Lung Ultrasound Findings in Patients With Coronavirus Disease (COVID-19)

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OBJECTIVE. Although chest CT is the standard imaging modality in early diagnosis and management of coronavirus disease (COVID-19), the use of lung ultrasound (US) presents some advantages over the use of chest CT and may play a complementary role in the workup of COVID-19. The objective of our study was to investigate US findings in patients with COVID-19 and the relationship of the US findings with the duration of symptoms and disease severity.

MATERIALS AND METHODS. From March 3, 2020, to March 30, 2020, consecutive patients with a positive reverse transcriptase polymerase chain reaction test result for the virus that causes COVID-19 were enrolled in this study. Lung US was performed, and the imaging features were analyzed. The Fisher exact test was used to compare the percentages of patients with each US finding between groups with different symptom durations and disease severity.

RESULTS. Our study population comprised 28 patients (14 men and 14 women; mean age ± SD, 59.8 ± 18.3 years; age range, 21–92 years). All 28 patients (100.0%, 28/28) had positive lung US findings. The most common findings were the following: B-lines (100.0%, 28/28), consolidation (67.9%, 19/28), and a thickened pleural line (60.7%, 17/28). A thickened pleural line was observed in a higher percentage of patients with a longer duration of the disease than in those with a shorter duration of the disease, and pulmonary consolidations were more common in severe and critical cases than in moderate cases.

CONCLUSION. Typical lung US findings in patients with COVID-19 included B-lines, pulmonary consolidation, and a thickened pleural line. In addition, our results indicate that lung US findings can be be used to reflect both the infection duration and disease severity.

During the first 3 months of 2020, the coronavirus disease (COVID-19) pandemic had evolved into an unprecedented health care crisis worldwide. In recognition that early diagnosis and subsequent isolation of patients with COVID-19 could effectively decrease the spread of the disease, the use of chest CT at initial presentation of patients with suspected COVID-19 has been promoted. Several studies have shown that unenhanced chest CT is sensitive for the early detection of the disease [1, 2] and is more sensitive than viral nucleic acid detection using reverse transcriptase polymerase chain reaction (RT-PCR) [3–5], although RT-PCR still remains the reference standard. When compared with chest CT, lung ultrasound (US) is advantageous given that it is a low-cost point-of-care tool that is repeatable and is free of ionizing radiation. The use of lung US for patients with suspected COVID-19 reduces the risk associated with transporting unstable patients to CT rooms while minimizing the exposure risk for medical devices and health care workers [6, 7]. This is especially important for preventing nosocomial outbreaks due to the high contagiousness of the virus. Although the utilization of lung US has been greatly developed in the past decades, few studies have analyzed the lung US findings of patients with COVID-19 [8, 9]. Therefore, the purpose of this study was to investigate lung US findings and their associated frequencies in patients with COVID-19, the relationship between lung US findings and the duration of COVID-19 symptoms, and the possibility of using lung US to assess the severity of COVID-19.

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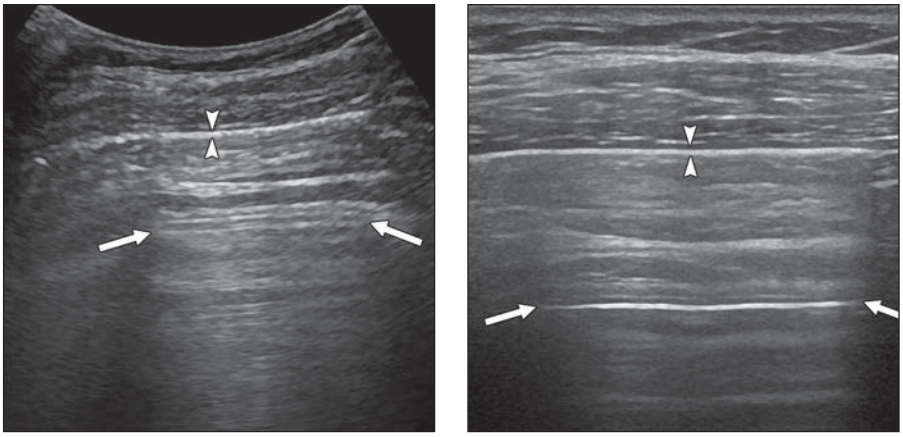

Fig. 1—Ultrasound (US) images of 32-year-old healthy male volunteer who was not participant in study.
A and **B,** Lung US images obtained with convex (**A**) and linear (**B**) probes. Both images show thin and smooth surface hyperechoic line, which is called pleural line (between *arrowheads*), and posterior horizontal echogenic lines, which are called A-lines (*arrows*). A-lines are differentiated from B-lines by their horizontal but not vertical distribution.

