



# Lung ultrasound-guided treatment for acute respiratory distress syndrome in a critically ill patient with severe COVID-19: a case report

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**Background:** Acute respiratory distress syndrome (ARDS) is a very common disease in the intensive care unit (ICU), with rapid progression and high mortality. Infections caused by the new severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) can easily progress to ARDS in severely ill patients. Early and rapid diagnosis as well as screening for ARDS during treatment is very important. Owing to the particularity of patients with coronavirus disease 2019 (COVID-19), computed tomography (CT) examination is not always possible, and chest radiographs have a low sensitivity and specificity for the diagnosis of lung diseases. Therefore, bedside lung ultrasound (LUS) can be used as a new tool for the diagnosis of ARDS in patients with COVID-19. In the non-gravity-dependent pulmonary field, there are bilateral non-uniform B lines. In the dorsal pulmonary field, the B lines are denser and even appears as “white lung”. Areas of consolidation are usually found in the dorsal pulmonary field, especially at the basilar part, with static or dynamic air bronchogram sign. In the fused B-line area, the “lung slip” usually decreases or disappears. The pleural line is irregular, thickened, and rough, with multiple small consolidations. The pulmonary ultrasound findings of primary and secondary ARDS were similar.

**Case Description:** In the abovementioned context, we share our experience with the treatment of one critical COVID-19 case and review the literature. An 81-year-old male patient with ARDS which is caused by COVID-19. The implementation of prone ventilation was guided by LUS, and we found that the pulmonary edema in the gravity-dependent area did improve over time. After 9 h of prone ventilation, the consolidation of the posterior area began to open. LUS shows the change from fragment sign to B line. After 16 h, the B-line was reduced, indicating that pulmonary edema was improving. The oxygenation could be improved. Pulmonary ultrasound makes the monitoring of prone ventilation visualized. As the same time, the patient was accepted high-flow nasal oxygen, mechanical ventilation and treated with oseltamivir, lopinavir/ritonavir, abidol and cefoperazone-sulbactam.

**Conclusions:** LUS-guided treatment was the key factor in the successful treatment of this case.

**Keywords:** Case report; coronavirus disease 2019 (COVID-19); acute respiratory distress syndrome (ARDS); lung ultrasound (LUS); prone position ventilation

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## Introduction

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) belongs to the  $\beta$ -type of coronaviruses. Several patients have been continuously affected by this viral disease in Wuhan City, Hubei Province, China, since December 2019 (1). Omicron is the latest strain. The source of infection that has been seen thus far is close contact with patients infected with this disease, including those with asymptomatic infection. The virus is mainly transmitted through infected droplets and close contact with infected people. The population is generally vulnerable. There are no specific clinical manifestations after infection, with most of those infected showing symptoms similar to those of the common viral pneumonia, such as fever, cough, muscle soreness, and so on. The diagnosis of the disease is mainly made using throat swab results and imaging findings. The main features of computed tomography (CT) imaging (2) are early multiple small patchy shadows and interstitial changes, evident in the extrapulmonary zone, multiple ground glass infiltrations and infiltrates in both lungs, and pulmonary consolidation in severe cases. Pleural effusions are infrequent. Clinical classification is divided into mild, typical, severe, and critical. Those meeting one of the following conditions are considered critically ill: (I) respiratory failure that requires mechanical ventilation; (II) shock; (III) organ failure or requiring intensive care unit (ICU) monitoring and treatment. Severe and critical illness can quickly progress to dyspnea and respiratory failure. LUS is handy, non-radioactive and basically free from environmental restrictions, which is commonly used in acute and critical environment. Acute respiratory distress syndrome (ARDS) is usually characterized by pulmonary

edema, lung consolidation and pleural effusion. The ultrasonographic findings of ARDS pulmonary edema were earlier than chest radiographs, the main manifestations are diffuse comet tail signs. LUS can also measure pleural effusion. In addition, lung consolidation caused by ARDS often requires lung reexpansion or prone ventilation. Through the changes of B-line, consolidation and other signs, lung ultrasound (LUS) plays a very important role in the evaluation of lung reexpansion and prone ventilation, so as to avoid the complications. The manifestations of respiratory failure and lung injury caused by coronavirus disease 2019 (COVID-19) are similar to those of ARDS, and may also progress to ARDS. Therefore, pulmonary ultrasound plays an important role in the treatment of COVID-19. We present the following article in accordance with the CARE reporting checklist (available at <https://apm.amegroups.com/article/view/10.21037/apm-22-1319/rc>).

