

Effects of SI and PCV on respiratory mechanics, early central drive and hemodynamics in patients with ARDS

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Abstract. Effects of sustained inflation (SI) and pressure-controlled ventilation (PCV) on respiratory mechanics, early central drive, and hemodynamics in patients with acute respiratory distress syndrome (ARDS) were investigated and compared. A retrospective analysis of 26 patients with ARDS, who were admitted to the Yiwu Central Hospital from March 2015 to March 2016, was performed. According to the ventilation method adopted by the patients with ARDS, 13 patients who received SI treatment were included in the SI group and 13 patients who received PCV treatment were included in the PCV group. The condition of central drive of the patients in the two groups was recorded and calculated continuously before and after recruitment maneuver (RM), the changes of each indicator of the respiratory function and hemodynamics were recorded and calculated before and after RM at 1, 10, 20 and 30 min. The differences were not statistically significant when comparing PIP, Pplate and Crs in patients in the SI group and the PCV group before RM with those after RM at 1, 10, 20 and 30 min ($P>0.05$), the differences were not statistically significant when comparing heart rate and mean arterial pressure in patients in the SI group and the PCV group before RM with those after RM at 1, 10, 20 and 30 min ($P>0.05$). However, central venous pressure in patients in the SI group after RM at 10 and 20 min was significantly higher than that in the PCV group, and the differences were statistically significant ($P<0.05$). VT/RMS, VE/RMS and ΔP_{di} /RMS in the SI group and the PCV group after RM were significantly higher than those before RM, and the differences were

statistically significant ($P<0.05$). There was little difference in the effect between SI and PCV on respiratory mechanics, early central drive and hemodynamics in patients with ARDS, and both mechanical ventilation methods enhanced the effect of central-mechanical-ventilation coupling after RM. Therefore, the two mechanical ventilation methods, SI and PCV, were equally available for patients with ARDS.

Introduction

Acute respiratory distress syndrome (ARDS) is edema that appears in diffuse pulmonary interstitial and alveolus and is caused by a variety of serious intrapulmonary and extrapulmonary diseases. The diseases facilitate the increase of lung water content, the decrease of lung volume, the continuous reduction of lung compliance and the collapse of alveolus. ARDS severely affects the function of ventilation and blood flow exchange (1,2). The fatality rate of ARDS is extremely high, and progressive respiratory distress and refractory hypoxemia are clinical syndromes characterized by ARDS (3,4). ARDS is a complicated syndrome whose nosogenesis is multifactorial due to the involvement of different pathogenies (5,6). Respiratory mechanics, early central drive and hemodynamics are commonly used as observation indicators of ARDS (7,8).

Mechanical ventilation therapy and non-mechanical ventilation therapy are the two main methods for the treatment of ARDS (9). Recruitment maneuver (RM) is mechanical ventilation therapy, which reopens the alveoli without ventilation or hypoventilation and improves the compliance of oxygenation and respiratory system. Mechanical ventilation therapy is an important treatment for ARDS (10). The common RM techniques include sustained inflation (SI) (11), pressure-controlled ventilation (PCV) (12), and IP (13). The most basic mechanical modes for patients with ARDS are SI and PCV (14). As a method which promotes RM of collapsed alveoli, SI can significantly improve lung compliance, oxygenation, and offset the disadvantages that collapsed alveoli hardly can achieve RM when the lung protective ventilation is strategized (15). PCV refers to a process in which the airway pressure and inspiratory time of the respirator are set up in advance. When the airflow enters the lungs quickly and the pressure level in the lungs is equal to the preset pressure level, the speed of the ventilative airflow will slow down and the preset pressure level of the

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respirator is maintained until the termination of inhaling and then exhaling (12). However, there are few studies relating to advantages and disadvantages of the effects of SI and PCV on respiratory mechanics, early central drive and hemodynamics in the treatment of patients with ARDS. This study compared the efficacy and safety of the two RM methods by observing the effects of SI and PCV on respiratory mechanics, early central drive and hemodynamics in patients with ARDS.

