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Original Article

Comparison of the effects of different mechanical ventilation modes on the incidence of ventilation-associated pneumonia: a case study of patients undergoing thoracic surgery

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Abstract: Objective: To investigate the effects of different mechanical ventilation modes on the incidence of ventilator-associated pneumonia (VAP) in patients undergoing thoracic surgery. Methods: From June 2019 to December 2021, the clinical data of 96 patients undergoing thoracic surgery in Cangzhou Central Hospital were retrospectively analyzed. A total of 44 patients who underwent constant flow mode were included in the control group (CG), and 52 patients who underwent auto flow mode were included in the observation group (OG). The respiratory mechanics, hemodynamics, blood gas analysis and serum levels of lung injury markers at different time points were compared between the two groups, and the incidence of VAP was analyzed. Results: At 1 hour and 4 hours of ventilation, the peak airway pressure (Ppeak), Pmean mean airway pressure (Pmean) and airway resistance (Raw) of the OG were lower than those of the CG, and the dynamic lung compliance (Cdyn) was higher than that of the CG ($P<0.05$). There were no statistically significant differences in mean arterial pressure (MAP), heart rate (HR), blood oxygen saturation (SpO_2), PH, arterial partial pressure of oxygen (PaO_2), arterial partial pressure of carbon dioxide ($PaCO_2$) between the OG and CG at 1 hour and 4 hours of ventilation respectively ($P>0.05$). The serum levels of pulmonary surfactant associated protein A (SP-A), human Clara cell protein (CC16) and serum ferritin (SF) in the OG were lower than those in the CG ($P<0.05$). The incidence of VAP in the OG (3.85%) was lower than that in the CG (15.91%) ($P<0.05$). Conclusion: In mechanical ventilation, auto flow mode can reduce the incidence of VAP, improve respiratory mechanics, and reduce lung injury in patients undergoing thoracic surgery, but has no significant effect on hemodynamics and blood gas analysis.

Keywords: Thoracic surgery, mechanical ventilation, const flow mode, auto flow mode, ventilator-associated pneumonia

Introduction

Mechanical ventilation is a kind of ventilation method that uses mechanical devices to control, replace or alter patients' spontaneous breathing movement, which can effectively improve patients' oxygenation, maintain airway patency and relieve pulmonary artery spasm [1, 2]. However, due to the elevated intrapulmonary pressure and excessive expansion of alveoli during mechanical ventilation, and influenced by special airway management and surgical posture in thoracic surgery, mechanical ventilation is easy to cause a series of pathophysiological changes, increase alveolar permeability and reduce oxygenation capacity, and thus induce different degrees of ventilator-induced lung injury (VILI) [3, 4]. Therefore, it is a key clinical problem to reduce the incidence of acute lung injury, ventilator-associated pneumonia and hypoxemia during mechanical ventilation.

Two-lung ventilation (TLV) and one lung ventilation (OLV) are commonly used protective mechanical ventilation strategies in thoracic surgery. Although they can reduce pulmonary inflammatory response and improve oxygenation, excessive intrathoracic pressure during TLV can easily hinder venous return, reduce cardiac output and lung compliance, and reduce alveolar ventilation. OLV can reduce the lung injury of the operating side, isolate the affected side of the lung, and avoid the inflow of liquid secretions from the affected side into the normal side. Pressure control ventilation (PCV) and volume control ventilation (VCV) are two ventilation modes of OLV. The air supply mode of PVC decelerates air flow, which can prevent local alveoli from being over inflated and expand alveoli with low compliance, but it is difficult to ensure the required tidal volume. The VCV can maintain a certain amount of ventilation and is easy to operate. However, if the dynamic lung compliance (Cdyn) decreases or the airway resistance (Raw) increases, it will induce high airway pressure and aggravate the degree of lung injury [5]. As one of the auxiliary functions of Zeus anesthesia machine, auto flow combines the advantages of VCV and PCV, and is the expansion and supplement of various constant volume ventilation modes [6]. In mechanical ventilation, the combination of VCV and auto flow can accelerate the airway pressure to reach the peak value, promote the even distribution of gas in the lungs, reduce the shunt rate in the lungs, and improve the ventilation blood flow ratio, so as to deliver the preset tidal volume with the flow velocity waveform of the lowest pressure and deceleration wave, which can ensure sufficient tidal volume and minimize lung injury [7, 8]. At present, there are few reports about the effectiveness and safety of VCV mode plus auto flow function at home and abroad. Therefore, whether lung function can be protected in thoracic surgery remains to be verified. In this research, we retrospectively studied the clinical data of 96 patients undergoing thoracic surgery. From the perspectives of VAP, respiratory mechanics and lung injury, we compared the application values of const flow and auto flow in mechanical ventilation, so as to explore the optimal individualized ventilation mode.

