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Features of Mechanical Lung Ventilation During Robot-Assisted Radical Prostatectomy in Patients with Different Body Mass Index

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Summary

The aim of the study. To evaluate effects of carboxyperitoneum and steep Trendenburg position on respiratory biomechanics and gas exchange indicators in patients with different body mass index (BMI) during robotic-assisted radical prostatectomy (RRP). To develop an algorithm for choosing the optimal mechanical lung ventilation (MLV) regimen.

Materials and methods. The study included 141 patients with verified prostate cancer who were candidates for RPR. Participants were divided into 2 groups based on BMI: group I included 88 patients with BMI<30 kg/m^2, group II — 53 patients with BMI≥30 kg/m^2. Indicators of respiratory biomechanics and gas exchange during ventilation in various modes (Volume Controlled Ventilation (VCV), Pressure Controlled Ventilation (PCV), Pressure Controlled– Inverse Ratio Ventilation (PC-IRV) were analyzed in each group at 5 consecutive stages of the procedure.

Results. The key parameters evidencing the effectiveness and safety of MLV during RRP procedure did not vary significantly under various ventilation regimens in the group of patients with a BMI<30 kg/m^2. Whilst in obese patients the use of VCV mode resulted in a significant increase of airway peak pressure (P_{peak}) already at the stage of placing them into a steep Trendelenburg position (35°), thus endangering with the development of ventilator-induced lung injury. Increased Ppeak was also accompanied by the drop in oxygen saturation and significantly lower SpO_2 values, starting from the stage of applying carboxyperitoneum and until the end of surgical intervention.

Conclusion. In non-obese patients, there's no particular ventilator regimen that is crucial for achieving the safety and effectiveness of RRP anesthesia management, all regimens can be used. In patients with BMI≥30 kg/m^2 PCV regimen and PC-IRV with inhalation/exhalation ratio of 1.5:1
can be considered as the optimal strategy for MLV during anesthesia for RRP surgery.

Keywords: robotic-assisted prostatectomy; Trendelenburg position; respiratory support; obesity

Conflict of interest. The authors declare no conflict of interest.

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Introduction

Today, radical prostatectomy is the «gold standard» treatment for localized prostate cancer (PC). In recent years, robotic-assisted surgery has become an important alternative in the treatment of PC patients [1].

One of the prerequisites for optimal visualization of the surgical field during robotic prostatectomy is CO_2 pneumoperitoneum. The optimal «working» pressure of carbon dioxide, from the point of view of patient safety and surgeon comfort, is 12 cm H_2O or less. At the time of port placement and suturing of the dorsal venous complex, a short-term increase to 15 cm H_2O may be acceptable. The second requirement is to place the patient in the Trendelenburg position (with the operating table tilted up to 40°) [2–4]. Each of these factors, alone or in combination, induces important changes in various organs and systems (primarily respiratory, cardiovascular, and excretory) and requires a timely response to prevent the development of life-threatening conditions [4, 5]. To date, there are only a few clinical studies on the effect of long-term pneumoperitoneum and Trendelenburg position on the patient's physiological parameters [6, 7].

The effect of the Trendelenburg position on the respiratory system may be due to the cranial displacement of the diaphragm when the head end of the table is tilted at the 30° to 45° angle used in operating rooms. This reduces lung compliance. The Trendelenburg position also has a negative effect on ventilation, reducing functional residual capacity [8].

During prolonged ventilation, regardless of the initial status of the lung, the negative effect of ventilatory support on the lung gradually becomes apparent, eventually leading to a serious disturbance

in ventilation-perfusion relationships. The greatest negative effect of ventilation on the lung is caused by high peak inspiratory pressure [9–11].

There are two ways to perform controlled ventilation during robotic-assisted radical prostatectomy (RARP), either pressure-controlled ventilation (PCV) or volume-controlled ventilation (VCV), with ventilatory support performed with an inverted inspiratory-expiratory ratio [12, 13].

Both modes compensate for the effects of pneumoperitoneum and abnormal positioning, allowing the patient's breathing and hemodynamics to be maintained in the normal range during surgery. C. C. Balick-Weber et al. studied the effects of PCV mode ventilation versus VCV mode ventilation during prostatectomy and found no hemodynamic advantage of one mode over the other. However, pressure-controlled ventilation decreased peak pressure and increased mean airway pressure during surgery. In addition, patients undergoing pressure-controlled ventilation had a significant increase in dynamic lung compliance compared to those on volume-controlled ventilation [14].

