ORIGINAL ARTICLES

Application of PRVC in laparoscopic surgery

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Abstract

Objective: To discuss the clinical significance and value of PRVC by monitoring, comparing and studying pressure control (PC), volume control (VC) and pressure-regulated volume control (PRVC) ventilation modes during pneumoperitoneum.
Methods: Ninety patients with laparoscopic cholecystectomy were randomly and equally divided into 3 groups (PC group, VC group and PRVC group). Esophageal pressure (PES), mean airway pressure (PAWM), peak airway pressure (PAP), arterial blood carbon dioxide partial pressure ($PaCO_2$), end-tidal carbon dioxide concentration in the expired air ($ETCO_2$), tidal volume (TV), mean arterial pressure (MAP) and heart rate (HR) were not only detected before pneumoperitoneum, but also in 5, 10, 15 and 20 minutes after pneumoperitoneum.
Results: PES after pneumoperitoneum in VC mode was obviously higher than that in PC and PRVC groups. In 10 minutes after pneumoperitoneum, levels of $PaCO_2$ and $ETCO_2$ became increased obviously in PC and VC groups ($p < .05$); levels of $PaCO_2$ and $ETCO_2$ were not only increased in PC group, but also the level of TV after pneumoperitoneum in PC group was significantly lower than that in the other two groups ($p < .05$). Levels of $PaCO_2$ and $ETCO_2$ were increased in PC and VC groups after pneumoperitoneum, along with the increase of MAP and HR ($p < .05$). After pneumoperitoneum, levels of MAP and HR in PRVC group were significantly lower than those in PC and VC groups ($p < .05$).
Conclusions: PRVC mode can effectively reduce the pneumoperitoneum-induced increase of PAWM, PAP and PES without the unusual increase of $PaCO_2$ and $ETCO_2$ during surgery, so as to guarantee the stability of vital signs in perioperative patients.

Key Words: PRVC, Laparoscopic, PES, $PaCO_2$, $ETCO_2$

In recent years, the theory of lung protective ventilation strategy is proposed for mechanical ventilation to minimize ventilator-induced lung injury.[1] Fully complying with the requirements of lung protective ventilation strategy theory,[2,3] PRVC mode can guarantee tidal volume (TV) by use of the microcomputer to continuously detect the thoracic and lung compliance and automatically adjust the level of pressure switch. Laparoscopic cholecystectomy is of less injury, shorter hospitalization and less stimulation to patients. However, as CO_2 diffuses into the blood and pneumoperitoneum causes intra-abdominal pressure to go up, they result in the abnormal movement of the diaphragm and the chest wall along with changes in pneodynamics. At present, pressure control (PC) and volume control (VC) are often used in laparoscopic cholecystectomy, but it remains to be controversial in the selection of these two modes.[4,5] The application of pressure-regulated volume control (PRVC) to laparoscopic cholecystectomy still remains vague in domestic and international reports. This experiment is intended to discuss the clinical significance and value of PRVC ventilation mode by monitoring, comparing and studying PC, VC and PRVC modes during pneumoperitoneum.

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1 Objects and methods

1.1 Research objects

The research was approved by Ethics Committee of our hospital and all patients and their families signed informed consent forms. Ninety patients with selective laparoscopic cholecystectomy, aged 20 to 65 years, ASA I-II, with the normal function of heart, lung, liver and kidney, no respiratory diseases, were chosen as research objects. No patients were converted into open-abdominal operation. By use of random number table and random number remainder, patients were randomly and equally divided into three groups (n = 30 in each group). Patients in Group I received PC ventilation; Group II received VC ventilation; and Group III received PRVC ventilation. There was no statistical significance in sex, age and weight in research objects of 3 groups ($p > .05$, see Table 1).

Table 1: Comparison of clinical data in patients of 3 groups ($\bar{x}$ ± s)

Group	Male	Female	Age (years)	Weight (kg)
I	15	15	43.1 ±9.7	65.2 ±8.2
II	17	13	41.6 ±10.8	61.3 ±7.9
III	16	14	44.7 ±11.0	64.2 ±8.7

1.2 Methods

Before surgery, 3 groups of patients were given 0.3 mg scopolamine by IM injection; and 2.5 mg/kg propofol, 1 mg/kg rocuronium bromide as well as 0.15 μg/kg•min remifentanil by IV injection during general anesthesia induction. Keep using 0.15 μg/kg•min remifentanil combined with 1.0%-1.5% isoflurane (inhalation) during general anesthesia. During the operation, the gas insufflator (Olympus UHI-3, Japan) was set at the pneumoperitoneum pressure of 12 mmHg.

