

● Original Contribution

LUNG ULTRASOUND SCORE IN EVALUATING THE SEVERITY OF CORONAVIRUS DISEASE 2019 (COVID-19) PNEUMONIA

LINA ZHAO,^{*,2} KANGLONG YU,^{*,2} QI ZHAO,^{*,2} RUI TIAN,^{*} HUI XIE,^{*} LIJUN XIE,^{*} PUYU DENG,^{*}
GUOGANG XIE,[†] AIHUA BAO,[†] and JIANG DU^{*}

^{*}Department of Emergency and Critical Care, Shanghai General Hospital of Shanghai Jiaotong University, Shanghai, China; and

[†]Department of Respiratory and Critical Care, Shanghai General Hospital of Shanghai Jiaotong University, Shanghai, China

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Abstract—The purpose of this study is to observe the potential of lung ultrasound in evaluating the severity of coronavirus disease 2019 (COVID-19) pneumonia. Lung ultrasound was performed in ten zones of the patients' chest walls. The features of the ultrasound images were observed, and a lung ultrasound score (LUS) was recorded. The ultrasound features and scores were compared between the refractory group (PaO₂/FiO₂ ≤ 100 mm Hg or on extracorporeal membrane oxygenation) and the non-refractory group. The prediction value of the LUS was studied by receiver operating characteristic (ROC) curve analysis. In total, 7 patients were enrolled in the refractory group and 28 in the non-refractory group. B-line patterns and shred signs were the most common signs in all patients. Patients in the refractory group had significantly more ground-glass signs (median 6 [interquartile range {IQR}, 2.5–6.5] vs. median 0 [IQR, 0–3]), consolidation signs (median 1 [IQR, 1–1.5] vs. median 0 [IQR, 0–3]) and pleural effusions (median 5 [IQR, 1.5–6] vs. median 0 [IQR, 0–0.25]). The LUS was significantly higher in the refractory group (33.00 [IQR 27.50–34.00] vs. 25.50 [IQR 22.75–30.00]). The ROC of the LUS showed a cutoff score of 32 with a specificity of 0.893 and a sensitivity of 0.571 in diagnosing refractory respiratory failure among patients. In COVID-19 patients, lung ultrasound is a promising diagnostic tool in diagnosing patients with refractory pneumonia. (E-mail: gowindj@163.com) © 2020 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: COVID-19, Lung ultrasound, ECMO, ARDS, Pneumonia.

INTRODUCTION

A cluster outbreak of pneumonia now known as the novel coronavirus (severe acute respiratory syndrome coronavirus 2 [SARS-CoV-2]) infectious disease occurred in Wuhan City, Hubei Province of China, beginning in December 2019 (Lu et al. 2020). The World Health Organization (WHO) has named the pneumonia caused by this virus coronavirus disease 2019 (COVID-19) and declared COVID-19 a global health emergency. (Commission 2019; Lu et al. 2020). As of June 2, 2020,

there are more than 6,430,000 patients confirmed to have COVID-19, and 385,000 deaths have occurred worldwide. Nearly 14% of the patients need intensive care unit (ICU) management because of severe acute respiratory distress syndrome (ARDS) (Wu and McGoogan 2020).

Computerized tomography (CT) scan is the key imaging modality for these patients (Chung et al. 2020; Pan et al. 2020). However, the disadvantages of a CT scan include the need to transport the patient to the CT room, radiation exposure and, most importantly, the risk of virus dissemination. As a result, lung ultrasound seems to be a safer and more convenient alternative to CT scans in a transportation-limited setting such as when mechanical ventilation or even extracorporeal membrane oxygenation (ECMO) is needed. In an urgent situation when a patient's situation deteriorates, a rapid imaging tool is urgently needed. Lung ultrasound has evolved in recent decades, especially in critical care and emergency management. Studies of lung ultrasound

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Address correspondence to: Jiang Du, Emergency and Critical Care Department, Shanghai General Hospital of Shanghai Jiaotong University; 650 New Songjiang Road, Songjiang District, Shanghai, China, 201620. E-mail: gowindj@163.com

² Lina Zhao, Kanglong Yu and Qi Zhao are co-first authors.

have proven the value of this imaging modality in identifying pulmonary diseases including pulmonary edema and pneumonia, especially in the emergency and intensive care settings (Lichtenstein and Meziere 2008; Lichtenstein 2009). We have introduced bedside ultrasound for the imaging assessment of patients with severe COVID-19 to evaluate the severity of pneumonia.