This study was replicated during RARP by E. M. Choi et al. They reported that the PCV mode had no advantage over the VCV mode in terms of respiratory mechanics or hemodynamics, except for better adherence to mode parameters and lower peak airway pressure. In this study, the development of hypoxemia during Trendelenburg with pneumoperitoneum was associated with an increase in dead airway space [15]. The use of PCV mode is recommended for obese patients and patients with pulmonary diseases, because their peak pressure in Trendelenburg position with pneumoperitoneum very often reaches a critical value (40 cm H_2O or more). Dangerous increase in peak pressure (>40 cm H_2O) can lead to pulmonary barotrauma, which is associated with alveolar destruction, release of inflammatory mediators, pneumothorax, increased permeability of pulmonary capillaries, microhemorrhages in the pulmonary interstitium [16–19].

Often the selected ventilation mode is ineffective and does not provide adequate oxygenation of the arterial blood. In this case, an attempt to further increase the controlled pressure ($P_{control}$), positive end-expiratory pressure (PEEP), inspired oxygen fraction (FiO_2) either does not lead to an improvement in blood oxygenation or requires reaching very high values ($P_{control}$>35 cm H_2O, PEEP 10–12 cm H_2O, FiO_2>60%). Some authors recommend the use of ventilation with an inverted inhalation/exhalation ratio in such situations [18]. Our experience, combined with the results of recent large randomized trials, shows that the optimal value of PEEP during ventilation in RARP is 5 cm H_2O [20, 21].

One of the most challenging patient groups (especially for teams with little experience in robotic surgery) are obese patients with a BMI over 30, which is associated with additional difficulties during anesthesia. In a study by A. L. Wiltz, obese patients had an increased intraoperative conversion rate compared to non-obese patients (2.3% vs. 0.9%, respectively), which was associated with increased airway pressure in 80% of cases. In general, these patients often have reduced pulmonary function and are prone to develop postoperative respiratory complications [22]. According to D. Meininger, arterial oxygenation is significantly impaired during laparoscopic surgery in the Trendelenburg position in overweight and obese patients (BMI greater than 25–30) [23]. An anesthesiologist can anticipate and prevent the development of a similar situation during anesthesia in obese PC patients undergoing RARP.

Aim of the study: To evaluate the effect of CO_2 pneumoperitoneum and Trendelenburg position on respiratory mechanics and gas exchange parameters in PC patients with different body mass indexes during robotic-assisted radical prostatectomy (RARP) and to develop an algorithm for selecting the optimal mode of respiratory support.

Materials and Methods

After approval by the Ethics committee of the Federal Research Center of Intensive Care Medicine and Rehabilitology, No. 5/20/6 dated December, 23, 2020 and obtaining written informed consents, 141 patients with verified diagnosis of prostate cancer who were to undergo RARP in 2022, were included in a prospective observational study.

The scheme of the study is presented in the Figure.

Study inclusion criteria:

— PC diagnosed using clinical, laboratory, instrumental and histological methods;

— elective RARP;

— ASA (American Society of Anesthesiologists) 1–2 risk of anesthesia;

—signed informed consent to participate in the study.

Exclusion criteria:

— refusal to participate in the study or to sign the informed consent form;

— ASA anesthesia risk score⩾3;

— chronic non-specific lung diseases and/or respiratory insufficiency 2–3 degrees;

— chronic heart failure NYHA (New York Heart Association) ⩾2 .

Patients were divided into 2 groups according to body mass index (BMI): group 1 included 88 subjects with BMI<30, group 2 included 53 participants with BMI⩾30. Respiratory mechanics and gas exchange parameters were studied in each group. Patients in each group were divided into 3 subgroups according to the ventilation mode used (VCV, PCV, PCV-IRV).

Respiratory biomechanics and gas exchange parameters were analyzed at the following key stages of surgery:

Stage 1: induction of anesthesia, horizontal position;

Stage 2: installation of CO_2 pneumoperitoneum, trocar placement;

Stage 3: 35° Trendelenburg position, 5 min after the start of the operation;

Stage 4: 45 min from the moment of bringing to the maximum Trendelenburg position;

Stage 5: horizontal position, end of surgery, pneumoperitoneum desufflation.

At each of the key stages, the following parameters were recorded:

— end-tidal carbon dioxide ($EtCO_2$), mm Hg;
— respiratory rate (RR), min^{-1};
— tidal volume (V_t), mL;
— peak airway pressure (P_{peak}), cm H_2O;
— mean airway pressure (P_{mean}), cm H_2O;
— blood oxygen saturation (SpO_2), %.

