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Original Article

The effects of different body positions during ventilation on the cardiopulmonary function, blood gas, and inflammation indicators in severe acute respiratory distress syndrome patients

Jinyang Zheng[1*], Shouyan Liu[2*], Junyan Zhang[3], Chengyun Zhao[4], Jiuhui Zhang[5], Yanrong Deng[6], Yuguo Wang[7]

[1]Rehabilitation Ward, Taishan Sanatorium of Shandong Province, Taian, Shandong Province, China; Departments of [2]Emergency Intensive Care Unit, [3]Infection Management, [5]Internal Medicine, The First People's Hospital of Taian, Taian, Shandong Province, China; [4]Outpatient Department of Infectious Diseases, The First People's Hospital of Taian, Taian, Shandong Province, China; [6]The Second Department of Respiratory, Taian Hospital District, The 960th Hospital of Chinese People's Liberation Army, Taian, Shandong Province, China; [7]Cancer Center Office, Taian Cancer Prevention and Treatment Hospital, Taian, Shandong Province, China. [*]Equal contributors and co-first authors.

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Abstract: Objective: To explore the effects of different body ventilation positions on the cardiopulmonary function, blood gas levels, and inflammatory indicators in severe acute respiratory distress syndrome patients. Methods: Eighty-eight patients with severe acute respiratory distress syndrome were randomly divided into group A (n=44) and group B (n=44). The patients in group A were treated with mechanical ventilation in the supine position, and the patients in group B were treated with mechanical ventilation in the lateral position. The cardiopulmonary function indicator changes (the pulmonary ventilation scores, acute physiology and chronic health scores, pulmonary artery systolic pressure levels, and RV/LV), the blood gas indicators (PaO_2, $PaCO_2$, SpO_2, PaO_2/FiO_2), the inflammatory indicators (IL-6, IL-8, TNF-α), the hemodynamic indicators (HR, SBP, DBP), the mechanical ventilation times, hospital stay durations, and the adverse reactions before and after the treatment were compared between the two groups. Results: After the treatment, the PV and APACHE II scores in the two groups were significantly reduced, the RV/LV and pulmonary artery systolic pressures were significantly increased, and the improvement in group B was bigger than it was in group A ($P<0.05$). The PaO_2, SpO_2, and PaO_2/FiO_2 levels were significantly increased, and the $PaCO_2$ levels were significantly reduced in both groups, and the improvement in group B was better than it was in group A ($P<0.05$). The TNF-α, IL-6 and IL-8 concentrations were significantly reduced in both groups, and the concentrations in group B were significantly lower than the concentrations in group A ($P<0.05$). The HR, SBP, and DBP were stable before and after the treatment, with no significant changes, and the differences had no statistical significance ($P>0.05$). The mechanical ventilation times and the hospital stay durations were shorter in group B than they were in group A ($P<0.05$). There was no significant difference in the incidence rate of adverse reactions between the two groups ($P>0.05$). Conclusion: Mechanical ventilation in the lateral decubitus position can effectively and safely improve cardiopulmonary function, improve oxygenation, and reduce the inflammatory response in patients with severe acute respiratory distress syndrome.

Keywords: Severe acute respiratory distress syndrome, mechanical ventilation, body position, cardiopulmonary function, blood gas indicators, inflammatory indicators, hemodynamics

Introduction

Acute respiratory distress syndrome is a pathological symptom involving a diffuse injury of the pulmonary capillaries and an increased pulmonary permeability due to a variety of serious diseases, with respiratory distress and intractable oxygenemia as the main clinical features [1]. Patients with a PaO_2/FiO_2 level ≤100 mmHg and a positive end-expiratory pressure (PEEP) ≥10 cmH_2O are considered to be in the severe range according to European Critical Care

Table 1. Comparison of the general data between the two groups ($\bar{x}$ ± sd; n, %)