## Case presentation

### Chief complaints

An 82-year-old male patient was admitted to a local hospital on 30 January 2020 due to worsening cough, expectoration, and fever of 38 °C for 3 days. His symptoms were noted to have been progressively worsening after light activity and he now required long-term oxygen therapy for his daily life activities. At the local hospital, he was treated with piperacillin-tazobactam and ambroxol, but his symptoms showed no improvement. A throat swab was sent for the nucleic acid detection of SARS-CoV-2, which tested positive on the following day. These results, combined with the CT scan findings, confirmed the diagnosis of coronavirus disease of 2019 (COVID-19). The patient was then transferred to the Department of Intensive Care Medicine, Affiliated Jinhua Hospital, Zhejiang University School of Medicine for further treatment. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal.

### History of illness

He had a history of asthma and chronic obstructive

### Highlight box

#### Key findings

- LUS can help diagnose ARDS and guide its treatment, which accuracy and portability are better than CT, so it can be used repeatedly in special environments such as the COVID-19 ward.

#### What is known and what is new?

- The role of LUS in the diagnosis and treatment of ARDS is very important;
- LUS can be well used in the COVID-19 ward.

#### What is the implication, and what should change now?

- To optimize the homogenized management of LUS, which can make LUS more accurate in the diagnosis and treatment of ARDS, thus to improve the prognosis of patients.

pulmonary disease (COPD) for more than 10 years, with the cough and expectoration always worsening during the winter and spring seasons.

### *Physical examination*

On examination, the patient was conscious but in poor spirits. He had shortness of breath, slightly pursed lips, and a barrel chest. His temperature was 36.5 °C, blood pressure 170/84 mmHg, and oxygen saturation (SpO<sub>2</sub>) 78%. In both lungs, wet and dry rales could be heard. Arrhythmia and proisystole were also identified. Both lower limbs did not have edema.

### *Laboratory examinations*

The blood tests showed the following results: C-reactive protein (CRP) 20.1 mg/L; white blood cells 7.39×10<sup>9</sup>/L; neutrophils (N) 0.926; absolute lymphocyte count 0.27×10<sup>9</sup>/L; hemoglobin 155 g/L; and platelets 112×10<sup>9</sup>/L.

### *Imaging examinations*

Chest CT showed chronic bronchitis, chronic right lower lung infection and emphysema, and bullae of the left upper lung.

### *Final diagnosis*

A diagnosis of (I) new coronavirus (SARS-CoV-2) infected pneumonia (critical illness); (II) respiratory failure; and (III) acute exacerbation of COPD was made.

### *Treatment*

The patient was put on high-flow nasal oxygen (flow of 60 L/min and oxygen concentration of 100%) and treated with oseltamivir (75 mg, nasal feeding, twice daily), lopinavir/ritonavir (3 tablets, nasal feeding, twice daily), abidol (2 tables, nasal feeding, 3 times daily), and cefoperazone-sulbactam (2 g, intravenously, 3 times daily). His blood gas results were as follows: lactic acid (Lac) 1.8 mmol/L, PH (potential of hydrogen) 7.46, partial pressure of carbon dioxide (PCO<sub>2</sub>) 32.5 mmHg, partial pressure of oxygen (PO<sub>2</sub>) 61.7 mmHg, oxygen saturation (SO<sub>2</sub>) 91.8%, PO<sub>2</sub>/fraction of inspired oxygen (FiO<sub>2</sub>) (oxygen index) 62. On the morning of the following day (31 January 2020), the patient was placed on non-invasive