After the patient was transported to the operating room, standard monitoring (electrocardiogram, non-invasive blood pressure, pulse oximetry) was started.

The dosage of drugs for combined endotracheal anesthesia was calculated based on ideal body weight. All patients received standard premedication on the operating table with 100% oxygen inhalation through a face mask with a flow of 6–8 L/min, consisting of 0.1% atropine sulfate (0.01–0.02 mg/kg), 0.2% clemastine (0.03–0.05 mg/kg), midazolam (0.02–0.06 mg/kg), 0.005% fentanyl (1–3 μg/kg). Anesthesia was induced by propofol at 1.5–2.5 mg/kg until target BIS values of 30-40 were achieved.

While in anesthesia, patients received a calculated dose of the non-depolarizing myorelaxant rocuronium bromide 0.5 mg/kg and underwent tracheal intubation with an 8.0–9.0 endotracheal tube. Because of the risk of displacement of the distal end of the endotracheal tube toward the carina and development of single-lung ventilation after the patient was placed in the Trendelenburg position, mandatory auscultatory monitoring was performed at all stages of patient positioning. After tracheal intubation, a nasogastric tube was placed to minimize the risk of traumatic injury to the stomach during trocar placement and to prevent the development of postoperative nausea and vomiting. Anesthesia was maintained with the inhalational anesthetic sevoflurane (Sevoran®), with BIS maintained in the range of 40–50. Myorelaxation was achieved by bolus injection of calculated doses of rocuronium bromide. Lung ventilation was performed using a Drager Primus apparatus (Dragerwerk, Germany) with an oxygen-air mixture (0.4/0.6) at a flow of 1 L/min in modes specific to each subgroup of patients. Respiratory rate settings during anesthesia were adjusted to achieve an optimal expiratory pCO_2 of 4.9–6.4 vol%. To maintain normocapnia, we took into account the constant inhalation of CO_2 through the robotic trocar port and its inevitable entry into the bloodstream, followed by the adjustment of ventilation parameters [24].

At the end of surgery, all patients were extubated and transferred to the recovery room for symptomatic management and clinical and laboratory monitoring.

RARP was performed using the da Vinci Si system (Intuitive Surgical, Mountain View, USA). After tracheal intubation, the patient was placed in the lithotomy position, and special soft fixators were placed under the patient's shoulders to limit his displacement relative to the operating table during surgery. Five ports were placed in the abdominal cavity for CO_2 pneumoperitoneum with an initial CO_2 pressure of 15 mm Hg. At the end of this phase and after the patient was placed in the Trendelenburg position, the gas pressure in the abdominal cavity was reduced to a safe level of 12 mm Hg.

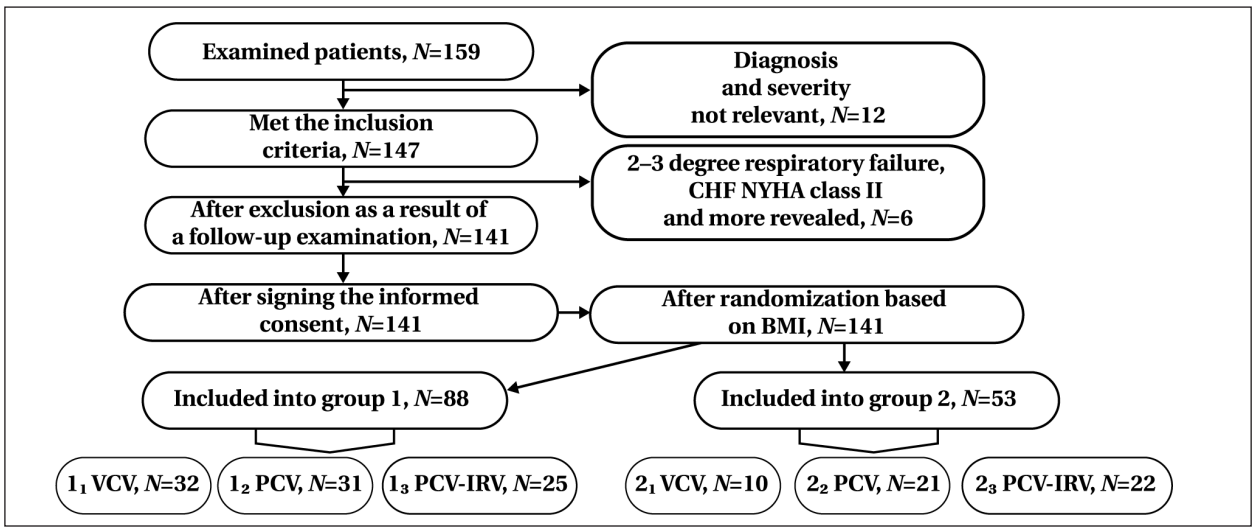

Fig. Flowchart of the study.