Materials and methods

Baseline data

From June 2019 to December 2021, we retrospectively studied the clinical data of 96 patients undergoing thoracic surgery in Cangzhou Central Hospital, including 54 males and 42 females. The age ranged from 39 to 79 years, with an average of (66.35±5.01) years old. There were 45 cases of lung carcinoma, 32 cases of esophageal carcinoma and 19 cases of chest trauma. According to the standards of American Society of Anesthesiologists (ASA), all patients were classified as grade I (45 cases), grade II (39 cases) and grade III (12 cases).

Inclusive criteria: The duration of mechanical ventilation was longer than 4 h; The ASA classification was I-III; There was no acute/chronic pulmonary inflammation or circulatory system disease; The patient received mechanical ventilation for the first time and had no previous history of other ventilator therapy; The clinical data of patients were complete.

Exclusive criteria: There was a history of pleural surgery, heart surgery and tracheotomy; The patient was complicated with severe chronic obstructive pulmonary disease or ventricular tachycardia, frequent ventricular premature beats, atrial fibrillation, atrial flutter and other serious arrhythmias; The patient was accompanied by neuromuscular disease (myasthenia gravis, Guillain-Barre syndrome, etc.), massive pleural effusion, diaphragmatic paralysis, pneumothorax and chest deformity; The patient suffered a flail chest or rib fracture; The patient suffered from severe pulmonary dysfunction, nervous system disease, abnormal coagulation function and immune system suppression; A pacemaker was installed in the body; The patient died during mechanical ventilation.

This study was approved by the Ethics Committee of our hospital (2018-043).

Methods

After entering the room, the patient was given oxygen, and the venous channel was opened. Electrocardiograms, blood oxygen saturation and other measures were routinely monitored. Anesthesia induction: The patient was intravenously injected with 0.2 μg/kg sufentanil (Langfang Branch of Sinopharm Industry Co., LTD., Batch No.: 190306), 0.3 mg/kg etomidate (Jiangsu Enhua Pharmaceutical Co., LTD., Batch No.: 190511) and 0.1-0.2 mg/kg cis-atracurium (Shanghai China Wines Da Industrial Co., LTD., Batch No.: 190421). Bronchial intubation was performed under HVL-1000 visual laryngoscope (Weihai Haigerui Medical Technology Co., Ltd.), and Zeus anesthesia machine was connected. Maintenance of anesthesia: The patient received constant speed infusion of remifentanil (Yichang Humanwell Pharmaceutical Co., LTD., Batch No.: 190506) at a rate of 10-20 μg/(kg·h), cis-atracurium at a rate of 5 μg/(kg·min), and continuous inhalation of sevoflurane (Shanghai Hengrui Pharmaceutical Co., LTD., Batch No.: 190425) [minimum alveolar concentration (MAC): 1.0-1.3]. Mechanical ventilation was performed with tidal volume of 6 ml/kg, respiratory rate of 12-14 min/time, end-tidal carbon dioxide of 30-35 mmHg, inspiratory-to-expiratory ratio of 1:1.5, and intraoperative pneumoperitoneum pressure of 12-14 mmHg. After pneumoperitoneum, patients in the CG were kept in the const flow mode until the end of surgery, while patients in the OG were changed from const flow mode to auto flow mode, and the BIS was controlled at 50-55 and the train of four stimulation (TOF) was 0. During the operation, lactated ringer's solution was administered to maintain a fluid volume between 800 ml and 1000 ml. If the patient develops ventilator-associated pneumonia after surgery, the appropriate single-agent anti-infection therapy with antibacterial spectrum should be selected according to the possible pathogenic bacteria. If the pathogen is a multidrug resistant pathogen, the combination therapy of antibacterial agents should be selected.