Group	Group A (n=44)	Group B (n=44)	t/χ^2	P
Gender (male/female)	28/16	26/18	0.192	0.661
Age (years)	48.6±6.2	49.5±6.7	0.654	0.515
Body Mass Index (kg/m^2)	21.59±1.84	22.07±1.98	1.178	0.242
ICU stay (d)	8.3±2.1	8.7±2.2	0.872	0.385
Etiological constitution			1.636	0.201
Pancreatitis	11 (25.00)	13 (29.55)		
Severe pneumonia	15 (34.09)	16 (36.36)		
Sepsis	9 (20.45)	8 (18.18)		
Aspiration	4 (9.09)	3 (6.82)		
Postoperative infection	5 (11.36)	4 (9.09)		
Concomitant underlying disease			0.258	0.611
Diabetes	8 (18.18)	9 (20.45)		
Hypertension	14 (31.82)	15 (34.09)		
Other	9 (20.45)	7 (15.91)		

Medicine. Mechanical ventilation is the main method of respiratory support therapy. Although there have been rapid advances in modern clinical lung protective strategies for mechanical ventilation, such as limiting the platform pressure and low tidal volume mechanical ventilation, there is still a high mortality rate among the critically ill patients. The correct ventilation strategy is the key to saving patients' lives [2, 3].

The supine position is the most conventional position used for ventilation, and it has a good effect. However, since the patient is kept in supine position for a long time, it will compress the skin to different extents, resulting in circulatory disorders and increasing the risk of pressure ulcers [4]. In recent years, a number of studies have confirmed that supine position ventilation is a salvage treatment for patients with severe acute respiratory distress syndrome. It can significantly improve the patients' oxygenation indicators and reduce their mortality in the short term [5, 6]. However, the supine position is not a physiological position, so it is difficult to achieve the supine position during ventilation, especially for obese patients, and there are also many controversies about the effects of ventilation in the supine position on the patient's cardiopulmonary function [7]. Compared with the ventilation in the supine position, the application rate of mechanical ventilation in the lateral decubitus position is lower, and there are few relevant studies. Some foreign researchers use a special bed, which can allow a maximum rotation of 124° axial rollover, that is, mechanical ventilation in a lateral decubitus position. One experiment revealed that this position can effectively improve oxygenation without affecting the hemodynamics [8]. It is important because this position is more labor-saving than the supine position, easy to implement, meets more physiological needs, and improves patient comfort. Based on this, this study explored the effects of different ventilation body positions on the cardiopulmonary function, blood gas levels, and inflammatory indicators in patients with severe acute respiratory distress syndrome. It is reported as follows.

Materials and methods

General data

A total of 88 patients with severe acute respiratory distress syndrome admitted to The First People's Hospital of Taian from January 2019 to February 2020 were recruited as the study cohort and randomly divided into group A and group B, with 44 patients in each group. There was no significant difference in the general data between the two groups (P>0.05). See **Table 1**. The study was reviewed and approved by the Medical Ethics Committee of The First People's Hospital of Taian.

Inclusion criteria

Inclusion criteria: All the patients met the criteria for the diagnosis of severe acute respiratory distress syndrome according to the European Critical Care Medicine diagnostic criteria for severe acute respiratory distress syndrome, patients whose PaO_2/FiO_2 levels were ≤100 mmHg, patients whose PEEP levels were ≥10 cmH_2O, patients with an acute onset of the disease, patients whose X-rays showed an infiltration shadow, patients whose mechanical ventilation times were >72 h, and patients whose families signed the informed consent form for the study [9].

Exclusion criteria: Patients with hemodynamic instability, patients with tumors, intracranial hypertension, or spinal injuries, patients who had undergone fracture surgery or abdominal surgery, patients with a head and face injury, patients with mandatory respiratory depression, pulmonary encephalopathy, patients who abandoned the treatment or who died halfway through the study, obese patients, patients with an abnormal immune system, and patients with a history of tracheal transplantation.