The sample size was determined by achieving a minimum statistical power of 80% and a first-order error of 5% according to the formula of Lopez-Jimenez F. et al. (1998). The study in group 1 (subgroup 1) was prematurely terminated after results indicating a high risk of lung volutrauma were obtained. Statistical analysis of the data was performed using Excel 2016 (Microsoft, USA) and SPSS Statistica v. 24 (IBM, USA). The Kolmogorov-Smirnov criterion with Lilliefors correction was used to test the distribution of quantitative variables for normality. Variables with normal distribution were described as mean and standard deviation (*M*±*SD*). Variables with non-normal distribution were reported as median and interquartile range (*Me* [*Q25*; *Q75*]). Qualitative parameters were expressed as absolute and relative values (*N* (%)). Significance of the difference between the studied groups for quantitative variables with normal distribution was evaluated using the Student's *t*-criterion for independent samples, in case of non-normal distribution using the Mann–Whitney criterion. The reliability of intragroup differences for repeated measurements of normally distributed parameters was assessed using Student's *t*-criterion for paired samples. One-way analysis of variance (ANOVA) was used to compare normally distributed data between three or more groups, and Kruskal-Wallis analysis of variance was used for non-normal distribution. Pearson's χ^2-squared test or Fisher's exact two-sided test for small samples was used to compare groups on qualitative variables. Differences were considered statistically significant at $P<0.05$, where P is the probability of a first-order error in testing the null hypothesis. The Bonferroni correction was used to control for the probability of a first-order error (error in rejecting the correct null hypothesis) in multiple comparisons.

Results and Discussion

The mean age of patients was 57.44±5.09 years in subgroup 1_1, 57.35±5.40 years in subgroup 1_2, and 56.60±4.35 years in subgroup 1_3 (P=0.84). The mean age of patients was 56.60±4.04 years in subgroup 2_1, 57.48±6.00 years in subgroup 2_2, and 57.86±5.09 years in subgroup 2_3 (P=0.39). The distribution of patients by age in the groups is shown in Table 1.

The BMI of the patients in the subgroups of both groups was also comparable. The median BMI was 27.0 [24.5; 29.0] in subgroup 1_1, 28.5 [24.25; 29.45] in subgroup 1_2, and 28.2 [25.15; 29.0] in subgroup 1_3 (P=0.12).

The median values in subgroups were as follows: subgroup 2_1 — 34.5 [31.25; 35.15], subgroup 2_2 — 33.25 [30.5; 35.0], subgroup 2_3 — 34.0 [31.2; 36.0] (P=0.20).

The distribution of patients by ASA is shown in Table 2. Two thirds of the included patients had ASA anesthesia risk grade 2, the differences between the groups were not significant.

When studying the respiratory biomechanics and gas exchange parameters in patients with normal BMI (Table 3) on volume-controlled ventilation (VCV), we came to the conclusion that its use in normal ventilation parameters can be considered quite safe (the maximum value of Ppeak recorded at the 4th stage of the study was 30.4±3.1 cm H_2O) and fully satisfies the physiological needs of the organism in providing adequate respiration (the minimum recorded value of SpO_2 was 96.2±3.0%). The PCV mode, used in patients with normal body mass index, also provided adequate oxygenation (the minimum SpO_2 value recorded was 96.0±1.3%) and the desired safety (the maximum P_{peak} value at stage 4 of the study was 28.5±5.6 cm H_2O). Pressure-controlled ventilation, but with inverted inspiration-expiration ratio (PCV-IRV), also created conditions to prevent pulmonary barotrauma (maximum P_{peak} value at stage 4 of the study was 29.1±2.3 cm H_2O), indicating that it could be used in patients without obesity, which is also in agreement with the study by L. Ashwort [25].

Thus, the stability of respiratory parameters in patients without obesity, regardless of the selected mode of ventilation under increased load from pneumoperitoneum and Trendelenburg position, demonstrated the adequacy and safety of anesthesia

Table 1. Distribution by age, *N* (%).