After induction, patients in Group I were given mechanical ventilation in PC mode. The parameters of the anesthesia machine (MAQUET Flow-I, Italy) were set as follows: inspiratory pressure (Pins) was adjusted to keep $ETCO_2$ (end-tidal carbon dioxide concentration in the expired air) at the level of 4.0-5.0 kPa. The rate of oxygen and the air provided were all 0.3 L/min, and the oxygen concentration was 41%. Patients in Group II were given mechanical ventilation in VC mode. The respiratory parameters of the anesthesia machine were set as follows: TV 8 mL/kg, PEEP (positive end-expiratory pressure) 0 cmH_2O, I/E 1:2, respiratory rate 16/min, oxygen inhalation concentration 41%. Patients in Group III were given mechanical ventilation in PRVC mode. The respiratory parameters in Group III were the same as Group II.

1.3 Observation indicators

It was required to record following data before pneumoperitoneum (T_1), in 5, 10, 15 and 20 min after pneumoperitoneum (T_2, T_3, T_4, T_5): esophageal pressure (PES), mean airway pressure (PAWM), peak airway pressure (PAP), arterial blood carbon dioxide partial pressure ($PaCO_2$), end-tidal carbon dioxide concentration in the expired air ($ETCO_2$), tidal volume (TV) and mean arterial pressure (MAP, the calculation formula is: MAP = DBP + 1/3 Pulse Pressure) and heart rate (HR). As pulse oxygen saturation (SpO_2) in each group at different time point were all 100% and the difference has no statistical significance, SpO_2 was not listed as an indicator.

PES can be detected via a float catheter (Swan-Ganz, USA), one end of which was connected to the monitor (M8003A, Germany) and the other end was placed into the middle esophageal region; blood biochemical indexes can be detected by use of blood-gas analyzer (i-STAT1 Analyzer MN: 300-G, USA) .

1.4 Statistical methods

The categorical data were compared by use of chi-square test. The measurement data acquired from each group were represented by $\bar{x}$ ± s, with SPSS 19.0 statistical software applied. Repeated Measures ANOVA was used in the comparison. The difference ($p < .05$) was of statistical significance.

2 Results

2.1 Comparison of pneodynamics in each group and among groups

After pneumoperitoneum, PES was significantly increased in each group ($p < .05$); PES in Group II was higher than that in Group I and Group III ($p < .05$). PAWM and PAP were obviously increased after pneumoperitoneum ($p < .05$, see Table 2).

2.2 Comparison of TV and CO_2 metabolism in each group and among groups

$PaCO_2$ and $ETCO_2$ became significantly increased at T_3 ($p < .05$) in Group I and Group II; TV in Group I at T_3, T_4 and T_5 was obviously lower than that in the other two groups ($p < .05$, see Table 3).

2.3 Comparison of vital signs in each group and among groups

MAP and HR became significantly increased at T_3 ($p < .05$) in Group I and Group II; MAP and HR in Group III at T_3,

T_4 and T_5 were obviously lower than those in Group I and Group II ($p < .05$, see Table 4).

Table 2: Comparison of pneodynamics in patients of 3 groups (n = 30, $\bar{x} \pm s$, cmH_2O)

Group	Indexes	T_1	T_2	T_3	T_4	T_5
I	PAWM	5.9 ±1.8$^{\&}$	11.2 ±3.7	12.1 ±4.1	10.8 ±2.9	11.3 ±3.5
	PAP	11.2 ±1.1$^{\&}$	17.4 ±2.1	18.3 ±2.0	19.5 ±2.1	19.7 ±1.9
	PES	1.5 ±0.4	6.0 ±2.2	5.8 ±2.6	6.1 ±2.7	5.9 ±2.3
II	PAWM	6.1 ±2.0$^{\&}$	12.1 ±4.0	11.9 ±3.7	11.7 ±4.0	12.3 ±2.9
	PAP	12.7 ±2.5$^{\&}$	15.2 ±2.4	20.6 ±3.8	21.5 ±4.7	19.8 ±3.4
	PES	1.8 ±0.6	9.1 ±3.5$^{\#}$	9.5 ±2.8$^{\#}$	8.9 ±3.7$^{\#}$	9.2 ±2.8$^{\#}$
III	PAWM	5.8 ±1.4$^{\&}$	11.8 ±2.8	12.8 ±3.4	11.9 ±2.6	12.7 ±3.2
	PAP	13.5 ±2.0$^{\&}$	13.4 ±1.9	19.3 ±2.6	20.4 ±3.8	18.6 ±3.6
	PES	1.6 ±0.8	7.1 ±1.8	6.4 ±2.4	6.9 ±3.0	6.5 ±2.7