mechanical ventilation. In the afternoon, the patient began resisting the machine. We reverted back to the high-flow oxygen, but the patient started desaturating, which led us to intubate the patient using invasive mechanical ventilation that evening (ventilator parameters: mode pressure control ventilation, pressure control 12 cmH<sub>2</sub>O, positive end expiratory pressure 6 cmH<sub>2</sub>O, respiratory rate times per minute, oxygen concentration 60%). LUS was performed immediately after intubation, which showed the following: an enhanced pleural line echo at each scan point; weak or non-existent pleural sliding sign; no A-line; B-lines at each scanning point, which increased in amount with gravity distribution; fragment sign near the pleural line at the upper blue point, lower blue point, and posterior blue point of the left lung; and the curtain sign at both diaphragmatic points. His blood gas results were as follows: Lac 3.1 mmol/L, PH 7.46, PCO<sub>2</sub> 32.6 mmHg, PO<sub>2</sub> 50.3 mmHg, SO<sub>2</sub> 83.9%, and PO<sub>2</sub>/FiO<sub>2</sub> 50. Lung recruitment could have been effective, but we could not maintain oxygenation for a prolonged period. On 1 February 2020, we performed prone position ventilation. The LUS revealed that there were huge amounts of B-lines at the posterior blue point on each side. After 9 h, his blood gases were reviewed, which revealed that Lac was 2.5 mmol/L, PH 7.37, PCO<sub>2</sub> 42.3 mmHg, PO<sub>2</sub> 50.5 mmHg, and SO<sub>2</sub> 84.4%. The LUS showed that B-lines had decreased at the left posterior blue point, had disappeared at the right posterior blue point, and had increased at the posterolateral alveolar and/or pleural syndrome (PLAPS) point of each side. After 16 h, his blood gas levels were as follows: Lac 2.0 mmol/L, PH 7.40, PCO<sub>2</sub> 39.3 mmHg, PO<sub>2</sub> 70.4 mmHg, and SO<sub>2</sub> 92.7%. The LUS showed that the B-lines had disappeared at the left and right posterior blue points. The fragment sign could be seen at the left upper blue points. When returned to supine position, we spotted that the B-lines had increased at the upper blue point, lower blue point, and at the PLAPS point in both the left and right lungs. The side effects of lopinavir and Abidor were mildly, and there were no symptoms such as nausea, vomiting and diarrhea, so the nutritional administration was smoothly during the treatment. In addition, the inflammatory markers were stable, and the antibiotics did not escalate.

### *Outcome and follow-up*

Following these treatments, the whole condition was gradually relieved, and prone position ventilation was stopped on 16th hour of admission. After 2 days, the

**Table 1** Timeline

Date	Event
1.27.2020	Presented with cough, expectoration, and fever
1.27.2020	Admission to local hospital
1.27.2020	Treated with piperacillin-tazobactam and ambroxol
1.28.2020	Nucleic acid detection of SARS-CoV-2 was tested positive
1.30.2020	Admission to our hospital
1.31.2020	High-flow & NIV, intubation
2.1.2020	Prone position ventilation
2.3.2020	Transferred to the First Hospital of Zhejiang province for further treatment

SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; NIV, non-invasive ventilation.

patient was transferred to the First Hospital of Zhejiang province for further treatment. Timeline is shown in *Table 1*.

## Discussion

Beside LUS is convenient, economical, non-invasive, dynamic, real time, and repeatable. Cortellaro *et al.* (3) reported that the sensitivity of chest X-rays (CXR) and bedside ultrasound for the diagnosis of pneumonia is 69% and 96%, respectively, showing a significantly higher sensitivity for ultrasound. Parlamento *et al.* (4) reported sensitivities of 75% and 96.9% for these techniques, respectively, to diagnose pneumonia. Thus, the value of ultrasound for the diagnosis of pneumonia is better than that of CXR.

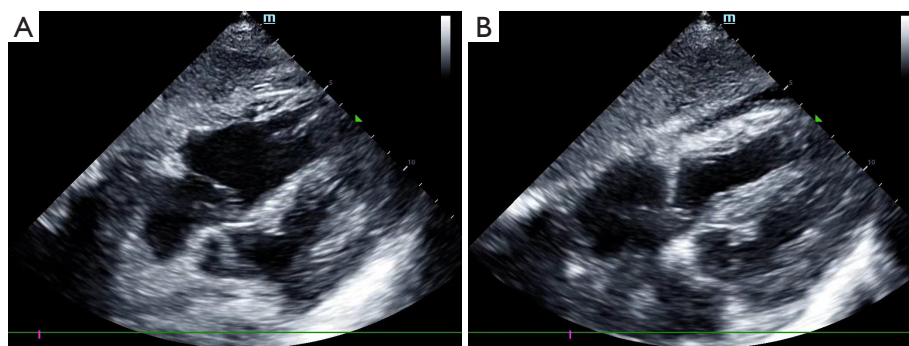
The condition of the patient we present herein advanced from severe to critical soon after admission, before progressing to ARDS (5). During this time, the assessment of the lung condition was very important for the evaluation of the effect of treatment and to guide further treatment, regardless of diagnosis. Chest radiographs and CT scan are commonly used in assessing the lung condition. These methods are, however, difficult to perform and difficult to repeat for patients with ARDS, given that they need to be in an isolation ward and are critically ill. Therefore, LUS is the best choice. The use of ultrasound as a diagnostic tool for lung conditions dates back to the 1960s (6), but it has not been used widely in intensive care settings until recently. The lung is composed of both gases and liquids.