Materials and Methods

Study Population and Groups Based on Disease Severity

This study was approved by the local ethics committee of Beijing Ditan Hospital, which waived the need for written informed consent because of the retrospective nature of the study. From March 3, 2020, to March 30, 2020, consecutive patients in Beijing Ditan Hospital with a positive RT-PCR test result for COVID-19 were enrolled in this study. No negative control cases were included. All patients were classified on the basis of disease severity into one of the following four disease severity types according to the Diagnosis and Treatment Protocol of Novel Coronavirus (5th trial version) [10]: mild, moderate, severe, or critical. Because all participants in the current study were inpatients, no patients were classified as having mild disease. In addition, severe and critical cases were merged into the severe disease group because of the small numbers of cases in each individual category.

Acquisition and Analysis of Lung Ultrasound Findings

During hospitalization, all patients underwent bedside lung US performed with one US system (Hi Vision Preirus, Hitachi Healthcare) in a sitting, supine, or decubitus position, and each available intercostal space was assessed. For each examination, convex (1-5–MHz) and linear (2-12–MHz) probes were used, and gray-scale images and video clips showing abnormal findings were saved. The clinical symptoms and the time interval between the onset of initial symptoms and the lung US examination were recorded. All patients were assigned to early (< 20 days), intermediate (20–30 days), or late (> 30 days) groups according to the time interval. The time intervals were arbitrarily determined after analysis for even distribution of the number of patients in each group.

Two radiologists with 6 and 20 years of experience in lung US independently reviewed the images and video clips, and a final finding was reached by consensus when discrepancies were present. For each patient, lung US evaluation included recording the presence or absence of the following findings: A-lines (Fig. 1), B-lines (Figs. 2 and 3), a thickened pleural line (Fig. 3), pulmonary consolidation (Fig. 3), and pleural effusion. Each lung US feature has been well defined and described in previous studies [11, 12]. All patients also underwent chest CT; the time interval between the lung US and CT examinations was 3 days or less.

Statistical Analysis

Statistical analyses were performed using SPSS software (version 21.0, IBM). Patient age is expressed as mean ± SD, and all categoric variables are expressed as counts and percentages. The Fisher exact test was used to compare the percentages of different US features among groups with early, intermediate, and late symptom durations as well as groups with moderate and severe disease; p values < 0.05 were considered statistically significant when comparing two groups, and statistical significance was adjusted to $p < 0.0167$ (0.05 / 3) when comparing three groups to avoid a type I error.

Results

Study Population and Clinical Data

The study population comprised 28 consecutive patients (14 men and 14 women; mean age ± SD, 59.8 ± 18.3 years; age range,

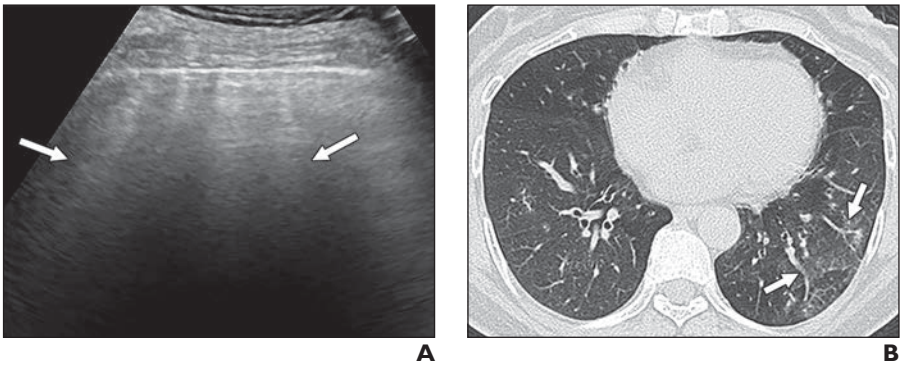

Fig. 2—58-year-old woman who presented with cough for 6 days and fever for 3 days. She had close contact with patient who had coronavirus disease (COVID-19), and reverse transcriptase polymerase chain reaction test result was positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).
A, Lung ultrasound image shows multiple B-lines (*arrows*).
B, Chest CT image shows ground-glass opacities (*arrows*). This patient was included in group with moderate disease.