Note. In comparison with Group I and Group III, $^{\#}p < .05$; in comparison with each other at every time point after pneumoperitoneum, $^{\&}p < .05$

Table 3: Comparison of TV and CO2 metabolism in patients of 3 groups (n = 30, $\bar{x} \pm s$)

Group	Indexes	T_1	T_2	T_3	T_4	T_5
I	$PaCO_2$ (mmHg)	37.5 ±4.8*	39.5 ±4.3	51.8 ±6.9	53.1 ±7.1	50.8 ±6.7
	$ETCO_2$ (mmHg)	38.4 ±4.6*	39.7 ±4.0	50.3 ±6.7	50.7 ±7.2	55.8 ±6.4
	TV (mL)	401.6 ±56.3	338.7 ±49.7$^{\#}$	343.5 ±44.6$^{\#}$	326.8 ±40.8$^{\#}$	337.4 ±39.7$^{\#}$
II	$PaCO_2$ (mmHg)	36.8 ±5.1*	38.6 ±4.9	50.1 ±5.7	52.4 ±6.7	52.4 ±7.3
	$ETCO_2$ (mmHg)	37.5 ±4.8*	42.9 ±5.1	47.1 ±3.6	51.4 ±6.7	52.2 ±6.7
	TV (mL)	398.9 ±46.4	388.8 ±39.2	390.6 ±42.3	389.1 ±44.5	383.8 ±51.8
III	$PaCO_2$ (mmHg)	37.4 ±4.2	39.4 ±6.1	42.3 ±6.7	41.9 ±5.7	43.8 ±6.4
	$ETCO_2$ (mmHg)	39.4 ±4.9	40.7 ±6.2	43.7 ±5.1	41.6 ±5.1	42.8 ±5.7
	TV (mL)	402.5 ±51	397.1 ±44.8	406.2 ±58.7	420.7 ±61.1	407.3 ±48.1

Note. In comparison with each other at every time point after pneumoperitoneum, $^{*}p < .05$; in comparison with each group, $^{\#}p < .05$

Table 4: Comparison of vital signs in patients of 3 groups (n = 30, $\bar{x} \pm s$)

	Indexes	T_1	T_2	T_3	T_4	T_5
I	MAP (mmHg)	73.8 ±8.1*	77.6 ±9.4	95.3 ±11.4	92.4 ±10.2	91.0 ±9.5
	HR (bpm)	70.2 ±9.1*	75.3 ±7.9	91.2 ±10.8	92.4 ±11.4	91.9 ±9.8
II	MAP (mmHg)	78.5 ±7.7*	81.7 ±8.9	98.1 ±10.6	97.3 ±11.4	104.6 ±12.8
	HR (bpm)	71.8 ±8.1*	78.7 ±7.6	90.4 ±7.4	92.6 ±8.0	89.8 ±7.6
III	MAP (mmHg)	76.8 ±8.6	80.6 ±10.1	79.8 ±10.7$^{\#}$	80.9 ±11.2$^{\#}$	79.1 ±8.7$^{\#}$
	HR (bpm)	72.5 ±9.1	79.4 ±9.2	71.9 ±10.6$^{\#}$	70.5 ±9.5$^{\#}$	72.7 ±8.9$^{\#}$

Note. In comparison with each other at T_3, T_4 and T_5, $^{*}p < .05$; in comparison with each group, $^{\#}p < .05$

3 Discussion

The main reasons for the popularity of minimally invasive surgery (MIS) are that the duration of operation is short and multiple operations can be performed in a day. Compared with traditional surgical methods, MIS has the following advantages:[6–8] less bleeding during surgery, less suffering, lower incidence rate of complications etc. Laparoscopic cholecystectomy, one of the most common surgeries in clinical practice, is usually performed under the condition of general anesthesia. The main reasons why CO_2 pneumoperitoneum can affect heart rate, blood pressure and other vital signs are:[9, 10] CO_2 diffuses into the blood and stimulates the carotid body and the aortic chemoreceptors to generate pressor reflex; the mechanical extrusion of pneumoperitoneum on the intra-abdominal great vessels, leads to the obstruction of venous return along with higher pressure of aortic outflow tracts; upward movement of the diaphragm and decrease of respiratory compliance affect respiratory metabolism system and further enhance the retention of CO_2 in the body. At present, PC and VC modes are two main choices applied to the general anesthesia in laparoscopic surgeries, and they cannot satisfactorily ease the fluctuation of vital signs caused by pneumoperitoneum. We chose PRVC mode to apply to anesthesia and compared it with PC and VC modes, in order to explore an anesthesia ventilation mode which is clinically appropriate for increasing CO_2 excretion without interfering with pneodynamics and a more suitable anesthesia for laparoscopic surgery.