Outcome measures

(1) Respiratory mechanics. At 1 hour and 4 hours of ventilation, the peak airway pressure (Ppeak), Pmean mean airway pressure (Pmean) and airway resistance (Raw) were measured by AS-507 lung function detector (Shanghai Yimu Medical Equipment Co., Ltd.), and the lung dynamic compliance (Cdyn), tidal volume (VT) and Ppeak-positive end-expiratory pressure (PEEP) were calculated. (2) Hemodynamics. Solar 8000 M multifunctional monitor (GE Company, USA) was used to continuously measure and record the mean arterial pressure (MAP), blood oxygen saturation (SpO_2) and heart rate (HR) of the patients at 1 hour and 4 hours of ventilation. (3) Blood gas analysis. At 1 hour and 4 hours of ventilation, the radial artery blood (3 ml) was drawn, and PH value, arterial oxygen partial pressure (PaO_2) and arterial carbon dioxide partial pressure ($PaCO_2$) were measured by PL2000 automatic blood gas analyzer (Shanghai Hanfei Medical Equipment Co., Ltd.). (4) Lung injury markers. At 1 hour and 4 hours of ventilation, the radial artery blood (3 ml) was drawn and centrifuged for 10 min (centrifugal radius: 6 cm, rotating speed: 3000 r/min), and then the supernatant was collected. Enzyme-linked immunosorbent assay (kit manufacturer: Shanghai Yuduo Biotechnology Co., LTD., Batch No.: 180624) was used to test the serum levels of pulmonary surfactant associated protein A (SP-A) and human Clara cell protein (CC16). Radioimmunoassay (kit manufacturer: Tianjin Union Medical Technology Group Co., LTD., Batch No.: 181008) was used to measure the levels of serum ferritin (SF). (5) VAP. The patient met the diagnostic criteria for ventilator-associated pneumonia [9]. If there is progressive infiltrating shadow or new focus on chest X-ray film after mechanical ventilation for more than 48 h in patients with tracheotomy or tracheal intubation, and the following two manifestations are met at the same time, the patient was diagnosed as ventilator-associated pneumonia: ① The peripheral blood white blood cell count was greater than 10×10^9/L or less than 4×10^9/L. ② Body temperature was below 36°C or above 38°C. ③ There was purulent secretion in trachea and bronchus. After excluding pulmonary diseases such as pulmonary tuberculosis, acute respiratory distress syndrome, pulmonary edema and pulmonary embolism, pneumonia within 48 hours after extubation and ventilator weaning was still judged as ventilator-associated pneumonia.

Statistical methods

SPSS 24.0 was used for statistical analysis, and the measuring materials conforming to the normal distribution were expressed by ($\overline{X} \pm S$) and tested by t. The enumeration data were expressed by rate and tested by χ^2. The difference was statistically significant with $P<0.05$. GraphPad Prism 7 was used to process the images.

Results

Baseline data

There was no statistically significant difference in gender, age, anesthesia time, ventilation time, operation time, disease type and ASA grade between the two groups ($P>0.05$, **Table 1**).

Respiratory mechanics

At 1 hour and 4 hours of ventilation, Ppeak, Pmean and Raw in the OG were lower than those in the CG, and Cdyn was higher than those in the CG ($P<0.05$, **Figure 1**).