Patients and methods

Patient information. Twenty-six patients with ARDS who were admitted to the Yiwu Central Hospital (Yiwu, China) from March 2015 to March 2016 were selected. According to the ventilation method adopted by the patients with ARDS, 13 patients with ARDS who were treated with SI were included in the SI group, including 8 males and 5 females. The age range was from 30 to 66 years, and the average age was 48.03 ± 10.01 years; 13 patients with ARDS who were treated with PCV were included in the PCV group, including 7 males and 6 females. The age range was from 29 to 65 years, and the average age was 48.04 ± 10.03 years. Inclusion and exclusion criteria were: All selected people conformed to the diagnostic criteria of WHO for ARDS (3). Patients who were <18 years old and had serious intracranial hypertension; with pneumothorax, bronchopleural fistula, chronic obstructive pulmonary disease, and hemodynamic instability (systolic pressure >180 or <90 mmHg); who received pulmonary lobectomy within 2 weeks; who had arrhythmia during RM (heart rate >140 beats/min); whose heart rates increased by 20 times/min after RM; whose arterial systolic pressure was abnormal (systolic pressure <90 mmHg); whose arterial systolic pressure decreased by 30 mmHg after RM; whose percutaneous arterial oxyhemoglobin saturation was abnormal (percutaneous arterial oxyhemoglobin saturation <90%) and whose percutaneous arterial oxyhemoglobin saturation decreased by >5% after RM, were excluded.

This study was approved by the Ethics Committee of the Yiwu Central Hospital. Patients who participated in this research had complete clinical data. The signed informed consents were obtained from the patients or the guardians. When comparing the general data of the patients in the two groups, there was no statistically significant differences ($P > 0.05$) (Table I).

Main instruments. Puritan Bennett 840 respirator (20160077; Shanghai Jumu Medical Devices Co., Ltd., Shanghai, China).

Methods. All patients with ARDS took the supine position during the mechanical ventilation. The secretions in airway of patients were completely cleared away before the artificial airway was established, and after patients were sedated and given analgesic, they were treated with ventilation therapy by connecting Puritan Bennett 840 respirator (20160077; Shanghai Jumu Medical Devices Co., Ltd.). A low tidal volume of 6–8 ml/kg were used to control ventilation, and breathing rate was regulated at the frequency of 15 times/min. The vital signs and blood gas analysis of all patients were closely monitored during the RM. The RM was used once in each group. Controlling lung expansion, one of the RM strategies, was used in the SI group: The respirator mode was adjusted to CPAP

mode. The positive end-expiratory pressure ventilation was maintained at 5 cm H₂O, the inspiratory pressure was from 30 to 45 cm H₂O, and the duration was 20 sec. Pressure controlled ventilation was used in the PCV group: The respirator mode was adjusted to BIPAP mode. The pressure was adjusted to a high pressure of 40 cm H₂O and a low pressure of 20 cm H₂O, and this condition was maintained for 2 min, then the ventilation condition and mode were recovered to what it used to be.

Observation indicators

i) **Respiratory mechanics.** The indicators of respiratory mechanics before and after RM at 1, 10, 20 and 30 min were monitored: Peak inflation pressure (PIP) cmH₂O, plateau pressure (Pplate) cmH₂O, and compliance of the respiratory system (Crs) ml/cmH₂O/kg.

ii) **Early central drive.** The indicators of central-mechanical-ventilation coupling before and after RM were monitored, including VE/RMS (l/μV), VT/RMS (ml/μV), ΔPdi/RMS (cmH₂O/μV); VT/RMS and VE/RMS reflected central-ventilation coupling and ΔPdi/RMS reflected central-mechanical coupling.

iii) **Hemodynamics.** Heart rate (HR), mean arterial pressure (MAP), and central venous pressure (CVP) were monitored and recorded before and after RM at 1, 10, 20 and 30 min.

Statistical analysis. SPSS 17.0 software system (SPSS, Inc., Chicago, IL, USA) was used to carry out the statistical analysis. The enumeration data were expressed in the form of [n (%)]. The measurement data were expressed as the mean ± SD. Independent-samples t-test was used in the comparison of the data between two groups, and χ^2 test was used in the enumeration data. One-way ANOVA test with Least Significant Difference test was used in the comparison of the data between groups. At $P < 0.05$ the difference was statistically significant.

Results

Comparison of each indicator of respiratory mechanics between two groups

i) **Comparison of PIP between two groups.** The differences were not statistically significant when comparing PIP in patients in the SI group and the PCV group before RM with that after RM at 1, 10, 20 and 30 min ($P > 0.05$). The comparison within the group showed that when the peak of PIP in patients in the SI group and the PCV group appeared at 1 min after RM, PIP was significantly higher than that before RM ($P < 0.05$). PIP of both groups gradually decreased after RM, and the comparison of PIP at different time-points showed that the differences were statistically significant ($P < 0.05$) (Table II).

ii) **Comparison of Pplate between two groups.** The differences were not statistically significant when comparing Pplate in patients in the SI group and the PCV group before RM with that after RM at 1, 10, 20 and 30 min ($P > 0.05$). The comparison within the group showed that when the peak of Pplate in patients in the SI group and the PCV group appeared at 1 min after RM, Pplate was significantly higher than that before RM ($P < 0.05$). Pplate of both groups gradually decreased after RM, and the comparison of Pplate at different time-points showed that the differences were statistically significant ($P < 0.05$) (Table III).