Pneumoperitoneum can result in different degree of increases in levels of PAWM, PAP and PES in all three ventilation modes. There was no significantly statistical difference in PAWM and PAP in the three groups at each time point ($p > .05$). However, PES in VC mode was significantly higher after pneumoperitoneum than that in PC and PRVC modes. It is indicated that PRVC is an intelligent new ventilation mode that is integrated with the advantages of two types of ventilation modes: VC and PC. The mechanism is to measure the relationship of ventilation volume/pressure each time and regulate the level of next inspiratory pressure based on the results in order to match the actual tidal volume to preset TV. One of characteristics that PRVC has is that airway pressure is low during ventilation, and it can reduce the risk of barotrauma at that time.[11]

$PaCO_2$ and $ETCO_2$ became increased significantly at T_3 in PC and VC modes ($p < .05$), but not in PRVC mode. PC can not only increase levels of $PaCO_2$ and $ETCO_2$, TV in PC Group was but also obviously lower than that in the other two groups ($p < .05$). Schirmer-Mikalsen et al.[2] found that PRVC mode could help patients with traumatic craniocerebral injury keep $PaCO_2$ and intracranial pressure more stable by alternating PC and PRVC ventilation mode to patients with traumatic brain injury every 2 hours. Patients with traumatic craniocerebral injury have spontaneous breathing, irregular change of abdominal pressure is similar to the abdominal compression in the endoscopic surgery, and their experimental results are in consistent with ours. As to the reason, Zheng GJ et al.[12] believed that, in the laparoscopic surgery, artificial pneumoperitoneum caused the intra-abdominal pressure to go up and the diaphragm to move upward, which resulted in lower lung compliance and higher airway pressure. Consequently, lung function is affected with alveolar ventilation decreased, so that the ratio of alveolar ventilation/blood flow and the volume of physiological dead cavities are increased along with increased levels of $PaCO_2$ and $ETCO_2$.

After pneumoperitoneum, PC and VC modes made MAP and HR increased significantly by increasing $PaCO_2$ and $ETCO_2$ ($p < .05$); however, MAP and HR in PRVC group were not significantly increased ($p > .05$), and the vital signs kept stable during the operation. After pneumoperitoneum, MAP and HR in PRVC group were significantly lower than those in PC and VC groups ($p < .05$), patients were with no obvious fluctuation of vital signs and the perfusion in important tracheas was in a constant state.

The application of PC mode to the laparoscopic surgery can not only increase levels of $PaCO_2$ and $ETCO_2$, but also reduce TV with the abdominal pressure increased. Although VC mode cannot reduce TV significantly, levels of $PaCO_2$ and $ETCO_2$ will go up with the increase of the abdominal pressure. The experiment shows that, PRVC mode can effectively reduce the pneumoperitoneum-induced increase of PAWM, PAP and PES without the unusual increase of $PaCO_2$ and $ETCO_2$ during surgery, so as to guarantee the stability of vital signs in perioperative patients. With the popularity of PRVC-mode anesthesia machines in future, PRVC ventilation mode will be an ideal and primary ventilation mode of the anesthesia machine.

In clinical practice, in the face of increased heart rate and blood pressure, anesthesiologists usually control them by enhancing anesthesia and using vasoactive drugs.[13] The application of PRVC mode can lead patients to go through the peri-operation period smoothly. Compared with PC and VC modes, PRVC mode has the following advantages: economical use of narcotic drugs reduces medical costs and medical expenses for patients; reduced use of inhaled narcotics cuts down the emission of abandoned wastes and reduces the pollution to the atmospheric environment; good effect of discharging CO_2 from the body decreases the interference with the intracorporeal environment; the maintenance of stability in the respiratory and the circulatory systems can effectively reduce the incidence of cardiovascular and cerebrovascular accidents. PRVC is a new mechanical ventilation mode of anesthesia machines, only high-end anesthesia workstations and anesthesia machines have the function of this kind. Due to high expenses of such anesthesia machines, the popularity of PRVC still needs a long-term process. This experiment is only to explore the comparison of the three ventilation modes under pneumoperitoneum. However, further studies are needed for the improvement in thoracoscopic, hysteroscopic and ERCP surgeries.

Conflicts of Interest Disclosure

The authors have no conflicts of interest related to this article.

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