Table 1. Comparison of baseline data between the two groups (n, $\bar{X}\pm S$)

Groups	Cases	Male/female	Age (years old)	Anesthesia time (min)	Ventilation time (h)	Disease type	ASA grade
						Lung cancer/esophageal cancer/thoracic trauma	Grade I/II/III
Control group	44	26/18	67.15±5.53	331.52±15.74	6.86±1.16	21/15/8	21/19/4
Observation group	52	28/24	65.96±4.29	329.84±16.39	6.29±1.89	24/17/11	24/20/8
χ^2/t		0.266	1.186	0.510	1.741	0.133	0.899
P		0.606	0.239	0.611	0.085	0.936	0.638

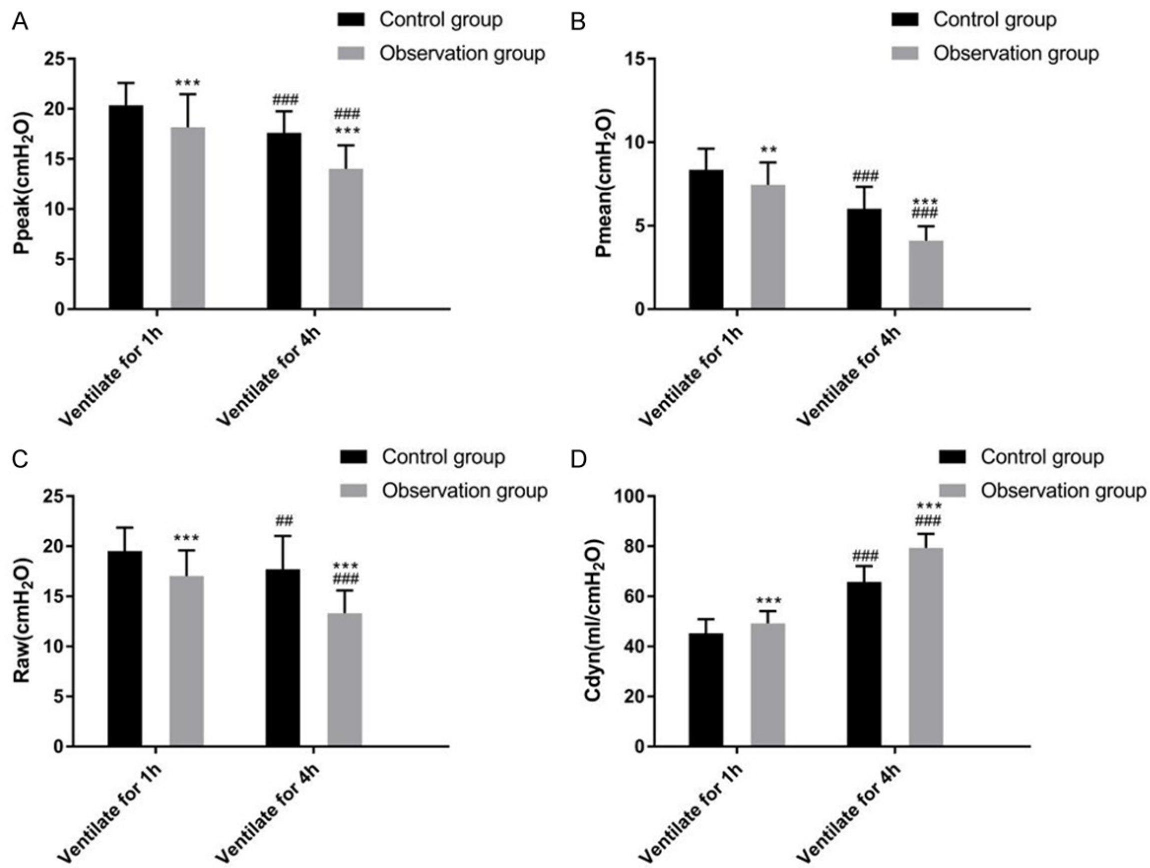

Figure 1. Comparison of respiratory mechanics between the two groups after ventilation. Note: (A) shows peak airway pressure; (B) shows Pmean mean airway pressure; (C) shows airway resistance; (D) shows dynamic lung compliance. Compared with the CG, $^{**}P<0.01$, $^{***}P<0.001$; Compared with ventilation for 1 h in this group, $^{\#\#}P<0.01$, $^{\#\#\#}P<0.001$.