MATERIALS AND METHODS

Study population

This retrospective study was performed at Shanghai General Hospital of Shanghai Jiaotong University and Shanghai Public Health Clinical Center of Shanghai Fudan University. Both are tertiary hospitals in Shanghai, China. All the patients were from the medical ICU department and had disease confirmed by reverse transcription polymerase chain reaction. All patients were enrolled from January 30, 2020, to February 29, 2020. Demographic information and epidemiologic history data were collected by chart review. This study was approved by the Ethics of Committees of Shanghai General Hospital Affiliated with the School of Medicine of Shanghai Jiaotong University. Informed consent for this retrospective study was waived.

Clinical classifications

All the patients had severe disease and were treated in the critical department according to the guidelines published by the National Health Commission of People's Republic of China (Committee). All patients were classified as having three types of disease: (i) severe type: respiratory distress with a respiratory rate of ≥ 30 breaths/min, an oxygen saturation of $\leq 93\%$ and a $\text{PaO}_2/\text{FiO}_2$ of ≤ 300 mm Hg in a resting state; (ii) critical type: respiratory failure requiring mechanical ventilation, shock and other organ failure requiring ICU monitoring and treatment; and (iii) refractory type: refractory respiratory failure with a $\text{PaO}_2/\text{FiO}_2$ of ≤ 100 mm Hg or patients who were treated with ECMO. We included patients with refractory-type disease in the refractory group and those with severe-type and critical-type disease in the non-refractory group. The lung ultrasound features and scores were studied and compared between the two groups.

Lung ultrasound assessment

All ultrasound evaluations were performed at the bedside by three physicians with more than 5 y of critical care experience. Operators were dressed in protective clothing, gloves and goggles to enter the isolation ward. All precautions for respiratory, droplet and contact isolation were provided in this ward. The ultrasound probe was placed in a sterile plastic sleeve or sterile glove. The

operator used a convex probe to perform an ultrasound of the lungs. Pulmonary ultrasound was screened first longitudinally and then transversely according to BLUE protocol (Lichtenstein 2009). The longitudinal examination began by finding the sonogram of the ribs and the pleural line between the two ribs to identify the lung tissue. A transverse examination was then performed to further clarify the images of the lungs. Image data were frozen and saved after obtaining the desired image, and the patient's name and examination location were marked. At the end of the procedure, we sterilized the probes in a dedicated area and placed the sterile plastic bag or sterile gloves in a medical recycling bag. All images were reviewed and scored by two physicians with more than 5 y of critical care ultrasound experience with the operator. An M7 Expert ultrasound system with a 5 MHz curved (C60 x) transducer was used for lung ultrasound assessment (Mindray Investment Co, Ltd, Shenzhen, China). We examined each side of the chest wall in five examination zones: The anterosuperior and anteroinferior zones were the second and fifth intercostal space in the midclavicular line; the latero-superior and latero-inferior zones were the same cross-sections at the midaxillary line; and the posterior zone was the subscapularis area on the back. In total, 10 zones were examined on every patient's chest wall. Patients were investigated in a semi-recumbent or supine position. We focused on the following patterns, and a numeric value was assigned according to the most severe finding: (1) 0 points, normal pattern with a smooth and sliding pleural line with parallel A lines; (2) 1 point, B-line patterns: B-lines were defined as discrete laser-like vertical hyperechoic artifacts arising from the pleural line and extending to the bottom of the image without fading (Lichtenstein *et al.* 1997); (3) 2 points, ground-glass sign with B-lines occupying the entire screen; (4) 3 points, shred sign that was fragmented similar to small consolidation under the pleural line; (5) 4 points, liver tissue-like consolidation sign; and (6) 4 points, pleural effusion. For one patient, the sum of the 10 zone numbers was recorded as the LUS score, which ranged from 0–40. The affected zones of each pattern were also recorded. This scoring system referenced some previously published scoring systems (Bouhemad *et al.* 2011; Soldati *et al.* 2020; Volpicelli *et al.* 2020).