Table I. Comparison of the general data of the patients in the two groups.

General data	SI group (n=13)	PCV group (n=13)	t/ χ^2 test	P-value
Sex				
Male	8 (61.54)	7 (53.85)	0.158	0.691
Female	5 (38.46)	6 (46.15)		
Age (years)				
≤48	5 (38.46)	6 (46.15)	0.158	0.691
>48	8 (61.54)	7 (53.85)		
BMI (kg/m ²)				
≤18.25	9 (69.23)	8 (61.54)	0.170	0.680
>18.25	4 (30.77)	5 (38.46)		
Blood routine				
Hb (gm/dl)	8.23±1.86	11.63±2.63	3.806	<0.001
RBC (x10 ¹² /l)	4.28±0.37	4.19±0.35	0.637	0.530
PLT (x10 ⁹ /l)	148.63±22.78	151.63±25.61	0.316	0.755
Liver function				
ALT (U/l)	22.41±10.43	20.41±8.45	0.537	0.596
AST (U/l)	19.35±8.63	17.48±7.24	0.599	0.555
Renal function				
TP (g/l)	130.50±10.44	75.98±10.23	13.450	<0.001
UREA (mmol/l)	8.09±1.03	4.12±1.67	7.295	<0.001
CRE (μmol/l)	200.56±20.12	98.49±18.08	13.610	<0.001
UA (μmol/l)	629.45±40.76	204.84±56.19	22.050	<0.001

Table II. Comparison of PIP (cmH₂O) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	27.01±8.34	28.46±8.05	0.451	0.656
After RM at 1 min	48.35±6.75 ^a	46.02±6.48 ^a	0.898	0.378
After RM at 10 min	31.51±6.01 ^b	34.39±5.04 ^b	1.324	0.198
After RM at 20 min	26.77±8.01	27.39±5.97	0.825	0.224
After RM at 30 min	23.58±7.93	25.59±6.49	0.707	0.486
F-test	22.720	21.400		
P-value	<0.001	<0.001		

^aThe difference was statistically significant when compared with that at different time-points in the group (P<0.05); ^bthe difference was statistically significant when compared with that after RM at 30 min in the group (P<0.05).

iii) *Comparison of Crs between two groups.* The differences were not statistically significant when comparing Crs in patients in the SI group and the PCV group before RM with that after RM at 1, 10, 20 and 30 min (P>0.05). The comparison within the group showed that when the valley value of Crs in patients in the SI group and the PCV group appeared at 1 min after RM, Crs was significantly lower than that before RM (P<0.05). Crs in the two groups showed an upward trend from 1 to 10 min after RM, but Crs in the two groups showed a downward trend from 10 to 30 min after RM, and the comparison of Crs at different time-points showed that the differences were statistically significant (P<0.05) (Table IV).

Comparison of the changes of each indicator of early central drive in the two groups before and after RM. Before RM, VT/RMS was 23.01±9.02 ml/μV, VE/RMS was 0.20±0.04 l/μV, ΔPdi/RMS was 0.37±0.18 cm H₂O/μV. VT/RMS in the SI group and the PCV group after RM was respectively 40.03±11.36 and 39.65±11.06 ml/μV, which were both significantly higher than VT/RMS before RM, and the differences were statistically significant (P<0.05); VE/RMS in the SI group and the PCV group after RM, respectively were 0.64±0.12 and 0.65±0.14 l/μV, which were significantly higher than VE/RMS before RM, and the differences were statistically significant (P<0.05); ΔPdi/RMS in the SI group and the PCV group after RM respectively were 0.57±0.11 cm

Table III. Comparison of Pplate (cmH₂O) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	23.74±5.07	23.01±5.27	0.722	0.360
After RM at 1 min	39.43±6.68 ^a	39.47±4.52 ^a	0.018	0.986
After RM at 10 min	24.19±4.06	25.56±5.02	0.765	0.452
After RM at 20 min	23.06±3.96	23.03±3.74	0.020	0.984
After RM at 30 min	20.83±4.69	21.79±4.99	0.505	0.618
F-test	29.210	31.180		
P-value	<0.001	<0.001		

^aThe difference was statistically significant when compared with that at different time-points in the group (P<0.05).