The gas rises and the liquid sinks. Ultrasound completely reflects the normal lung tissue, producing artifacts such as A-lines or a small number of B-lines. The proportion of fluid changes and different types of phenomena appear when ultrasound detects different degrees of deaeration of lung tissue. It is these artifacts, such as fragment sign, tissue-like sign, and more than a dozen other signs, that provide us with evidence (7,8). Therefore, bedside LUS can be used as a new tool for the diagnosis of ARDS in patients with COVID-19 (9-11).

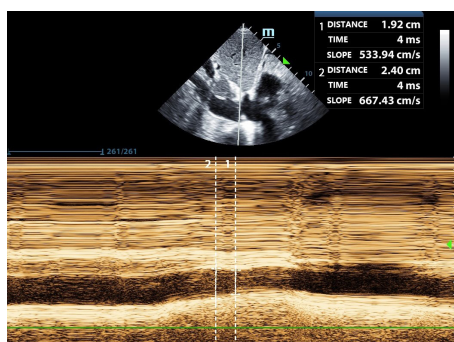
In patients with ARDS, the presence, severity, or timing of ARDS is not an independent risk factor for short-term death. However, ARDS does significantly contribute to 2-year mortality (12). This suggests that even if the patient does not die from ARDS itself, they could die from other primary diseases. Therefore, in the acute phase of ARDS, clinicians should strive to improve treatment strategies for the primary disease that caused ARDS.

The patient had been diagnosed with COPD and hypertension many years before his current admission. Circulatory failure occurred following tracheal intubation, and norepinephrine was administered to maintain blood pressure. At this point, the reason for the occurrence of shock had to be found immediately. The fluid administration limited by lung sonography (FALLS) protocol (7,13) is a method of integrating cardiac ultrasound based on the blue or blue-plus protocol, as described by Lichtenstein, for the identification of shock causes, which is classified by hemodynamic reasons. As the patient had a barrel-shaped chest with significant weight loss, the cardiac sections could not be easily obtained. Judging from the available subxiphoid 4-chamber cardiac section and inferior vena cava section, the heartbeat was normal, the ejection fraction (EF) was about 30–50% (*Figure 1*), and there was no severe cardiogenic pulmonary edema. Respiratory variation could be measured in the inferior vena cava, and its value was 20% (*Figure 2*). We considered that the patient had fluid responsiveness, as the respiratory variation of the inferior vena cava was greater than 18% during mechanical ventilation. We temporarily ruled out obstructive shock due to the comprehensive assessment of the size ratio of the 4 chambers of the heart and the variation of the inferior vena cava. Other sections of the heart could not be assessed, and invasive hemodynamic monitoring, such as pulse index continuous cardiac output (PiCCO) and the Swan-Ganz catheter, was unavailable in the isolation wards. Hence, the cardiac output could not be accurately measured, and septic shock could not be completely ruled out. In





**Figure 1** The end of the diastolic phase (A) and the systolic phase (B). The meaning of green arrow is focal position.