Age, years	Values in groups								*P*
	Group 1 and subgroups				Group 2 and subgroups				
	1_1, *N*=32	1_2, *N*=31	1_3, *N*=25	Total, *N*=88	2_1, *N*=10	2_2, *N*=21	2_3, *N*=22	Total, *N*=53	
45–50	—	2 (6.7)	3 (12.0)	5 (5.7)	1 (10.0)	2 (9.5)	1 (4.5)	4 (7.5)	0.73
51–55	13 (43.3)	11 (36.7)	7 (28.0)	31 (35.2)	2 (20.0)	7 (33.3)	9 (40.9)	18 (34)	0.88
56–60	14 (46.7)	12 (40.0)	11 (44.0)	37 (42.0)	6 (60.0)	8 (38.1)	8 (36.4)	22 (41.5)	0.95
61–65	3 (10.0)	3 (10.0)	4 (16.0)	10 (11.4)	1 (10.0)	—	3 (13.6)	4 (7.5)	0.57
66–70	—	2 (6.7)	—	2 (2.3)	—	4 (19.0)	1 (4.5)	5 (9.4)	0.1
71–75	2 (6.7)	1 (3.3)	—	3 (3.4)	—	—	—	—	0.29

Table 2. Distribution of patients according to anesthesia risk, *N* (%).

ASA	Values in groups								*P*
	Group 1 and subgroups				Group 2 and subgroups				
	1_1, *N*=32	1_2, *N*=31	1_3, *N*=25	Total, *N*=88	2_1, *N*=10	2_2, *N*=21	2_3, *N*=22	Total, *N*=53	
1	6 (18.8)	9 (29.0)	5 (20.0)	20 (22.7)	2 (20.0)	4 (19.0)	6 (27.3)	12 (22.6)	0.84
2	26 (81.3)	22 (71.0)	20 (80.0)	68 (77.3)	8 (80.0)	17 (81.0)	16 (72.7)	41 (77.4)	0.84

Table 3. Respiratory parameters in patients with normal BMI (*N*=88) during surgery with different ventilation modes (*M*±*SD*).

Ventilation mode	Stage				
	1	2	3	4	5
End-tidal carbon dioxide ($EtCO_2$), mm Hg					
VCV	31.1±8.4	34.3±8.1	38.2±8.4	37.7±9.2	40.1±8.9
PCV	32.3±1.2	35.1±1.1	36.7±1.3	36.8±2.5	39.2±4.3
PCV-IRV	33.1±3.2	35.3±1.6	35.2±3.4	36.4±2.1	39.5±3.2
Respiratory rate, min^{-1}					
VCV	9.1±1.7	10.3±1.2	12.5±1.3	12.1±1.1	13.0±1.2
PCV	9.1±0.5	10.2±1.4	12.1±1.6	12.2±1.1	13.6±1.9
PCV-IRV	9.4±1.3	10.3±1.6	11.7±1.2	12.5±1.6	12.6±2.4
Tidal volume (V_t), ml					
VCV	630.1±25.4	640.5±37.2	645.0±32.1	658.3±38.5	690.0±57.2
PCV	615.9±45.7	625.5±52.4	637.2±36.3	690.4±42.1	636.5±54.6
PCV-IRV	620.8±18.3	636.7±31.5	656.2±37.1	649.9±41.4	678.2±37.8
Peak airway pressure (P_{peak}), cm H_2O					
VCV	14.2±3.6	23.8±3.2	29.4±5.3	30.4±3.1	15.7±3.2
PCV	14.4±5.2	22.0±2.1	27.4±6.8	28.5±5.6	14.3±6.8
PCV-IRV	12.2±4.1	21.4±4.5	27.7±4.5	29.1±2.3	13.7±5.1
Mean airway pressure (P_{mean}), cm H_2O					
VCV	9.8±1.1	13.1±2.4	15.1±4.7	16.4±4.1	8.3±3.1
PCV	10.1±1.1	16.3±3.4	19.5±4.2	20.7±8.2	11.0±4.4
PCV-IRV	8.7±1.1	11.2±3.6	13.1±5.2	14.3±4.5	7.7±5.2
Blood oxygen saturation (SpO_2), %					
VCV	97.1±1.3	96.2±3.0	97.2±6.4	97.1±1.0	98.5±2.6
PCV	97.5±1.2	96.0±1.3	97.7±0.8	97.4±1.1	99.5±2.0
PCV-IRV	98.4±1.1	97.2±3.0	97.5±4.1	98.8±3.3	98.4±3.1

Note. The *P* values for pairwise comparisons of respiratory parameters at different stages of surgery are shown in Tables 5 and 7.

support of RARP adjusted to timely correction of ventilation parameters at different stages of surgery. In all patients with normal body mass index, regardless of the chosen mode of respiratory support, it was necessary to correct RR and V_t upward to prevent hypoventilation in the stages from pneumoperitoneum to extubation. The $EtCO_2$ values remained within the acceptable physiological range throughout the operation, but at the end of the operation their regular and significant increase was observed, requiring a slight correction of the ventilatory parameters towards hyperventilation (increase in respiratory rate and tidal volume).