Table IV. Comparison of Crs (ml/cmH₂O/kg) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	39.34±11.82	38.49±12.03	0.182	0.858
After RM at 1 min	28.03±8.33 ^a	27.57±7.92 ^a	0.144	0.887
After RM at 10 min	38.90±10.36	37.64±11.57	0.293	0.772
After RM at 20 min	36.94±6.69	35.59±6.81	0.510	0.615
After RM at 30 min	34.90±7.04	34.78±6.88	0.044	0.965
F-test	3.342	2.786		
P-value	0.016	0.034		

^aThe difference was statistically significant when compared with that before RM and after RM at 10 min in the group (P<0.05).

Table V. Comparison of the changes of each indicator of early central drive in the two groups before and after RM.

Index	Before RM	After RM		F-test	P-value
		SI group (n=13)	PCV group (n=13)		
VT/RMS (ml/μV)	23.01±9.02	40.03±11.36 ^a	39.65±11.06 ^a	11.070	<0.001
VE/RMS (l/μV)	0.20±0.04	0.64±0.12 ^a	0.65±0.14 ^a	72.34	<0.001
ΔPdi/RMS (cmH ₂ O/μV)	0.37±0.18	0.57±0.11 ^a	0.55±0.12 ^a	8.034	0.001

^aThe group that after RM was significantly higher than that before RM, with a statistically significant difference (P<0.05).

H₂O/μV and 0.55±0.12 cm H₂O/μV, which were both significantly higher than ΔPdi/RMS before RM, and the differences were statistically significant (P<0.05); the differences were not statistically significant when comparing VT/RMS, VE/RMS, ΔPdi/RMS in the SI group with those in the PCV group after RM (P>0.05) (Table V and Fig. 1).

Comparison of each indicator of hemodynamics in the two groups

i) *Comparison of HR between two groups.* The differences were not statistically significant when comparing HR in patients in the SI group and the PCV group before RM with that after RM at 1, 10, 20 and 30 min (P>0.05). The comparison within the group showed that when the peak of HR in patients in the SI and the PCV group appeared at 1 min after RM, HR

was significantly higher than that before RM (P<0.05). HR of both groups gradually decreased after RM, and the comparison of HR at different time-points showed that the differences were statistically significant (P<0.05) (Table VI).

ii) *Comparison of MAP between two groups.* The differences were not statistically significant when comparing MAP in patients in the SI group and the PCV group before RM with that after RM at 1, 10, 20 and 30 min (P>0.05). The comparison within the group showed that when the valley value of MAP in patients in the SI group and the PCV group appeared at 1 min after RM, MAP was significantly lower than that before RM (P<0.05). MAP of both groups gradually increased after RM, and the comparison of MAP at different time-points showed that the differences were statistically significant (P<0.05) (Table VII).