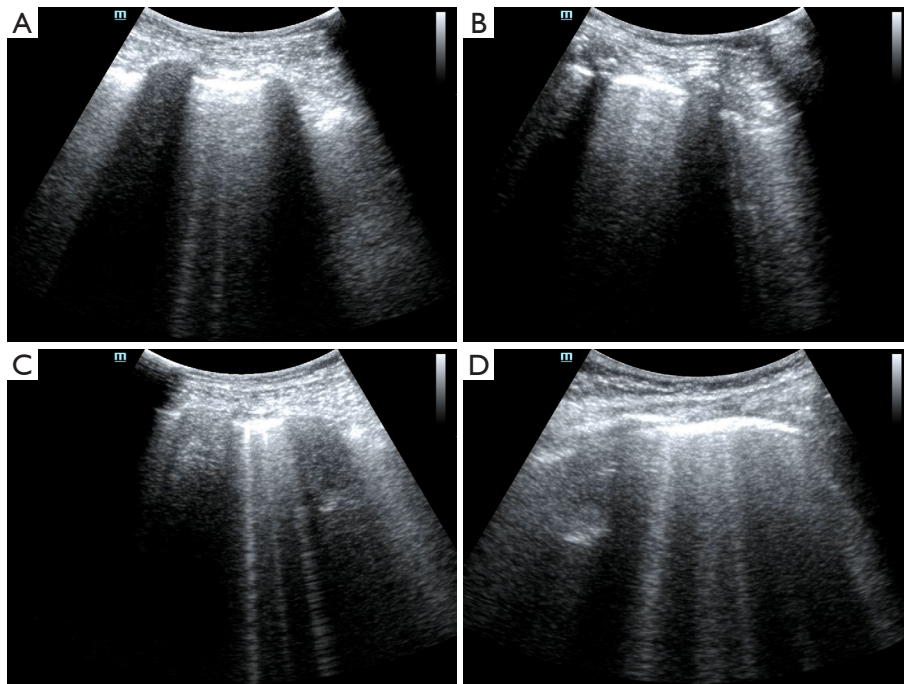


**Figure 2** The variation of inferior vena cava is 20%. The meaning of green arrow is focal position.

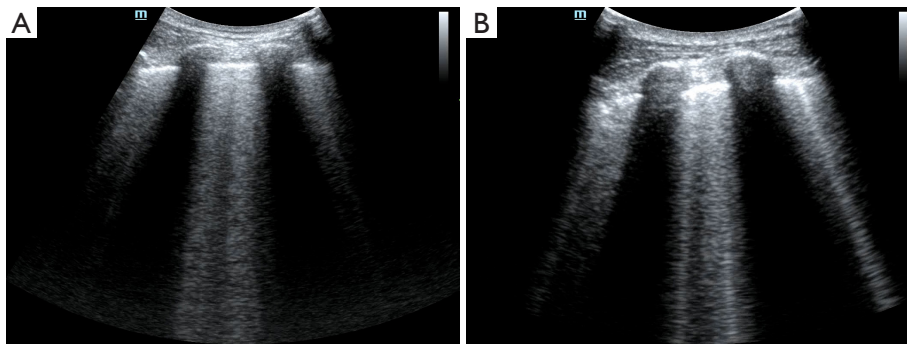
summary, we believed that the patient's cardiac function was acceptable and that there was volume responsiveness, but there were B-lines in multiple parts of the lungs indicated by LUS (Figure 3). To avoid the possibility of aggravating pulmonary edema due to fluid administration, we used colloidal fluids. We later discovered that when the amount of colloid had reached about 600 mL, blood pressure improved and norepinephrine administration was gradually stopped. After the blood pressure was stable, colloidal fluids were continued for resuscitation. We had hoped to improve the condition of lung edema by using diuretics, but this approach was unsuccessful.

It was difficult to establish whether ARDS was the main effect that had led to the lung edema. It is difficult to distinguish ARDS from acute cardiogenic pulmonary edema by only relying on the B-lines (14). In this case, by this point, the causes of shock had been identified using the FALLS protocol and dealt with accordingly. The features of ARDS on the ultrasound were consistent with what was expected including the following characteristics:

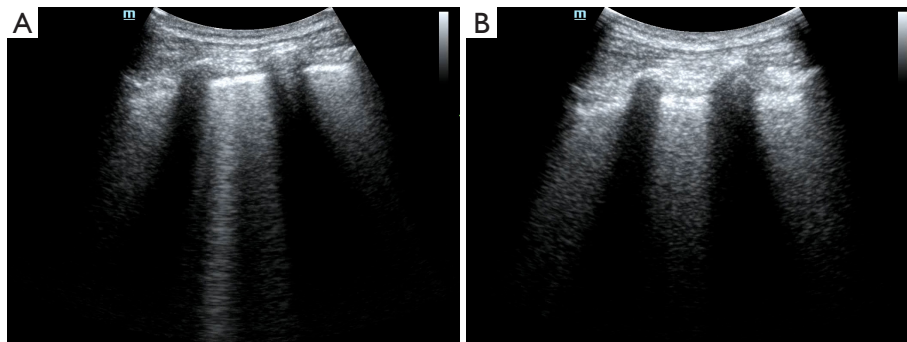
consolidation of the anterior wall of the subpleura; weakened or disappeared sliding pleural sign; the presence of normal lung parenchyma; irregular thickening of the pleural line; and asymmetrical B-line distribution. These findings suggested that the pathophysiology of ARDS showed heterogeneous changes in the lungs. Given the poor SpO<sub>2</sub> and the improved circulation, prone position ventilation was performed as the next step. Guérin *et al.* (15) reported that in patients with severe ARDS, early implemented prone position ventilation can significantly reduce mortality at 28 and 90 days. Immediately after the patient was in the prone position (16), LUS was performed. Both left and right posterior blue points showed B-lines, with the left side being more obvious and heterogeneous than the right side (Figure 4). This was also consistent with the characteristics of ARDS pathophysiological changes. After 9 h, we repeated the LUS. The B-lines were still showing on the left posterior blue point but they were less than before. There were no B-lines on the right posterior blue point (Figure 5), but they were present on both sides of the PLAPS points, in greater number than before (Figure 6). At this time, the oxygenation situation had improved from about 60% to 100%, and the SpO<sub>2</sub> had been maintained between 88% and 92%, which suggested that the lung tissue in the gravity-dependent parts was involved. We performed LUS again, after 16 h, in the prone position. B-lines were not observed on both posterior blue points and light fragment sign could be seen on the left posterior blue point (Figure 7). After the patient was placed into the supine position again, many B-lines were visible on the upper blue point, lower blue point, and PLAPS points on both sides (Figures 8,9). The most basic pathophysiological change of ARDS is damage to the alveolar capillaries, which increases the permeability of the alveolar-capillary



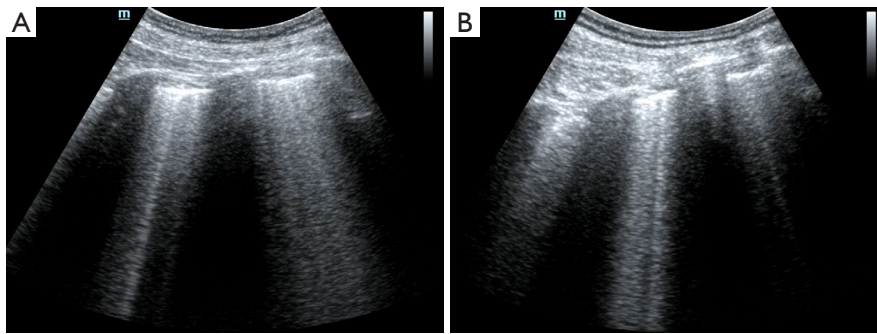
**Figure 3** Lung ultrasound before prone ventilation. (A) The right upper blue point. (B) The left upper blue point. (C) The right lower blue point. (D) The left lower blue point.



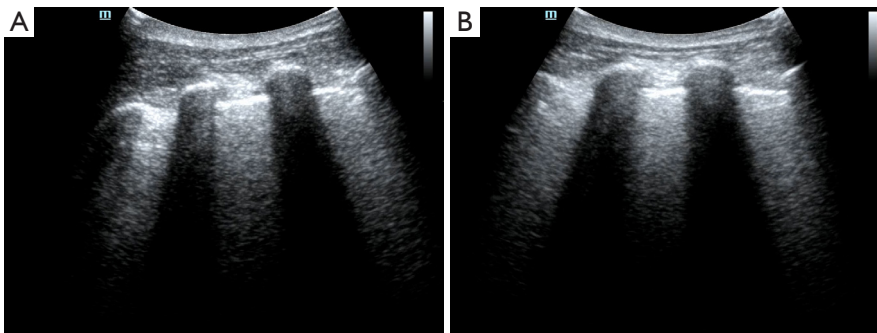
**Figure 4** Double side of posterior blue points after prone ventilation immediately. (A) Left posterior blue point. (B) Right posterior blue point.