Statistical analysis

We compared the demographic and LUS data between the non-refractory group and the refractory group. Statistical analysis was performed with RStudio 1.2.1335 (RStudio, Inc., Boston, Massachusetts, USA). Normally distributed data are expressed as the mean (standard deviation [SD]) and were analyzed by Student's *t*-test. Non-normally distributed data are

expressed as the median (interquartile range [IQR]) and were analyzed by the Wilcoxon test. Proportions are expressed as numbers (percentages) and were compared by the χ^2 test or Fisher's exact test. Receiver operating characteristic (ROC) curves were plotted to illustrate the accuracy in recognizing patients with refractory pneumonia.

RESULTS

Patient selection and demographic information

A total of 35 patients were enrolled in this study. In total, 28 patients were in the non-refractory group, and seven were in the refractory group. As shown in Table 1, the mean age was not significantly different between the groups. In the non-refractory group, there were 8 patients on mechanical ventilation and 20 on high-flow nasal cannula. In the refractory group, all seven patients were on ECMO in the end. In total, 15 patients were mechanically ventilated. There were 7 patients from Wuhan and 5 patients who had traveled to Wuhan within 14 d (Table 1).

Table 1. Demographic data

	Refractory Group	Non-refractory Group	<i>p</i> Value
	N = 7	N = 28	
Sex = Male (%)	6 (85.7)	18 (64.3)	0.524
Age (mean [SD])	62.14 (17.86)	64.14 (13.87)	0.749
CURB65 (mean [SD])	2.86 (0.90)	2.04 (1.07)	0.071
PSI (mean [SD])	141.43 (48.64)	103.43 (39.14)	0.036
APACHEIII (mean [SD])	15.29 (5.91)	12.14 (3.60)	0.080
Wuhan residence (%)	1 (14.3)	6 (21.4)	1.000
Wuhan visiting (%)	2 (28.6)	3 (10.7)	0.546
Seafood market visiting (%)	0 (0)	0 (0)	NA
COVID-19 patient contacting (%)	2 (28.6)	14 (50.0)	0.553
PaO ₂ /FiO ₂ (mean [SD])	77.57 (25.17)	192.69 (111.53)	0.011
ARDS severity (%)			0.005
Mild	0 (0.0)	11 (39.3)	
Moderate	1 (14.3)	11 (39.3)	
Severe	6 (85.7)	6 (21.4)	
oxygenation (%)			<0.001
HFNC	0 (0.0)	20 (71.4)	
Ventilation	0 (0.0)	8 (28.6)	
ECMO	7 (100.0)	0 (0.0)	
Smoking (%)	0 (0.0)	3 (10.7)	0.880
Hypertension (%)	3 (42.9)	10 (35.7)	1.000
Diabetes (%)	1 (14.3)	4 (14.3)	1.000
Cancer (%)	0 (0)	0 (0)	NA
CKD (%)	0 (0)	0 (0)	NA
Drinking (%)	0 (0.0)	2 (7.1)	1.000
Cardiovascular disease (%)	1 (14.3)	5 (17.9)	1.000
COPD (%)	0 (0.0)	1 (3.6)	1.000

APACHEIII, Acute Physiology and Chronic Health Evaluation III; ARDS, acute respiratory distress syndrome; CKD, chronic kidney disease; COPD: chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; CURB65, CURB-65 score for pneumonia severity; ECMO, extracorporeal membrane oxygenation; HFNC, high-flow nasal cannula; PSI, pneumonia severity index; RT-PCR, reverse transcription polymerase chain reaction; SD, standard deviation

Table 2. The median involved zones of different lung ultrasound patterns in each patient

Ultrasound Patterns	Refractory Group (N = 7)	Non-refractory Group (N = 28)	<i>p</i> Value
Normal pattern (median [IQR])	0.00 [0.00–0.00]	0.00 [0.00–0.00]	1.000
B-line pattern (median [IQR])	4.00 [2.00–7.00]	6.50 [6.00–10.00]	0.046
Ground-Glass pattern (median [IQR])	6.00 [2.50–6.50]	0.00 [0.00–3.00]	0.004
Shred signs (median [IQR])	6.00 [6.00–7.00]	8.00 [7.00–9.00]	0.133
Consolidation pattern (median [IQR])	1.00 [1.00–1.50]	0.00 [0.00–0.00]	<0.001
Pleural effusion (median [IQR])	5.00 [1.50–6.00]	0.00 [0.00–0.25]	0.005

IQR = interquartile range.

In refractory group, grand glass pattern, consolidation pattern and pleural effusions were significantly more than in the non-refractory group.

