improving gas exchange, improving the oxygenation and attenuating VILI. This benefit may result from two mechanisms: The first is the increase in the aerated lung mass, which contributes to minimize the lung heterogeneity. The second is the prevention of the repeated opening and closure of the terminal respiratory units [24, 25].

Concerning the effects of IRV on the arterial oxygenation, our results were in accordance with, Kim et al. [10] investigated the effect of prolonged inspiratory time on gas exchange and respiratory mechanics in patients undergoing laparoscopic surgeries. They revealed that PaO_2 and PF ratio were significantly higher in IRV group and equal ratio ventilation group in compared to conventional ratio ventilation group.

Moreover, Zhang et al. [26] compared the effects of conventional ratio ventilation and IRV on the arterial oxygenation, cardiopulmonary function and inflammatory cytokine of bronchoalveolar lavage in morbid obese patients undergoing gynecological laparoscopy, and postulated that IRV improves the arterial oxygenation, PaO_2 and PF ratio, in obese patients without adverse respiratory and hemodynamic effects.

Many other studies observed that prolonged inspiratory time has been verified to improve the arterial oxygenation and enhance respiratory mechanics in variant types of surgeries without deleterious hemodynamic effects [11, 27-30].

It is well-known that atelectasis formation following induction of anesthesia, during surgery and also postoperatively may promote perioperative and postoperative hypoxemia and also postoperative pneumonia [31, 32]. It is established that IRV improves arterial oxygenation through increasing mean airway pressure, maintaining alveoli in an inflated state, reducing intrapulmonary shunt, improving VQ mismatch and decreasing dead space ventilation [27].

In contrast with our results , Kim et al. [33] postulated that the changes in PaO_2 did not differ between equal ratio ventilation group and conventional ratio ventilation group. The disparity in the results may be attributed to different type of surgery and different I / E ratio.

Our results showed that RM and IRV resulted in increasing Pmean and Cdyn as compared to the conventional ventilation. Ppeak and Pplatue were significantly higher in RMG than CG than IRVG.

Our results were in agreement with Sprung et al. [34] investigated alveolar RM and arterial desflurane concentration in obese patients undergoing bariatric surgeries. They conducted that RM had significantly higher Cdyn and mean airway pressure than the control group.

Also, Tafer et al. [35] evaluated the effects of RM on respiratory mechanics in patients subjected to laparoscopic bariatric surgery. They noted that RM group had significantly higher lung compliance than control group.

Furthermore, Bluth et al. [36] studied the effect of intraoperative high PEEP With RM and low PEEP with conventional ventilation on postoperative pulmonary complications in obese patients in a large multicentre randomized clinical trial. They showed that RM group had significantly higher Ppeak and Pplat than the low PEEP group with hemodynamic stability.

Moreover, kudoh et al. [20] evaluated the effects of RM with PEEP on lung compliance in robot-assisted laparoscopic radical prostatectomy. They reported that RM group significantly increased lung compliance compared to control group.

A pneumoperitoneum with CO2 insufflation can affect the cardiopulmonary system in several ways. Lung volumes decrease and CO_2 absorption increases [37]. Pneumoperitonium also decreases FRC and lung compliance [38]. The decrease in respiratory system compliance and lung volumes are significantly reverted by the application of RM with PEEP [39].

On contrary to our results, Aretha et al. [40] investigated the effectiveness of RM and PEEP during general anesthesia for cesarean section. They declared that Ppeak was significantly lower in the RM group compared to the control group. Differences in type of surgery and physiological changes in pregnant obese patients may contribute to the discrepancy between their results and ours.

Regarding the effects of IRV on the respiratory mechanics, our results were similar to that of Zhang et al. [26] stated that IRV group had significantly higher Cdyn of respiratory system and mean airway pressure and significantly lower Ppeak and Pplat in compared to conventional ratio ventilation group.

Moreover, Jo et al. [30] demonstrated that I/E ratios of 1:1 and 2:1 had significantly higher mean airway pressure and Cdyn and significantly lower Ppeak than conventional I/E ratio ventilation without deleterious hemodynamic effects.

Furthermore, Yang et al. [41] observed that IRV group had significantly higher Cdyn and mean airway pressure and lower Ppeak than conventional ratio ventilation group.

Obese patients are susceptible to high Ppeak due to the reduction of lung compliance and functional residual capacity [42]. Ppeak increases and lung compliance decreases during pneumoperitonium in the obese patients undergoing laparoscopic surgeries. On the one hand, CO_2 insufflation elevated the abdominal pressure, pushed the diaphragm into the thorax, raised pleural pressure and compressed lung, which would result in the reduction in lung compliance and diminution of lung volumes [43]. The lower peak airway pressure in the IRV group was possibly due to slowing inspiratory flow and prolonging inspiratory time of IRV. Higher mean airway pressure might be achieved by prolongation of I:E ratio [44].

As regard intrinsic PEEP, and in consistence with our result, Fuiter et al. [7] studied the impact of intraoperative RM on respiratory mechanics and arterial oxygenation in 30 healthy weight and 30 obese patients undergoing laparoscopic surgery. They concluded that, there was no intrinsic PEEP detected during or after RM in healthy weight or obese patients.

Also, Kim et al. [10] investigated the effect of prolonged inspiratory time on gas exchange and respiratory mechanics in patients undergoing laparoscopic surgeries, and postulated that intrinsic PEEP only increased in IRV group and was significantly higher than conventional ratio ventilation and equal ratio ventilation.

The significant increase of intrinsic PEEP in IRV group in our results could be explained by the fact that, IRV has short expiratory time, so might lead to air trapping in the lungs with significant increase in intrinsic PEEP. Although, mechanical ventilation also generated intrinsic PEEP in conventional ratio ventilation; possibly because of hyperinflation and high airway pressure; but intrinsic PEEP still significantly higher in IRV than conventional ventilation [26]

As regarding the cardiac output, our results were in consistence with Bohm et al. [45] who showed that RM and high PEEP did not cause significant differences in cardiac output, end diastolic area or segmental wall motion abnormalities.

Moreover, Zhang et al. [26] demonstrated that there was no statistically significant difference between IRV and conventional ratio ventilation as regard cardiac output.

Concerning postoperative complication, our there was only one case of postoperative hypoxia in the control group which need admission to ICU. The patient needed CPAP mask for four hours in the ICU. After that the patient discharged safely from ICU.

Several researches demonstrated that RM and IRV was safe and tolerable maneuver used to improve arterial oxygenation with no significant change in the hemodynamic parameters; HR and MAP and no deleterious intraoperative or postoperative complication [6,8,11,16, 19,20, 21,22,26 ,29,30,36,45,46].

Unfortunately, many limitations were found in this study. First, we did not measure the real extent of RM nor IRV. To confirm the real extent of RM or IRV, end expiratory lung volume or imaging study (such as computed tomography or ultrasonography) should be done which was very difficult during the surgery. Second, we did not record the postoperative extent or effectiveness of RM nor IRV as we did not provide direct evidence of atelectic areas by computed tomography. Third, our study was not double blinded. It seemed neither feasible nor realistic to blind the anesthetist monitoring the patient.

5. CONCLUSION

RM and IRV had provided better arterial oxygenation and respiratory mechanics compared to conventional ventilation in morbid obese patients undergoing laparoscopic bariatric surgery. However, RM had better gas exchange than IRV. Both were hemodynamically tolerable without intraoperative or postoperative complications.

ETHICAL AND CONSENT

A written informed consent was obtained from all patients. Procedures were approved by the Institutional ethical committee with approval code: 31557/ 05/ 17.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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