Methods

All the patients were given anti-infection, acid-base balance, water and electrolyte balance corrections, nutritional support and other symptomatic treatment according to their pathogenesis. A Drager Savina 300 ventilator (Draegerwerk AG & Co. KGaA, Germany) was used according to the *Guidelines for Mechanical Ventilation in Patients with Acute Respiratory Distress Syndrome*, using intermittent positive pressure ventilation or intermittent mandatory ventilation + pressure support ventilation support mode [10]. The respiratory rate was 14-20 times/min, the respiratory rate was 1:2, the tidal volume was 6-8 mL/kg, the PEEP was 6-10 cmH_2O, and the FiO was 40%-60%. Before the ventilation, the each patient's respiratory secretions were fully cleared, and after the start of mechanical ventilation, intravenous sedation with 5 μg/kg midazolam (Jiangsu Jiuxu Pharmaceutical Co., Ltd., China) and 15 μg/kg fentanyl (Langfang Branch of China National Pharmaceutical Industry Co., Ltd., China) was required, followed by a controlled intravenous infusion of 0.3-0.6 μg/(kg·min) midazolam and 0.025-0.1 μg/(kg·min) fentanyl using an infusion pump. If necessary, muscle relaxation was maintained using an intermittent intravenous injection of 0.08-0.1 mg/kg vecuronium (Jiangsu Huatai Chenguang Pharmaceutical Co., Ltd., China). Group A was treated with mechanical ventilation in the supine position, with the head of the bed elevated 30°-40°. Group B was treated with mechanical ventilation in the lateral decubitus position, and after monitoring each patient's hemodynamic stability, the head was deviated to the right, and the trunk and buttocks were inclined to the right, and a soft pillow was used as padding to prevent the compression of the facial limbs, and the left leg was rotated 90° to the right, the right leg was extended, and the patient was transferred to supine ventilation 1-2 hours later.

Outcome indicators

Cardiopulmonary function indicators

The total pulmonary ventilation scores: The pulmonary ventilation (PV) was evaluated using pulmonary ultrasonography, and the total pulmonary ventilation score was calculated [11]; (1) 0 point (N): less than 3 isolated B lines or lung sliding signs were observed in the normal ventilation area; (2) 1 point (B1): moderate lung tissue loss of pneumatization, and multiple clear B lines were observed; (3) 2 points (B2): severe lung tissue loss of pneumatization, and the fusion B line density was observed; (4) 3 points (C): lung parenchyma, which could resemble hepatoid structures and bronchial inflation signs; 3 points (C/P): combined pleural effusion, and the worst value during the ventilation was used as the measurement result, and all the scores were accumulated as PV.

APACHE II scores: The patient's condition and prognosis were evaluated using Acute Physiology and Chronic Health Evaluation (APACHE II score), mainly including three parts: acute physiology, chronic health status, and age [12]. The final score was the sum of the three, with a total possible score of 71 points, and the higher the score, the more severe the condition.

RV/LV and pulmonary artery systolic pressure: The ratio of the right ventricular end-diastolic diameter to the left ventricular end-diastolic diameter (RV/LV) and the pulmonary arterial systolic pressure were measured using vivid E8 echocardiography (GE, USA).

Blood gas indicators

Four milliliters of peripheral venous blood were drawn from the patients before and after the treatment, and the serum was obtained using centrifugation at 2,500 r/min for 15 min. The arterial partial pressure of oxygen (PaO_2), the arterial partial pressure of carbon dioxide ($PaCO_2$), the saturation (SpO_2), and oxygenation indicators (PaO_2/FiO_2) levels were measured using a GEM3000 blood gas analyzer (Beckman, USA).

Inflammatory indicators

Four milliliters of peripheral venous blood were drawn from the patients before and after the treatment, and the serum was obtained throu-

Table 2. Comparison of the cardiopulmonary function between the two groups ($\overline{x}$ ± sd)

Group	Group A (n=44)	Group B (n=44)	t	P
PV (points)				
Before treatment	27.68±3.51	27.57±3.46	0.148	0.883
After treatment	22.45±2.14***	19.45±1.87***	7.002	<0.001
APACHE II score (points)				
Before treatment	28.67±3.64	29.06±3.78	0.493	0.623
After treatment	16.68±1.54***	14.14±1.21***	8.603	<0.001
RV/LV				
Before treatment	0.51±0.09	0.50±0.09	0.521	0.604
After treatment	0.60±0.11***	0.67±0.12***	2.852	0.005
Pulmonary artery systolic pressure (mmHg)				
Before treatment	31.62±5.48	31.39±5.37	0.199	0.843
After treatment	34.22±5.81***	37.54±6.57***	2.511	0.014

Note: Compared with the group before treatment, ***P<0.001. PV: pulmonary ventilation; APACHE: Acute Physiology and Chronic Health Evaluation.

gh centrifugation at 2,500 r/min for 15 min. The tumor necrosis factor (TNF-α) levels were measured using enzyme-linked immunosorbent assays using an IAMMGE detector (Beckman, USA). The interleukin-6 (IL-6) and interleukin-8 (IL-8) levels were measured using radioimmunoassays with the help of a gc-2010 radioimmunoassay counter (Anhui Zhongke Zhongjia Scientific Instrument, China). The kits were purchased from Shanghai Jinma Experimental Equipment Co., Ltd., China.