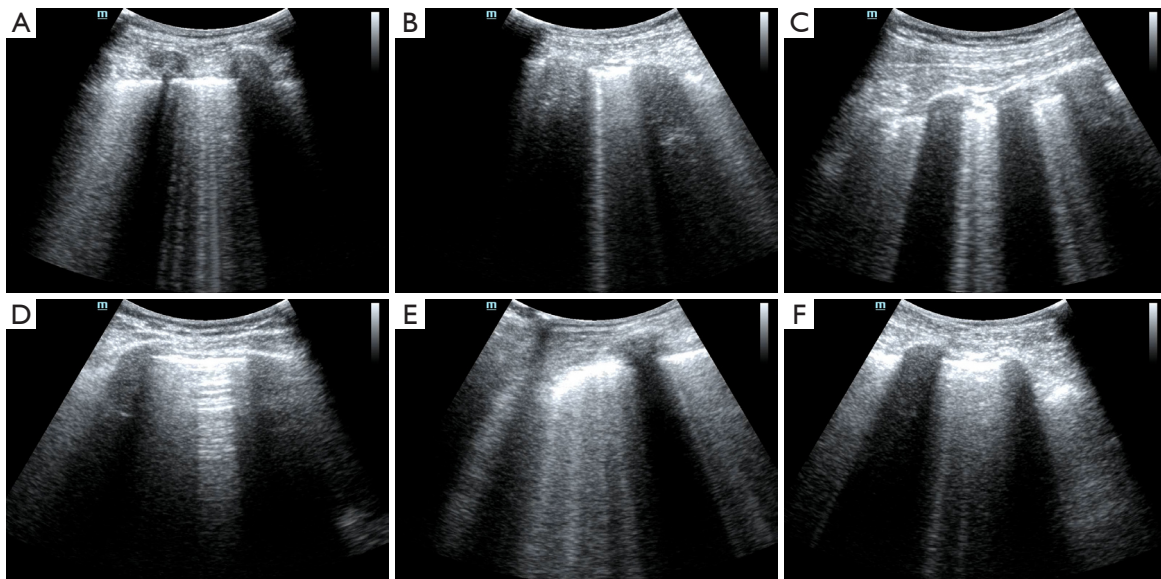
**Figure 5** Double side of posterior blue points after prone ventilation 9 h later. (A) Left posterior blue point. (B) Right posterior blue point.



**Figure 6** Double side of PLAPS blue points after prone ventilation 9 h later. (A) Left PLAPS blue point. (B) Right PLAPS blue point. PLAPS, posterolateral alveolar and/or pleural syndrome.