The choice of ventilatory mode in this group of patients was not of fundamental importance, since any of them allowed to provide acceptable blood oxygenation without using high toxic concentrations of oxygen and preventing the risk of barotrauma. Continuous dynamic monitoring of respiratory homeostasis parameters and timely correction of ventilator parameters depending on the stage of the operation and the patient's organism response were of the utmost importance.

The choice of ventilator mode in patients with BMI⩾30 was crucial for safe anesthesia. Due to the excessive increase of the peak airway pressure (Table 4), the maximum P_{peak} at stage 4 of the study was 38.2±3.1 cm H_2O when using the controlled-volume mode, there was a real risk of lung volutrauma, which is unacceptable within the concept of safe anesthesia. The results obtained contributed to the termination of the study in this subgroup. This mode of ventilation cannot be considered safe enough to fully satisfy the physiological needs of the organism to provide adequate breathing in patients with excessive body weight.

Pressure-controlled ventilation in obese patients met the criteria of adequacy and safety (the maximum P_{peak} at the 4th stage of the study was 33.7±2.10 H_2O, the minimum recorded value of SpO_2 was 95.7±2.2%), but after the end of surgery, in order to completely eliminate the accumulated carbon dioxide, one should not rush with early extubation and weaning. In comparison with the standard PCV ventilation, PCV with inverse inhalation/exhalation ratio allowed to obtain lower values of peak pressure (the maximum P_{peak} at the 4th stage of the study was 31.7±3.1 cm H_2O) in patients with excess body weight, thus reducing the probability of barotrauma, while the blood oxygenation parameters did not decrease, with SpO_2 being even higher at the 2nd and 4th stages of the operation. The mean hospital stay of the patients in both groups did not differ and was 7±1 days.

Conclusion

In PC patients without obesity the choice of a specific ventilation mode is not crucial to achieve safety and efficiency of anesthesia support in RARP. Controlled-pressure ventilation and its variant with inversion of the inhalation/exhalation ratio (1.5:1) can be considered the optimal method of ventilatory support during anesthesia for RARP in PC patients with BMI ⩾30.

Table 4. Respiratory parameters of obese patients (*N*=53) throughout surgery with different modes of ventilation (*M*±*SD*).

Ventilation mode	Stage				
	1	2	3	4	5
End-tidal carbon dioxide ($EtCO_2$), mm Hg					
VCV	34.4±3.2	37.3±1.8	40.2±1.8	42.3±2.6	44.3±2.4
PCV	33.6±2.5	34.4±1.4	42.1±2.3	41.5±2.9	43.3±1.6
PCV-IRV	32.7±1.6	33.8±0.8	41.6±1.7	42.1±2.1	42.6±1.4
Respiratory rate, min^{-1}					
VCV	12.6±0.5	14.0±1.2	15.0±1.1	16.4±1.3	16.2±1.6
PCV	12.1±2.3	13.5±0.8	16.3±1.3	17.0±2.2	16.2±0.8
PCV-IRV	13.7±1.8	13.1±1.3	16.2±2.2	16.3±3.3	15.2±0.8
Tidal volume (V_t), ml					
VCV	610.8±9.1	600.3±13.4	605.9±21.5	565.7±23.4	629.1±34.3
PCV	600.7±18.4	580.7±31.8	608.7±24.5	595.9±29.1	646.3±26.4
PCV-IRV	616.5±27.7	591.7±39.2	589.5±45.1	596.2±47.3	637.7±37.9
Peak airway pressure (P_{peak}), cm H_2O					
VCV	16.3±2.2	31.1±2.1	37.0±4.5	38.2±3.1	16.7±4.2
PCV	15.2±1.1	33.5±1.1	32.2±2.1	33.7±2.1	16.5±3.0
PCV-IRV	14.4±1.1	30.2±1.3	30.5±2.1	31.7±3.1	15.5±3.0
Mean airway pressure (P_{mean}), cm H_2O					
VCV	11.1±2.1	18.4±2.1	22.6±3.3	23.2±4.3	10.2±5.1
PCV	10.4±2.3	21.1±3.3	22.4±2.4	23.5±3.1	9.7±3.4
PCV-IRV	11.4±1.2	22.1±4.4	19.8±5.1	21.7±4.1	11.1±3.4
Blood oxygen saturation (SpO_2), %					
VCV	96.8±1.2	94.7±1.1	93.7±2.0	93.8±1.4	96.9±2.1
PCV	96.8±1.9	95.7±2.5	96.5±3.6	95.7±2.2	97.5±1.3
PCV-IRV	96.4±4.1	96.5±1.2	96.4±3.1	97.7±1.4	97.8±3.1