Hemodynamic indicators

The heart rates (HR), systolic blood pressures (SBP), and diastolic blood pressure (DBP) changes were observed and recorded before and after the treatment.

Treatment-related indicators

The duration of the mechanical ventilation and the durations of the hospital stays were recorded.

Adverse reactions

The occurrence of any adverse reactions such as flatulence, decreased blood pressure, excessive sedation, or pulmonary infections were recorded during the treatment.

Statistical methods

SPSS 22.0 software was used. The measurement data in accordance with a normal distribution were expressed as $\overline{x}$ ± sd. Independent sample t-tests were used for the comparisons between groups. Paired t-tests were used for the intra-group before-after comparisons. The enumeration data were expressed as n/%. χ^2 tests were used for the comparisons. P<0.05 was considered statistically significant.

Results

General data

There was no significant difference in the general data such as gender, age, body mass index, ICU stay, etiological composition or combined underlying diseases between the two groups (P>0.05). Therefore, the two groups were comparable. See **Table 1**.

Cardiopulmonary function indicators

Before the treatment, there was no significant difference in the PV, APACHE II scores, RV/LV, or the pulmonary artery systolic pressure between the two groups (P>0.05), and after the treatment, the PV and APACHE II scores were significantly decreased, the RV/LV, and the pulmonary artery systolic pressures were significantly increased in both groups, and the improvement in group B was better than it was in group A (P<0.05). See **Table 2** and **Figure 1**.

Blood gas indicators

Before the treatment, there was no significant difference in the blood gas indicators between the two groups (P>0.05). After the treatment, the PaO_2, SpO_2, and PaO_2/FiO_2 were significantly increased, and the $PaCO_2$ was signifi-