Lung ultrasound imaging findings

Ultrasound morphology features and their distributions are shown in Table 2. The B-line pattern (Fig. 1b) and shred sign (Fig. 1d) were the most typical ultrasound features that were frequently found in both groups. The median number of zones that showed a shred sign was 6 [IQR 6–7] in the refractory group and 8 [IQR 7–9] in the non-refractory group. Patients in the refractory group showed fewer B-line patterns than those in the non-refractory group (4 [IQR 2–7] vs. 6 [IQR 6–7], $p = 0.046$). The ground-glass pattern (Fig. 1c) occurred significantly more frequently in the refractory group than in the non-refractory group (6 [IQR 2.5–6.5] vs. 0 [IQR 0–3]). Although the consolidation pattern (Fig. 1e) was not that frequently found in both groups, it seemed that the refractory group had significantly more consolidation patterns. For the effusion pattern (Fig. 1f), there were significantly more patients with this pattern in the refractory group than in the non-refractory group (5 [IQR 1.5–6] vs. 0 [IQR 0–0.25]).

Lung ultrasound score in differentiating critical patients

The refractory group showed a higher LUS score than the non-refractory group (33.00 [IQR 27.50–34.00] vs. 25.50 [IQR 22.75–30.00], $p = 0.047$) (Fig. 2a). In different scanning zones, the refractory group always has a higher LUS score (Fig. 2b). The scores in the non-refractory group were equal between zones. In the refractory group, the scores were higher in the gravity-dependent zones. However, Wilcoxon analysis found no significant difference between zones in patients with refractory disease. When LUS was used in distinguishing patients with refractory disease, the cutoff point was 32 points (Fig. 3a). At this point, predicting a refractory situation had a specificity of 0.893 and a sensitivity of

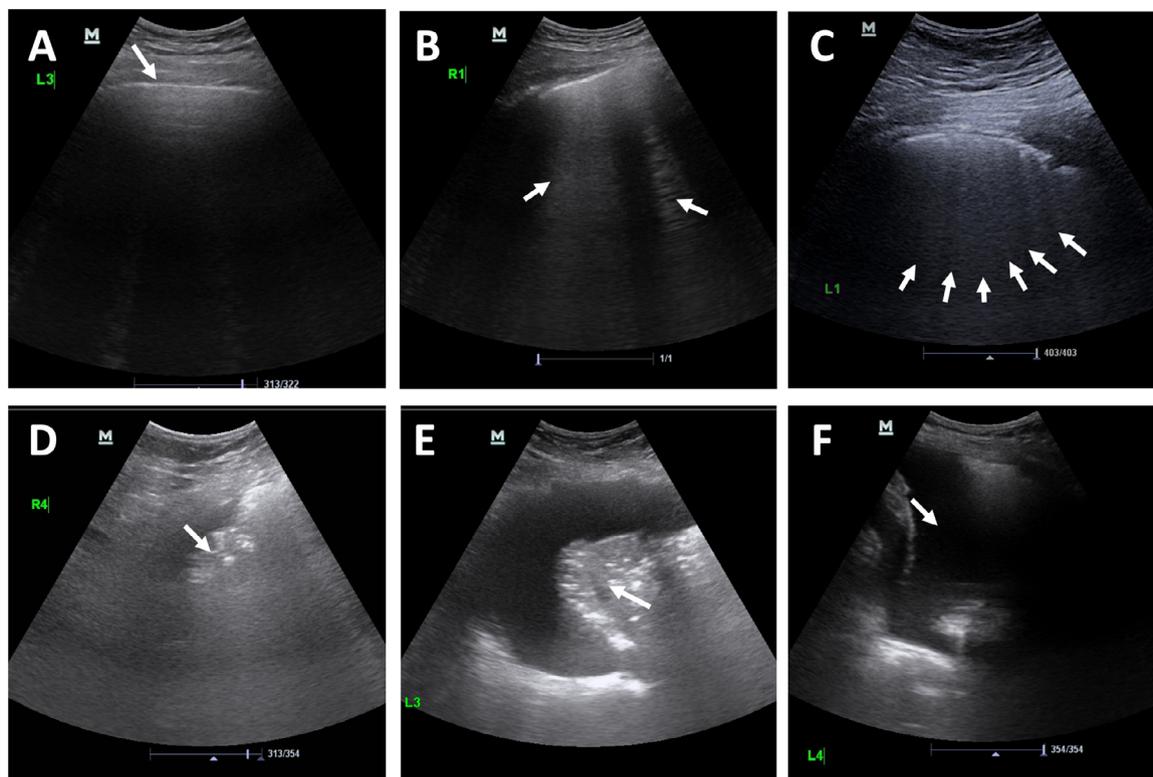


Fig. 1. Typical ultrasound and computed tomography images. (a) Smooth pleural line (*white arrow*) with an A-line; (b) B-line pattern; (c) ground-glass pattern with multiple B-lines (*white arrow*); (d) shred sign; (e) consolidation sign; (f) pleural effusion.