Hemodynamics

At 1 hour and 4 hours of ventilation, there were no statistically significant differences in MAP, SPO_2 and HR between the two groups (P>0.05, **Figure 2**).

Blood gas analysis

At 1 hour and 4 hours of ventilation, there were no statistically significant differences in PH value, PaO_2 and $PaCO_2$ between the two groups (P>0.05, **Figure 3**).

Serum levels of lung injury markers

There were no statistically significant differences in serum SP-A, CC16 and SF levels between the OG and CG at 1 hour of ventilation (P>0.05). At 4 hours of ventilation, the serum SP-A, CC16 and SF in the OG were lower than those in the CG (P<0.05) (**Figure 4**).

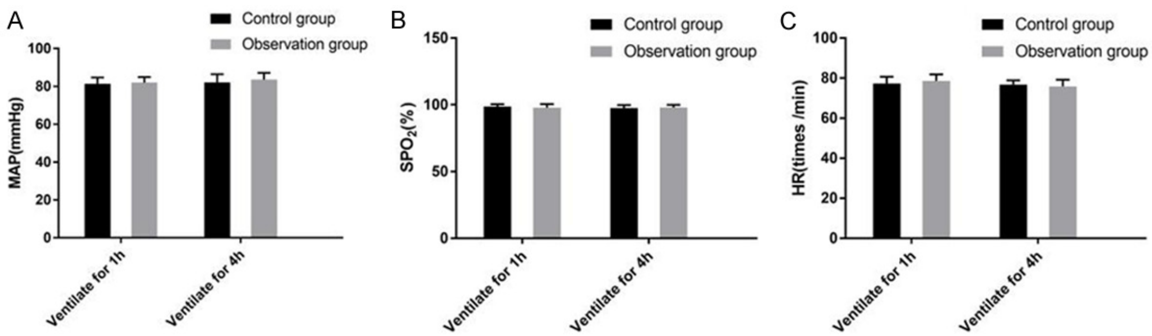

Figure 2. Comparison of respiratory mechanics between the two groups after ventilation. Note: (A) is mean arterial pressure; (B) is blood oxygen saturation; (C) is heart rate.

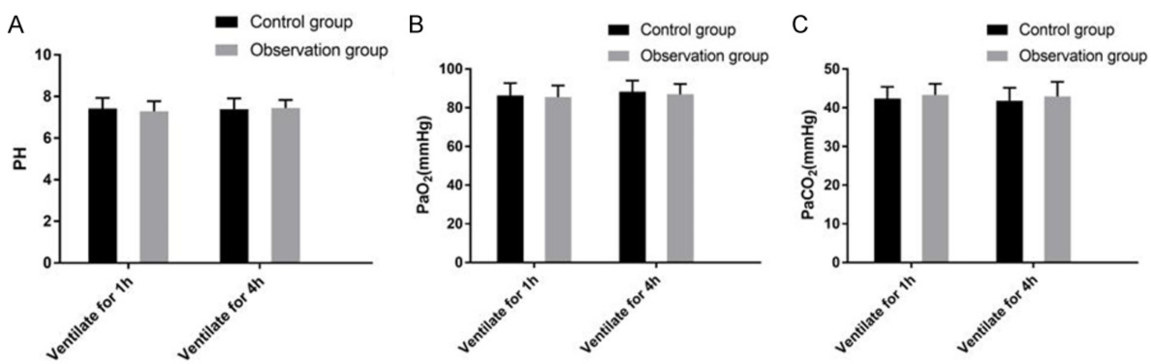

Figure 3. Comparison of respiratory mechanics between the two groups after ventilation. Note: (A) is hydrogen ion concentration; (B) is pressure of oxygen; (C) is pressure of carbon dioxide.