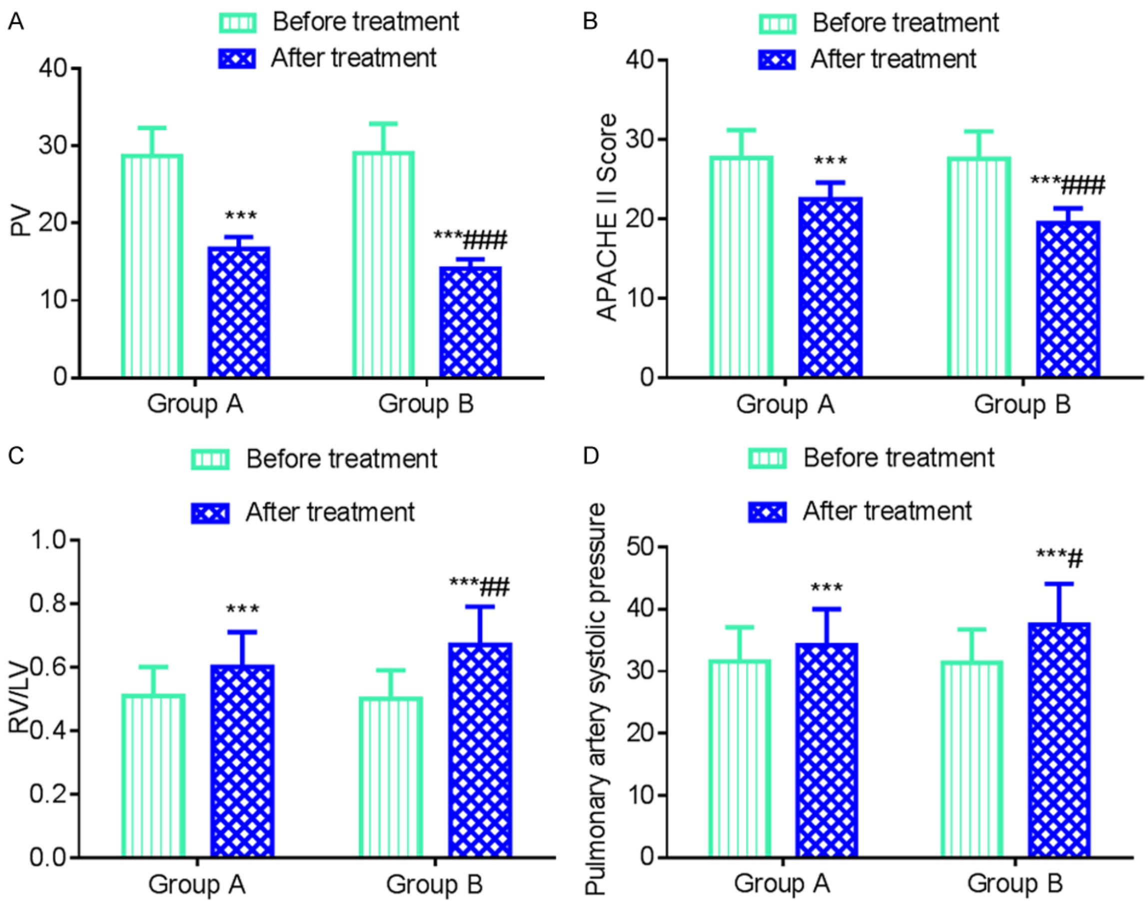

Figure 1. Comparison of the cardiopulmonary function between the two groups. A: PV; B: APACHE II scores; C: RV/LV; D: Pulmonary artery systolic pressure. Compared with the group before the treatment, $^{***}P<0.001$; compared with group B after the treatment, $^{\#}P<0.05$, $^{\#\#}P<0.01$, $^{\#\#\#}P<0.001$. PV: pulmonary ventilation; APACHE: Acute Physiology and Chronic Health Evaluation.

Table 3. Comparison of the blood gas indicators between the two groups ($\bar{x}$ ± sd)

Group	Group A (n=44)	Group B (n=44)	t	P
PaO_2 (mmHg)				
Before treatment	53.19±7.51	52.98±7.34	0.133	0.895
After treatment	67.54±8.69***	74.01±9.35***	3.362	0.001
$PaCO_2$ (mmHg)				
Before treatment	54.84±7.98	55.13±8.23	0.168	0.867
After treatment	46.65±5.76***	40.38±4.58***	5.652	<0.001
SpO_2 (%)				
Before treatment	80.25±9.23	79.96±9.45	0.146	0.884
After treatment	90.17±9.15***	96.58±11.76***	2.854	0.005
PaO_2/FiO_2 (mmHg)				
Before treatment	89.53±10.25	91.87±11.84	0.991	0.324
After treatment	213.25±29.47***	246.10±32.55***	4.963	<0.001

Note: Compared with the group before the treatment, $^{***}P<0.001$.

cantly decreased in both groups, and the improvement in group B was bigger than it was in group A (P<0.01). See **Table 3**.

Inflammatory indicators

Before the treatment, there was no significant difference in the inflammatory indicators between the two groups (P>0.05). After the treatment, the TNF-α, IL-6, and IL-8 concentrations were significantly decreased in both groups, and the indicators were significantly lower in group B than they were in group A (P<0.001). See **Table 4**.

Hemodynamic indicators

The HR, SBP, and DBP levels were stable before and after the treatment in both groups,

Table 4. Comparison of the inflammatory indicators between the two groups ($\bar{x}$ ± sd)

Group	Group A (n=44)	Group B (n=44)	t	P
TNF-α (μg/mL)				
Before treatment	17.03±2.98	17.05±3.05	0.031	0.975
After treatment	10.39±2.14***	8.47±1.52***	4.852	<0.001
IL-6 (μg/mL)				
Before treatment	15.09±2.61	15.11±2.74	0.035	0.972
After treatment	9.23±2.05***	6.66±1.32***	6.992	<0.001
IL-8 (pg/mL)				
Before treatment	16.38±2.74	16.57±2.81	0.321	0.749
After treatment	10.68±2.16***	6.41±1.05***	11.793	<0.001

Note: Compared with the group before the treatment, ***P<0.001.