0.571. The ROC curve of the $\text{PaO}_2/\text{FiO}_2$ is also shown in [Figure 3](#), and the cutoff point is 114, with a specificity of 0.74 and a sensitivity of 100%. The area under the curve (AUC) of the $\text{PaO}_2/\text{FiO}_2$ ROC was 0.894. However, LUS did not differentiate well between the two severe and critical groups of patients, with an AUC of only 0.52 ([Fig. 3b](#)).

DISCUSSION

COVID-19 has already affected nearly 6,430,000 people worldwide. Although CT is the most important imaging modality for viral pneumonia, the high risk of transporting ventilated patients or patients on ECMO with hemodynamic failure limits CT availability. Furthermore, the risk of COVID-19 contagiousness should be evaluated before transportation. In addition, in the ICU, protective clothing makes stethoscopes have limited utility. Lung ultrasound has significantly evolved in the critical care and emergency department because of its theoretical and practical aspects. We introduced ultrasound for the examination of COVID-19 lesions because in critical care, ultrasound is an optimal tool for patients

on mechanical ventilation or ECMO. Both convex and linear probes can be used for ultrasound of the lungs ([Radzina and Biederer 2019](#); [Soldati et al. 2019](#); [Buonsenso et al. 2020](#)). However, because the convex probe may be more suitable for obese patients, it can also be used for abdominal and even cardiac examinations; thus, a convex probe was used in this study instead of a linear probe. Both [Buonsenso et al. \(2020\)](#) and [Soldati et al. \(2019\)](#) have suggested that wireless probes and tablets represent the most appropriate ultrasound equipment. These devices can easily be wrapped in single-use plastic covers to reduce the risk of contamination and allow simple sterilization procedures. However, the unavailability of these devices limited our choice. Daily assessment of the lungs can provide an assessment of the severity of lung disease because patients with refractory disease have more decreased lung aeration that can be evaluated by the lung ultrasound score (LUS). The LUS could differentiate between the two groups when they were divided into refractory and non-refractory groups ($p = 0.047$). We have not divided the patients into three groups (the severe group, the critical group and the refractory group) because the LUS could not