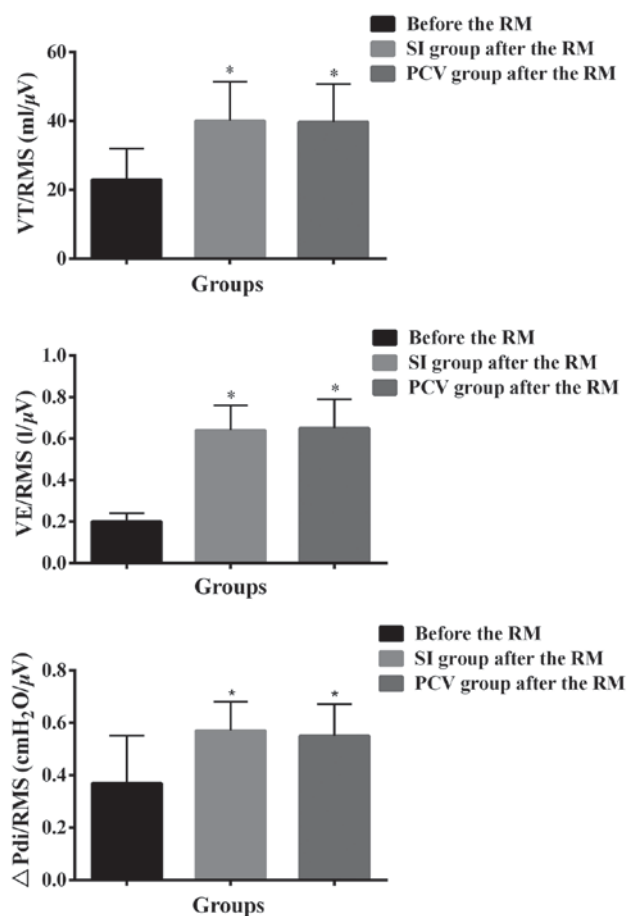


Figure 1. Comparison of each indicator of early central drive in the two groups before and after RM. VT/RMS in the SI and the PCV group after RM was significantly higher than that before RM, and the difference was statistically significant ($P<0.05$). VE/RMS in the SI and the PCV group after RM was significantly higher than that before RM, and the difference was statistically significant ($P<0.05$). $\Delta Pdi/RMS$ in the SI and the PCV group after RM was significantly higher than that before RM, and the difference was statistically significant ($P<0.05$). When comparing VT/RMS, VE/RMS and $\Delta Pdi/RMS$ in the SI group after RM with those in the PCV group, the differences were not statistically significant ($P>0.05$). *The difference was statistically significant when the indicators of the group were compared with those before RM ($P<0.05$).

iii) *Comparison of CVP between two groups.* When the two groups were compared, it was found that there were no significant differences between the two groups before RM and at 1 and 30 min after RM. CVP in patients in the SI group at 10 and 20 min after RM was significantly higher than that in the PCV group, and the difference was statistically significant ($P<0.05$). The comparison within the group showed that when the peak of CVP in patients in the SI group and the PCV group appeared at 1 min after RM, CVP was significantly higher than that before RM ($P<0.05$). CVP of both groups gradually decreased after RM, and the comparison of CVP at different time-points showed that the difference was statistically significant ($P<0.05$) (Table VIII).

Discussion

The mortality of patients with ARDS is up to 39-69%. The obvious decrease of pulmonary volume and the uneven lesions are the important features of ARDS (16). It has been reported

that the incidence of patients with ARDS is closely related to the indicators of respiratory function in their own biological mechanism, including PIP, Pplate, Crs, the condition of central-mechanical-ventilation coupling before and after RM, hemodynamics, HR, MAP, and CVP (8). The treatment of ARDS is mainly based on the active treatment of protopathy, and patients with ARDS are treated with mechanical ventilation to prevent further lung damage and reduce acute lung damage or the case fatality rate of ARDS (16,17). In the process of mechanical ventilation, the occurrence of high airway pressure is frequent, which will result in barotrauma. The traditional volumetric ventilation mode easily results in barotrauma due to the constant volume and high peak pressure, and different ventilation modes may have different effects on patients with ARDS (18,19). RM is an important means for the treatment of ARDS. There are many types of RM used in clinical practice, among which SI and PCV are commonly used for the treatment of ARDS (20). At present, there are few studies on the advantages and disadvantages of the effects of SI and PCV on respiratory mechanics, early central drive and hemodynamics in the treatment of patients with ARDS. This study compared the efficacy and safety of the two RM methods by observing the effects of SI and PCV on respiratory mechanics, early central drive and hemodynamics in patients with ARDS.

In this study, according to the ventilation method adopted by patients with ARDS, 13 patients who received SI treatment were included in the SI group. At the same time, 13 patients who received PCV treatment were included in the PCV group. The changes of respiratory mechanics, early central drive and hemodynamics in the two groups before RM were compared with those after RM. The comparison of each indicator of respiratory mechanics in the two groups showed that the differences were not statistically significant when comparing PIP, Pplate and Crs in patients in the SI group and the PCV group before RM with those after RM at 1, 10, 20 and 30 min ($P>0.05$). However, the comparison of each indicator of hemodynamics in the two groups showed that the differences were not statistically significant when comparing HR and MAP in patients in the SI group and the PCV group before RM with those after RM at 1, 10, 20 and 30 min ($P>0.05$). When comparing the two groups with each other, the CVP in patients in the SI group after RM at 10 and 20 min was significantly higher than that in the PCV group, and the differences were statistically significant ($P<0.05$). Based on the above results, we speculated that there was little difference in the effect between SI and PCV on respiratory mechanics in patients with ARDS, but the CVP in patients in the SI group after RM at 10 and 20 min was significantly higher than that in the PCV group, which suggested that SI had a greater effect than PCV on hemodynamics in patients with ARDS. At present, there are few studies related to the effects of the mechanical ventilation methods SI and PCV, on respiratory mechanics and hemodynamics in patients with ARDS. Some studies have shown that there is little difference in the effect between SI and PCV on respiratory mechanics and hemodynamics in patients with ARDS; the two mechanical ventilation methods, SI and PCV, are equally available for patients with ARDS. There is no conclusion that one ventilation method could replace another kind of ventilation method (21,22). The