Table 5. Comparison of the hemodynamics between the two groups ($\bar{x}$ ± sd)

Group	Group A (n=44)	Group B (n=44)	t	P
HR (beats/min)				
Before treatment	113.35±15.67	111.59±14.75	0.543	0.589
After treatment	110.59±15.18	109.71±14.88	0.275	0.784
SBP (mmHg)				
Before treatment	112.18±16.36	110.58±15.91	0.465	0.643
After treatment	114.23±16.69	113.18±16.40	0.298	0.766
DBP (mmHg)				
Before treatment	72.44±9.85	74.68±10.49	1.033	0.344
After treatment	74.63±10.84	74.56±10.55	0.031	0.975

Table 6. Comparison of the duration of the mechanical ventilation and the hospital stays between the two groups ($\bar{x}$ ± sd, day)

Group	Duration of mechanical ventilation	Hospital stay
Group A (n=44)	8.1±1.5	19.5±1.1
Group B (n=44)	6.8±1.1	17.3±1.3
t	4.636	8.569
P	<0.001	<0.001

with no significant changes, so the differences were not statistically significant (P>0.05). See **Table 5**.

The durations of the mechanical ventilation and the hospital stays

The durations of the mechanical ventilation and the hospital stays in group B were significantly lower than they were in group A (P<0.001). See **Table 6**.

Adverse reactions

There was no significant difference in the incidence rate of adverse reactions between the two groups (P>0.05). See **Table 7**.

Discussion

The strategy to treat acute respiratory distress syndrome is to promote atelectasis or atrophic alveolar recruitment, expand the lung volume, reduce the intrapulmonary shunt rate and improve the hypoxic state. Mechanical ventilation can improve gas distribution in the lungs, reduce respiratory resistance, and increase the oxygenation indicators to relieve the dyspnea symptoms [13]. Since an excessive inflammatory response is the essence of acute respiratory distress syndrome. An Excessive release of the inflammatory mediators will directly lead to a severe diffuse injury of the pulmonary vascular endothelium and the alveolar epithelium, increase the vascular permeability in the lungs, make the alveolar space exudate protein-rich fluid, form a hyaline membrane and a pulmonary edema, then reduce the lung volume, and reduce the lung compliance, resulting in a severe imbalance of the pulmonary blood flow to ventilation ratio causing ischemia and hypoxia. Hypoxia will aggravate the inflammatory response, thus creating a vicious cycle and further aggravating the lung injury [14]. Therefore, in addition to the corresponding anti-infection treatment, a reasonable mechanical ventilation mode can regulate the secretion of the inflammatory factors by improving the oxygenation and controlling the excessive inflammatory response. However, unreasonable ventilation modalities can aggravate the damage to the capillary endothelial cells and the alveolar epithelium, exposing the capillary basement membrane and creating opportunities for basement membrane adhesion and the activation of the inflammatory cells and their entry into the lungs

Table 7. Comparison of the adverse reactions between the two groups (n, (%))

Group	Flatulence	Blood pressure decreased	Sedation too deep	Lung infection	Total Occurrence
Group A (n=44)	0 (0.00)	2 (4.55)	1 (2.27)	0 (0.00)	3 (6.82)
Group B (n=44)	1 (2.27)	1 (2.27)	0 (0.00)	1 (2.27)	3 (6.82)
χ^2					0.000
P					1.000

[15]. Kong et al. pointed out that mechanical ventilation in the lateral decubitus position can effectively reduce the inflammatory response in acute respiratory distress syndrome and ventilation in the lateral position combined with vibration expectoration is better [16]. The results of this study pointed out that the inflammatory factor levels in both groups were reduced after the treatment, confirming that by improving oxygenation, the inflammatory response can be reduced to a certain extent, and the improvement in group B was better than it was in group A, suggesting that mechanical ventilation in the lateral decubitus position improves oxygenation and has a better effect in controlling the inflammatory response.