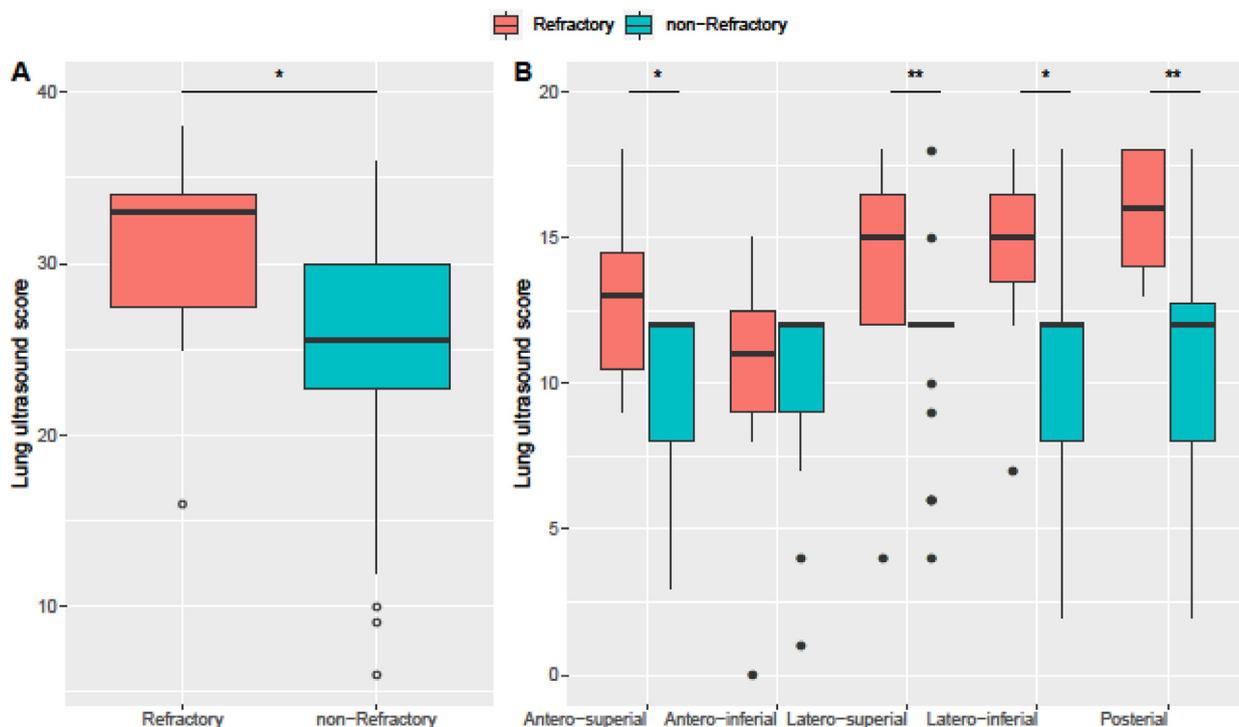


Fig. 2. Lung ultrasound score in different groups/scanning zones. (a) The lung ultrasound score in the refractory group was higher than that in the non-refractory group. (b) In most scanning zones, the lung ultrasound score was higher in the refractory group than in the non-extracorporeal membrane oxygenation (ECMO) group.

differentiate well between the severe group and the critical group ($p = 0.18$).

More ground-glass patterns and pleural effusions may indicate a more critical status. Ground-glass sign indicates a high ratio of fluid to air. This pattern was more frequently found in the refractory group. Previous CT studies have found few effusions (Chung et al. 2020; Fang et al. 2020; Pan et al. 2020). However, in the

present study, more pleural effusions may have been related to refractory respiratory failure. The reason may be that patients with refractory disease in this study had more severe disease or were in progressed stages, and mechanical ventilation may have further injured the lungs of these patients. When the density of the lung increases to that of solid tissue, consolidation appears. Although there were more consolidation patterns in the

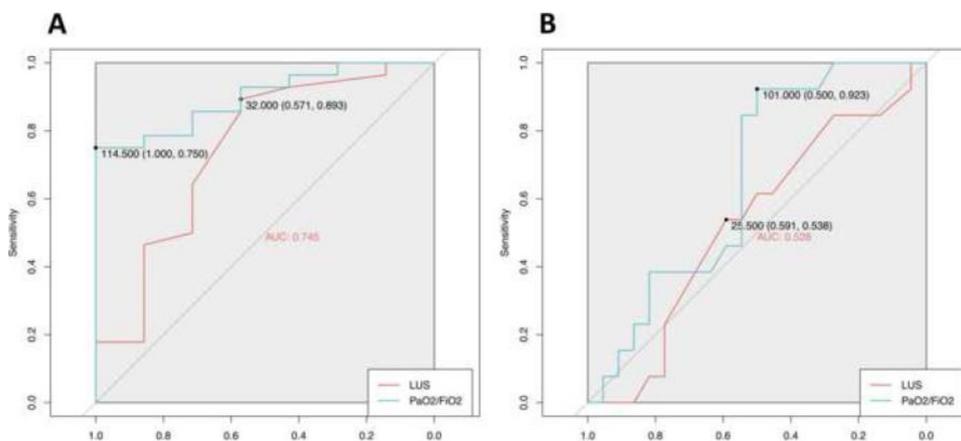


Fig. 3. Receiver operating characteristic curve of the lung ultrasound score (LUS) in the assessment of the severity of coronavirus disease 2019 (COVID-19) patients. (a) The AUC of the LUS in diagnosing patients with refractory disease. At a cutoff score of 32, the LUS had an 89.4% specificity, and at a 114 cutoff value, the PaO₂/FiO₂ had a 100% sensitivity. (b) The AUC of the LUS in diagnosing severely critical patients was low (cutoff of 25.5, area under curve of 0.528).

refractory group, consolidation patterns were not so frequently found in either groups. Previous CT studies have also found few consolidation patterns (Chung *et al.* 2020; Fang *et al.* 2020; Pan *et al.* 2020).