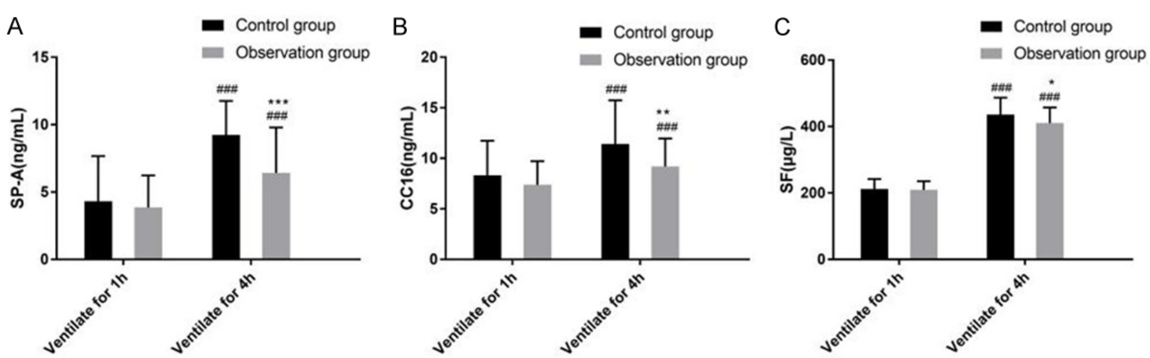

Figure 4. Comparison of serum levels of lung injury markers between two groups after ventilation. Note: (A) is surfactant associated protein A; (B) is human Clara cell protein; (C) is serum ferritin. Compared with the CG, $^{*}P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$; Compared with ventilation for 1 h in this group, $^{\#\#\#}P<0.001$.

Incidence of VAP

In the CG, there were 7 cases of VAP, with an incidence of 15.91%. In the OG, there were 2 cases of VAP, with an incidence of 3.85%. The incidence of VAP in the OG was lower than that in the CG, and the difference was statistically significant ($\chi^2=4.082$, $P=0.043$). None of the 9 patients with VAP had multi-drug resistant pathogens, and their symptoms were gradually relieved after single-agent anti-infection treatment with antibacterial spectrum.

Discussion

VCV is one of the commonly used ventilation modes in general anesthesia of thoracic surgery, which can ensure a certain ventilation volume. However, excessive ventilation pressure during mechanical ventilation can cause the gas in alveoli to spill out to the tissues around the lungs and alveolar interstitium, which causes barotrauma [10, 11]. Therefore, the mechanical ventilation aims to reduce lung injury and airway pressure on the basis of ensuring adequate tidal volume.

In this research, the results revealed that the Ppeak, Pmean and Raw of the OG were lower than those of the CG, and the Cdyn was higher than that of the CG at 1 hour and 4 hours of ventilation, but there were no significant differences in MAP, SPO_2, HR, PH, PaO_2 and $PaCO_2$ between the OG and CG. It can be seen that the auto flow mode in mechanical ventilation can improve the respiratory function of patients, but has minor influence on hemodynamics and blood gas analysis indexes. Arslan et al. [12] have found that VCV combined with auto flow mode can improve respiratory mechanics and Cdyn of patients undergoing open heart surgery. Yao et al. [13] have reported that VCV ventilation mode combined with auto flow function can increase Cdyn, reduce Ppeak and neutrophil elastase (NE) levels, but it does not significantly improve arterial oxygenation function, which is essentially consistent with the conclusion of this research. However, other scholars put forward different views. Zheng et al. [14] pointed out in a meta-analysis of random effect model that the PaO_2 of VCV plus auto flow at 1 h of ventilation was significantly higher than that of VCV alone. Pu et al. [15] have revealed that the combination of VCV and auto flow mode in mechanical ventilation can significantly improve the oxygenation and respiratory mechanical function of patients during operation. The results reflected by domestic and foreign studies are different, so the influence of VCV mode plus auto flow function on blood gas indexes and hemodynamics still needs to be further confirmed. The reasons for the above differences may be related to the following two points: First, all patients received lung protective ventilation strategy during mechanical ventilation in this research, which can achieve lung protection and improve oxygenation to a certain extent. Secondly, the participants selected in this research are all patients undergoing thoracic surgery, and their preoperative pulmonary function is normal, so there is a certain compensatory mechanism for hypoxia during operation.