Table VI. Comparison of HR (beat/min) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	107.20±19.09	108.27±22.46	0.131	0.131
After RM at 1 min	127.34±24.95 ^a	126.66±25.01 ^b	0.069	0.945
After RM at 10 min	123.63±21.03	110.41±21.68	1.578	0.128
After RM at 20 min	117.99±19.45	108.05±20.85	1.257	0.221
After RM at 30 min	110.38±20.11	109.42±20.43	0.121	0.905
F-test	2.140	1.670		
P-value	0.087	0.169		

^aThe difference was statistically significant when comparing the condition of the group with that in each group at each time-point, apart from the group at 10 min after RM ($P<0.05$); ^bthe difference was statistically significant when comparing the condition of the group with that in each group at each time-point ($P<0.05$).

Table VII. Comparison of MAP (mmHg) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	83.21±18.26	81.57±15.02	0.250	0.805
After RM at 1 min	70.86±11.40 ^a	71.34±12.56 ^b	0.102	0.920
After RM at 10 min	71.94±12.73	80.59±18.01	1.414	0.170
After RM at 20 min	77.80±14.99	82.04±18.69	0.638	0.530
After RM at 30 min	82.92±18.76	83.12±17.59	0.028	0.980
F-test	1.851	1.086		
P-value	0.131	0.372		

^aThe difference was statistically significant when comparing the condition of the group with that in each group at each time-point, apart from the group at 10 min after RM ($P<0.05$); ^bthe difference was statistically significant when comparing the condition of the group with that in each group at each time-point ($P<0.05$).

Table VIII. Comparison of CVP (cmH₂O) in the patients in the two groups.

Index	SI group (n=13)	PCV group (n=13)	t-test	P-value
Before RM	10.24±1.43	10.68±1.11	0.876	0.390
After RM at 1 min	15.46±1.92	14.89±1.69	0.804	0.430
After RM at 10 min	14.12±1.59 ^a	11.61±2.01	3.531	0.002
After RM at 20 min	13.68±2.01 ^a	10.01±1.02	5.871	<0.001
After RM at 30 min	10.39±1.03	9.59±1.30	1.739	0.095
F-test	26.70	26.85		
P-value	<0.001	<0.001		

^aThere were statistically significant differences between this group and the PCV group at the same time-point ($P<0.05$).

changes of each indicator of early central drive in patients in the two groups before and after RM showed that VT/RMS, VE/RMS and ΔP_{di} /RMS in the SI group and the PCV group after RM were both significantly higher than those before RM, and the differences were statistically significant ($P<0.05$). However, when respectively comparing VT/RMS, VE/RMS and ΔP_{di} /RMS in the SI group after RM with those in the PCV group after RM, and the differences were not statistically significant ($P>0.05$). Therefore, we believed that the two mechanical ventilation methods, SI and PCV, had similar effects on early central drive in patients with ARDS, and could

enhance the effect of central-mechanical-ventilation coupling after RM. There are few studies on the effects of SI and PCV on early central drive in patients with ARDS, but we still consulted a small number of studies which were related to the effect of early central drive in patients with ARDS to support the rationality of the results of this study (23).

In this study, the number of enrolled patients was small, which may result in some contingency on the results. In conclusion, there is little difference between the effect of SI and PCV on respiratory mechanics and early central drive and hemodynamics in patients with ARDS, and both of the

mechanical ventilation methods can enhance the effect of central-mechanical-ventilation coupling after RM. Therefore, the mechanical ventilation methods SI and PCV, are equally available for patients with ARDS.

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Availability of data and materials

The datasets used and/or analyzed during the present study are available from the corresponding author on reasonable request.

Authors' contributions

MJ was in charge of the study and drafted the manuscript. MC, TC, YJ, JZ, XW and XHo acquired the data. XHu and NZ were responsible for observation indicators and analyzed the data. NZ reviewed the manuscript and finalized it. All authors read and approved the final manuscript.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Yiwu Central Hospital (Yiwu, China). Each patient who participated in this research, signed an informed consent and had complete clinical data.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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