According to the results of the study, the improvement in the blood gas indicators in group B was better than it was in group A, and the improvement in the cardiopulmonary function was better than it was in group A, suggesting that mechanical ventilation in the lateral decubitus position is more conducive to improving patients' respiratory and cardiopulmonary functions. Li et al. pointed out that lateral decubitus ventilation can improve oxygenation and airway sputum drainage in patients with acute respiratory distress syndrome, but it has no significant effect on the hemodynamics and ventilator mechanical indicators, which is also consistent with the results of this study [17]. Although the mechanism of improving oxygenation using mechanical ventilation in lateral decubitus position has not yet been clarified, it may be due to the following facts learned from the results of this study: 1) Due to the gravity-dependent effect, when the patient is in a supine position, the thoracic pressure gradient will be increased from ventral to dorsal, and the pulmonary exudate can easily fall in the drooping lung area, aggravating the regional lesions, which is also an important theoretical basis for the postural treatment of the disease. Mechanical ventilation in the lateral decubitus position can increase lung volume and can allow a collapse and atelectasis by reducing this gradient, which is also consistent with the thrust of the strategies for the treatment of acute respiratory distress syndrome [18, 19]. 2) With lateral decubitus ventilation, the pulmonary edema fluid will be redistributed ventrally, which promotes the collapse and atelectasis alveolar recruitment [20]. 3) Gattinoni et al. pointed out that patients with acute respiratory distress syndrome were treated with supine mechanical ventilation, and the shunt site was vertically distributed along the axial direction of gravity, resulting in a transpulmonary pressure lower than the airway opening pressure, affecting the ventilation effect, while lateral position ventilation can reduce the partial gravity dependence, and then improve the ventilation effect [21]. 4) Thoracic pressure will increase pulmonary vascular resistance, increase right heart afterload, and lead to abnormal cardiac function. The lateral decubitus position can improve the ventilation status of the compressed area through the direct effect of abdominal organ weight, eliminating the compression effect of solid lung tissue and the compression effect of the lung tissue and heart [22, 23]. 5) The lateral decubitus position changes the position of the diaphragm and the mode of movement of the phrenic nerve, which facilitates the regulation of the respiratory movement and improves the ventilatory function. At the same time, the lateral decubitus position is prone to increase the flow into the large airway due to gravity, which also facilitates the drainage of secretions and makes the drainage more adequate [24]. 6) The patient is in a supine position for a long time without any muscle movement, which can also easily affect the blood circulation and form complications such as deep venous thrombosis and pressure ulcers. Appropriate turning can also prevent these complications, enhance muscle strength, and have positive implications for the disease outcome. The results of this study showed that the hemodynamics of patients in both groups were stable during the treatment, and the incidence of adverse reactions was also low, indicating that mechanical ventilation in the lateral decubitus position will not cause severe fluctuations in HR, MAP, etc. due to the change of body position for patients in a critical condition. On the other hand, our results indicate that this body position is effective and safe for improving the prognosis, without increasing the patient's discomfort. The mechanical ventilation and hospital stays in group B were also higher/longer than they were in group A, indicating that mechanical ventilation in the lateral decubitus position can also help patients breathe spontaneously as soon as possible and promote the rehabilitation from the disease.

In addition, a common complication of mechanical ventilation is ventilator-associated lung injury, and the lung-protective mechanical ventilation strategy can avoid the excessive expansion of the alveoli and pull the vascular endothelial cells and alveolar epithelium through the neap tidal volume and optimal PEEP, so as to better improve body oxygenation and enhance the prognosis. Mechanical ventilation in the lateral decubitus position decreases the thoracic pressure and reduces the repeated opening and closing and overdistension of the airways in gravity-dependent and non-gravity-dependent areas of the lungs, thereby reducing ventilator-associated lung injuries [25].

In summary, mechanical ventilation therapy in the lateral decubitus position can effectively and safely improve cardiopulmonary function, improve oxygenation, and reduce the inflammatory responses in patients with severe acute respiratory distress syndrome. However, there may be bias in the results due to the small sample size in this study. Due to the influence of time, funds and other factors, the study did not explore whether cardiopulmonary function injury caused by mechanical ventilation can be recovered. Since the patients were given relevant symptomatic treatment during the ventilation therapy, which may have also affected the study results, it is necessary to prolong the follow-up and related mechanisms in the future for further in-depth studies.

Disclosure of conflict of interest

None.

Address correspondence to: Shouyan Liu, Department of Emergency Intensive Care Unit, The First People's Hospital of Taian, No. 289 Lingshan Street, Taishan District, Taian 271000, Shandong Province, China. Tel: +86-15092833298; E-mail: liushouyan1tai@163.com

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