Relevant data show that the incidence of VILL during mechanical ventilation is as high as 6.2%-24% in patients without lung injury before operation. If the patient with VILL is not treated in time, it can develop into adult respiratory distress syndrome, systemic multi-system organ failure and so on, which will affect the prognosis of patients [16, 17]. Mechanical ventilation can induce the up-regulation of cytokines such as interleukin (IL)-1β, which leads to the pre-inflammatory state of the body, promotes the synthesis of acute protein such as SF, increases the release of superoxide anion, damages the immune system and lung function, and then leads to VILL. Tracheal intubation, anesthesia and other operations during mechanical ventilation may damage patients' tracheal epithelial cells and mucociliary clearance, inhibit cough reflex, and provide a fast passage for bacteria from the upper respiratory tract to the lower respiratory tract, thus easily inducing VAP [18]. SP-A can maintain the homeostasis of alveolar epithelium, regulate immune defense and maintain the stability of alveolar structure during lung injury, and may be involved in the mechanism of remodeling, repair and regeneration of lung parenchyma. CC16 is secreted by Clara cells distributed in bronchiole mucosa of lung, which can protect pulmonary surfactant from degradation and remove harmful substances deposited in the respiratory tract. Watson et al. [19] have revealed that SP-A can maintain lung homeostasis through the dual effects of immunomodulation and anti-infection. Wang et al. [20] have revealed that the serum CC16 level is positively correlated with the severity of ventilator-associated pneumonia in the elderly, and it can effectively predict the prognosis of patients. In this research, the serum SP-A, CC16 and SF of the OG at 4 hours of ventilation were lower than those of the CG, and the incidence of VAP was less than that of the CG. Laski et al. [21] have revealed that compared with const flow, auto flow mode can reduce mechanical ventilation complications such as ventilator-associated pneumonia and atelectasis, and improve respiratory mechanics. The conclusion is similar to that of this study. This shows that auto flow mode during mechanical ventilation in patients undergoing thoracic surgery can reduce lung injury and the risk of VAP. The reason may be that the inspiratory flow velocity waveform is a decelerated wave and the airway pressure reaches its peak in a short time. When the airway is blocked, the pressure consumption and eddy current can be reduced, which is conducive to oxygen diffusion and rapid inflation of alveoli, thus reducing the inspiratory peak pressure and improving the diffusion function and gas exchange function in the lung. Inspiratory pressure and flow velocity can be automatically adjusted according to the changes in thoracic and lung compliance and airway resistance of patients, and the preset tidal volume can be met with the lowest airway pressure, which is conducive to improving the ventilation-blood flow ratio and the distribution of gas in the lung, so as to minimize barotrauma and reduce the degree of lung injury [22]. In addition, patients can breathe freely throughout the ventilation cycle, which can increase patient-ventilator coordination, improve patient tolerance and comfort, facilitate patient-ventilator synchronization, and reduce the incidence of VAP.

To sum up, auto flow mode in mechanical ventilation can reduce the incidence of VAP, improve respiratory mechanics, and reduce lung injury in patients undergoing thoracic surgery, but has no significant effect on hemodynamics and blood gas analysis. However, there are still some limitations in this study. For example, this study is a retrospective classification study, and there may be some errors when collecting patient data. The included sample size is limited and the source is single. All the patients were those with normal preoperative pulmonary function who had undergone thoracic surgery, so the protective effect of auto flow mode on lung function of patients with poor lung function needs to be further studied with large sample size.

Disclosure of conflict of interest

None.

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