The shred sign and B-line patterns were the most typical ultrasound features but were not specific to distinguish patients with refractory disease because we found many B-lines and shred signs in both groups. Previous literature regarding CT scan disclosed that COVID-19 lesions are always distributed at the peripheral part of the lungs (Pan *et al.* 2020). This characteristic is beneficial for lung ultrasound to detect small fragments such as the shred sign in the shallow part of the lungs. The B-line pattern is considered to be highly reliable in diagnosing interstitial lesions and viral etiologies (Lichtenstein *et al.* 1997; Cortellaro *et al.* 2012) such as H1 N1 and H7 N9 (Testa *et al.* 2012; Tsai *et al.* 2014). However, this pattern is not related to a more critical status in COVID-19 patients. The reason may be that the number of B-lines was not described and analyzed in detail in this study.

The LUS exhibits a high specificity of 89.4% in distinguishing refractory respiratory failure in COVID-19 patients. Although the AUC of the LUS is lower than that of the PaO₂/FiO₂, the LUS exerts a much higher specificity than the PaO₂/FiO₂. If we combined the high specificity of the LUS and the high sensitivity of the PaO₂/FiO₂, we may have a much more reliable diagnosis. While one patient had a PaO₂/FiO₂ lower than 114, we had a 100% sensitivity in distinguishing patients with refractory disease. A further LUS assessment of more than 32 points on the LUS can improve the specificity to nearly 90%. Thus, we can have a more accurate model to differentiate refractory respiratory failure among patients who might need urgent life-saving maneuvers such as ECMO. ECMO was recommended by the WHO interim guidelines for eligible COVID-19 patients who had developed refractory ARDS (Ramanathan *et al.* 2020). Available evidence from similar patient populations suggests that carefully selected patients with severe ARDS who do not benefit from conventional treatment might be successfully supported with venovenous ECMO. In this study, the patients in the refractory group were all put on venovenous ECMO, and the LUS exhibited a high specificity of 89.4% in distinguishing refractory respiratory failure in COVID-19 patients. A previous study disclosed that lung ultrasound is a valuable tool for bedside assessment of lung aeration in patients supported by ECMO (Lu *et al.* 2019). However, such a practice has not been reported in COVID-19 patients.

Based on ultrasound findings, we have used lung ultrasound in the following routine works: (1) daily assessment of the severity of lung lesions: B-lines

gradually disappear and are replaced by A-lines, and consolidation that progressively disappears might indicate an improvement in the lungs, while more interstitial syndrome or more consolidation may indicate progression of the disease; (2) management of ECMO patients in put-on or weaning: an LUS of more than 32 might indicate a refractory status in this patient; namely, more interstitial syndrome and more consolidations detected by the LUS are directly correlated with the severity of the lung injury, which may indicate the need for venovenous ECMO; (3) diagnosis of the reason for rapid deterioration among patients; and (4) reducing the need for CT scan.

Our study has limitations. First, this is a retrospective experience-based study with a small sample size; thus, the extrapolations of the conclusion may not be strong enough to be suitable for other critical COVID-19 patients. Second, the acoustic beam cannot reach the deeper part of the lungs, and ultrasound features are always indirect artifacts of the lesions. Third, with ultrasound, some parts of the thorax cannot be screened, especially the back because patients with severe disease are always in the supine position. According to the recommendation by Soldati *et al.* (2020), all patients should have a lung ultrasound at 14 sites. However, 15 patients in this study were mechanically ventilated, and a good ultrasound examination of the back could not be obtained. Therefore, we focused only on evaluating lung ultrasound in the lower back segment in all patients. There were four fewer sites examined than Soldati *et al.* recommended; thus, the patient score may have been underestimated. Although we used conservative fluid therapy for all of our patients, we were still not completely sure if the patient had fluid overload and congestive heart failure. These conditions might also influence the B-lines and the analysis of the LUS.

In summary, COVID-19 patients share common ultrasound patterns such as B-lines and shred signs. However, patients with refractory COVID-19 have more ground-glass signs, consolidation patterns and pleural effusion. The LUS can be used to distinguish critical patients who might need ECMO with a high specificity of 90%. Ultrasound can be used as a routine tool for daily assessment of the lung aeration of severely critical COVID-19 patients.

Conflict of interest disclosure—The authors declare no competing interests.

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