Note. The *P* values for pairwise comparisons of respiratory parameters at different stages of surgery are shown in Tables 6 and 7.

Supplement

Table 5. *P*-values for pairwise comparisons of respiratory parameters at different stages of surgery in patients with normal BMI (*N*=88) and with different modes of ventilation (*M*±*SD*).

Ventilation mode	Stage									
	1–2	1–3	1–4	1–5	2–3	2–4	2–5	3–4	3–5	4–5
End-tidal carbon dioxide ($EtCO_2$), mm Hg										
VCV	0.06	<0.001	<0.001	<0.001	0.08	0.02	0.01	0.41	0.14	0.21
PCV	0.37	0.03	0.004	<0.001	0.19	0.12	0.04	0.84	0.02	0.03
PCV-IRV	0.19	0.05	0.06	<0.001	0.74	0.17	0.09	0.34	0.03	<0.001
Respiratory rate, min^{-1}										
VCV	0.11	<0.001	<0.001	<0.001	0.01	<0.001	<0.001	0.52	0.06	0.01
PCV	0.02	<0.001	<0.001	<0.001	0.002	0.001	<0.001	0.89	0.03	0.003
PCV-IRV	0.06	<0.001	<0.001	<0.001	0.03	<0.001	<0.001	0.26	0.02	0.83
Tidal volume (V_t), ml										
VCV	<0.001	<0.001	<0.001	<0.001	0.83	0.02	<0.001	<0.001	<0.001	<0.001
PCV	0.43	0.02	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
PCV-IRV	0.02	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	0.71	<0.001	<0.001
Peak airway pressure (P_{peak}), cm H_2O										
VCV	<0.001	<0.001	<0.001	0.89	<0.001	<0.001	<0.001	0.34	<0.001	<0.001
PCV	<0.001	<0.001	<0.001	0.98	0.06	<0.001	<0.001	0.42	<0.001	<0.001
PCV-IRV	0.003	<0.001	<0.001	0.71	<0.001	<0.001	0.001	0.12	<0.001	<0.001
Mean airway pressure (P_{mean}), cm H_2O										
VCV	<0.001	<0.001	<0.001	0.13	0.01	<0.001	<0.001	0.5	<0.001	<0.001
PCV	<0.001	<0.001	<0.001	0.87	0.004	0.01	<0.001	0.83	<0.001	0.047
PCV-IRV	<0.001	<0.001	<0.001	0.58	0.01	<0.001	<0.001	0.34	0.003	<0.001
Blood oxygen saturation (SpO_2), %										
VCV	<0.001	0.91	0.98	<0.001	0.63	0.03	<0.001	0.93	<0.001	<0.001
PCV	<0.001	0.07	0.68	<0.001	<0.001	0.01	<0.001	0.24	<0.001	<0.001
PCV-IRV	0.10	0.48	0.44	0.99	0.82	0.24	0.19	0.36	0.76	0.85

Table 6. *P*-values for pairwise comparisons of respiratory parameters at different stages of surgery in obese patients (*N*=53) and with different ventilator modes (*M±SD*).