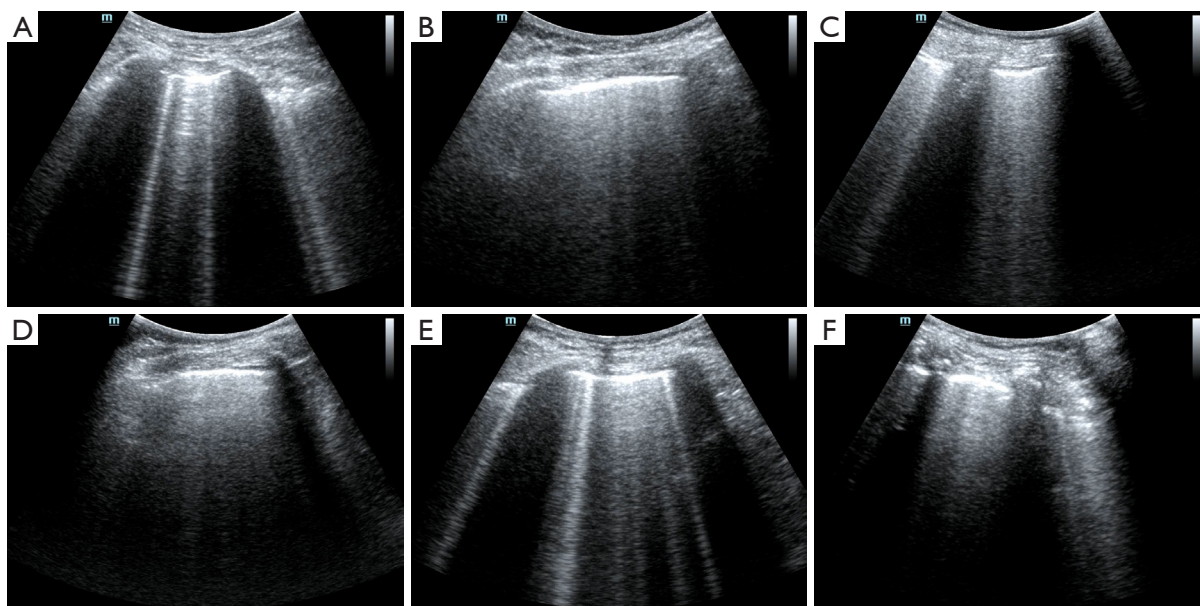


**Figure 7** Double side of posterior blue points after prone ventilation 16 h later. (A) Left posterior blue point. (B) Right posterior blue point.



**Figure 8** Comparison of the right upper blue point, the right lower blue point, the right PLAPS point after 16 hours of prone and immediately prone ventilation. (A) The right lower blue point after 16 h. (B) The right lower blue point. (C) The right PLAPS blue point after 16 h. (D) The right PLAPS point. (E) The right upper blue point after 16 h. (F) The right upper blue point. PLAPS, posterolateral alveolar and/or pleural syndrome.





**Figure 9** Comparison of the left upper blue point, the left lower blue point, the left PLAPS point after 16 hours of prone and immediately prone ventilation. (A) The left lower blue point after 16 h. (B) The left lower blue point. (C) The left PLAPS point after 16 h. (D) The left PLAPS point. (E) The left upper blue point after 16 h. (F) The left upper blue point. PLAPS, posterolateral alveolar and/or pleural syndrome.

and decreases the effective lung volume due to the large amount of exudate. These injuries are significantly gravity dependent (17). Monitored by LUS, changes we observed were consistent with these pathophysiological changes of ARDS. The uneven distribution of the B-line and the consolidation of the lungs under the pleura also confirmed that the damaged and collapsed lung tissue could be involved. The changes in B-lines and oxygenation at different periods after prone ventilation also showed that the patient's damaged and collapsed lung tissue had expandability, which provided direction for further treatment.

As mentioned above, the lung injury and exudative changes in ARDS are gravity dependent. After 16 h of prone position ventilation, the number of B-lines significantly increased in the lung tissue near the anterior chest wall. Changes in prone position ventilation suggested that the injured lung tissue had good expandability. Therefore, after returning to the supine position, we performed a ventilation strategy for this patient with small tidal volume ventilation and intermittent lung retention. We provided a tidal volume of about 6 mL/kg and tested lung retention every half an hour. About 2 h later, the B-line at the upper and lower blue points had decreased significantly.

The fundamental purpose of various treatment schemes for patients with ARDS is to improve oxygenation while minimizing further lung injury. However, patients with ARDS often have combined problems such as shock and multiple organ failure. In addition to correcting oxygenation, we also need to solve problems such as circulation and volume status. We used the FALLS protocol, combined with pulmonary and cardiac ultrasound, to clarify the cause of the hemodynamic instability and to lay the foundation for further prone position ventilation. Before and after prone position ventilation, the recoverability of the lung was reflected by the bedside lung ultrasound in emergency (BLUE) protocol more intuitively, comparing the parameters of oxygenation and circulation. In summary, the timing of high-frequency oscillating ventilation and implementation of extracorporeal membrane oxygenation (ECMO) should be more accurate.

### Conclusions

The fundamental purpose of various treatment schemes for patients with ARDS is to improve oxygenation while minimizing further lung injury. However, patients with



ARDS often have combined problems such as shock and multiple organ failure. In addition to correcting oxygenation, we also need to solve problems such as circulation and volume status. We used the FALLS protocol, combined with pulmonary and cardiac ultrasound, to clarify the cause of the hemodynamic instability and to lay the foundation for further prone position ventilation. Before and after prone position ventilation, the recoverability of the lung was reflected by the BLUE protocol more intuitively, comparing the parameters of oxygenation and circulation.

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### Footnote

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Declaration of Helsinki (as revised in 2013). Written informed consent was obtained from the patient for publication of this case report and accompanying images. A copy of the written consent is available for review by the editorial office of this journal.

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