Ventilation mode	Stage									
	1–2	1–3	1–4	1–5	2–3	2–4	2–5	3–4	3–5	4–5
End-tidal carbon dioxide ($EtCO_2$), mm Hg										
VCV	0.002	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.01	0.21
PCV	0.40	<0.001	<0.001	<0.001	<0.001	<0.001	0.20	<0.001	<0.001	0.03
PCV-IRV	0.17	<0.001	<0.001	<0.001	<0.001	<0.001	0.62	<0.001	0.50	<0.001
Respiratory rate, min^{-1}										
VCV	0.02	<0.001	<0.001	<0.001	0.04	<0.001	<0.001	0.003	0.003	0.67
PCV	0.03	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.19	<0.001	0.41
PCV-IRV	0.67	0.13	0.09	0.01	0.01	0.01	0.001	0.90	0.40	0.13
Tidal volume (V_t), ml										
VCV	0.69	0.01	0.03	0.08	0.004	0.009	0.05	0.95	0.14	0.53
PCV	0.01	0.42	0.21	<0.001	0.04	0.28	<0.001	0.21	<0.001	<0.001
PCV-IRV	0.01	0.001	0.001	<0.001	0.93	0.79	<0.001	0.83	<0.001	<0.001
Peak airway pressure (P_{peak}), cm H_2O										
VCV	<0.001	<0.001	<0.001	0.98	<0.001	<0.001	<0.001	0.79	<0.001	<0.001
PCV	<0.001	<0.001	<0.001	0.78	<0.001	0.53	<0.001	0.20	<0.001	<0.001
PCV-IRV	<0.001	<0.001	<0.001	0.99	0.40	0.001	<0.001	0.13	<0.001	<0.001
Mean airway pressure (P_{mean}), cm H_2O										
VCV	<0.001	<0.001	<0.001	0.79	<0.001	<0.001	<0.001	0.66	<0.001	<0.001
PCV	<0.001	<0.001	<0.001	0.64	0.03	<0.001	<0.001	0.32	<0.001	<0.001
PCV-IRV	<0.001	0.001	<0.001	0.91	0.12	0.61	<0.001	0.14	<0.001	0.005
Blood oxygen saturation (SpO_2), %										
VCV	<0.001	<0.001	<0.001	0.84	<0.001	<0.001	<0.001	0.88	<0.001	<0.001
PCV	0.09	0.70	0.18	0.34	0.79	0.98	0.03	0.69	0.19	0.07
PCV-IRV	0.96	0.99	0.48	0.61	0.98	0.06	0.26	0.19	0.34	0.96

Table 7. *P*-values for pairwise comparisons of respiratory parameters in different modes of ventilatory support during surgery in patients with normal BMI and obesity.

Ventilation mode	With normal body mass index (*N*=88)					With obesity (*N*=53)				
	Stage					Stage				
	1	2	3	4	5	1	2	3	4	5
End-tidal carbon dioxide ($EtCO_2$), mm Hg										
VCV-PCV	0.74	0.71	0.53	0.72	0.83	0.53	<0.001	0.05	0.40	0.32
VCV-IRV	0.39	0.67	0.08	0.70	0.63	0.20	<0.001	0.005	0.94	0.09
PCV-IRV	0.68	0.88	0.42	0.79	0.76	0.27	0.14	0.45	0.60	0.04
Respiratory rate, min^{-1}										
VCV-PCV	0.96	0.88	0.58	0.88	0.40	0.55	0.41	0.09	0.49	0.98
VCV-IRV	0.71	0.97	0.23	0.61	0.69	0.18	0.13	0.18	0.99	0.06
PCV-IRV	0.36	0.90	0.57	0.45	0.38	0.03	0.60	0.95	0.77	0.03
Tidal volume (V_t), ml										
VCV-PCV	0.68	0.49	0.46	0.26	<0.001	0.30	0.42	0.88	0.06	0.19
VCV-IRV	0.26	0.89	0.53	0.76	0.50	0.66	0.77	0.26	0.04	0.86
PCV-IRV	0.64	0.62	0.14	0.13	0.23	0.23	0.66	0.43	0.98	0.77
Peak airway pressure (P_{peak}), cm H_2O										
VCV-PCV	0.92	0.27	0.66	0.56	0.67	0.43	0.04	0.03	0.003	0.88
VCV-IRV	0.37	0.18	0.55	0.37	0.36	0.07	0.65	0.001	<0.001	0.57
PCV-IRV	0.16	0.80	0.96	0.84	0.90	0.28	0.001	0.36	0.18	0.64
Mean airway pressure (P_{mean}), cm H_2O										
VCV-PCV	0.84	0.11	0.15	0.45	0.37	0.46	0.11	0.89	0.77	0.67
VCV-IRV	0.19	0.38	0.75	0.39	0.89	0.73	0.02	0.05	0.37	0.69
PCV-IRV	0.09	0.04	0.01	0.19	0.46	0.27	0.47	0.04	0.14	0.55
Blood oxygen saturation (SpO_2), %										
VCV-PCV	0.32	0.88	0.60	0.46	0.26	0.99	0.36	0.03	0.25	0.52
VCV-IRV	0.05	0.47	0.96	0.002	0.88	0.72	<0.001	0.02	<0.001	0.35
PCV-IRV	0.05	0.19	0.88	0.003	0.19	0.53	0.14	0.93	0.01	0.83

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