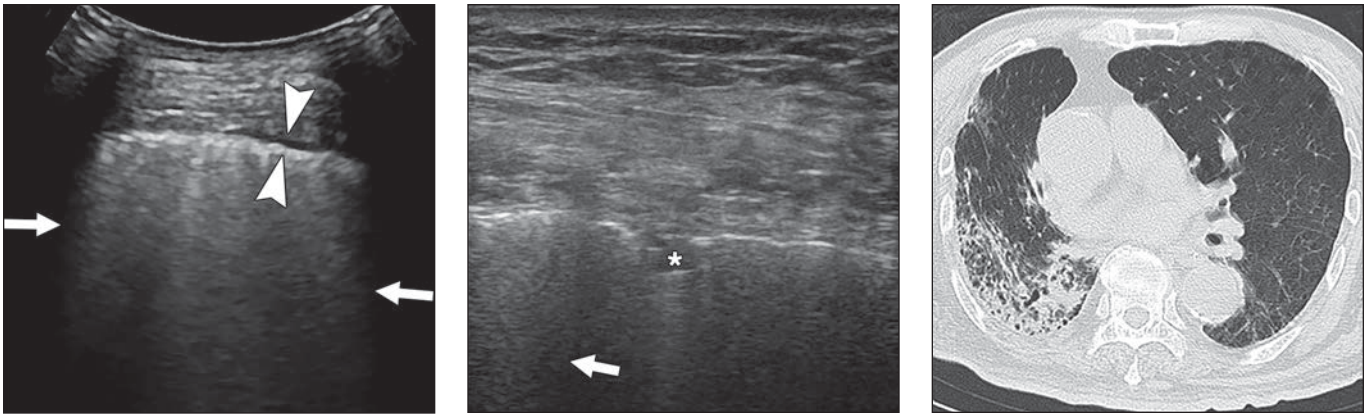

Fig. 3—82-year-old man who presented with cough, dyspnea, and fever for 10 days. He had close contact with patient who had coronavirus disease (COVID-19), and reverse transcriptase polymerase chain reaction test result was positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).
A and **B,** Lung ultrasound images obtained with convex (**A**) and linear (**B**) probes. Multiple confluent B-lines (*arrows*), patchy pulmonary consolidation (*asterisk*, **B**), and thickened pleural line (between *arrowheads*, **A**) are visualized.
C, Chest CT image shows reticular and interlobular septal thickening and patchy, focal opacities associated with architectural distortion. This patient was classified in critical group and was assigned to severe group for statistical analysis.

21–92 years). Fever was observed in 23 patients (82.1%), and cough and dyspnea were observed in 14 (50.0%) and six (21.4%) patients respectively. Four patients (14.3%) complained of fatigue, and one patient had diarrhea (3.6%). Disease was classified as moderate type in 13 patients (46.4%) and as severe type in 15 patients (53.6%).

Lung Ultrasound Findings and Features

All 28 patients had positive findings on both lung US and chest CT. On US, B-lines were present in all patients (28/28, 100.0%; Figs. 2 and 3), and 19 (67.9%) patients had pulmonary consolidation (Fig. 3). Thickened pleural lines were observed in 17 patients (60.7%, Fig. 3), and only one patient (3.6%) had a small amount of pleural effusion.

Lung Ultrasound Findings and Symptom Duration

The mean time interval between the onset of initial symptoms and the lung US examination was 26.8 ± 13.3 days (range, 4–54 days). The frequency of each lung US finding classified by the duration of symptoms is shown in Table 1. US showed B-lines in all patients regardless of the duration of symptoms. US showed that one patient in the early group had a pleural effusion. Pleural line thickening was rarely visualized in the early group (1/9, 11.1%), whereas six patients (66.7%) and 10 patients (100.0%) in the intermediate and late group, respectively, had thickened pleural lines ($p = 0.05$ between early and intermediate groups, $p = 0.001$ between early and late groups, $p = 0.087$ between intermediate and late groups). The percentages of patients with pulmonary consolidation seen on US were similar for the three groups: early group, 66.7%; intermediate group, 66.7%; and late group, 70.0% ($p = 0.984$).

Lung Ultrasound Findings and Disease Severity

There were 13 and 15 patients in the moderate and severe groups, respectively. The frequency of each US finding classified by disease severity is shown in Table 2. The percentages of patients with an US finding of a thickened pleural line were similar for the two groups (moderate group vs severe group, 61.5% vs 60.0%; $p = 1.0$). US showed pulmonary consolidation in a significantly higher percentage of patients in the severe group (86.7%) than in the moderate group (46.2%) ($p = 0.042$). The only patient with a pleural effusion detected on US was in the moderate group.

Discussion

Before the pandemic of COVID-19, bedside US had been used in the isolation unit for lung imaging of patients with other infectious diseases such as Ebola hemorrhagic fever to gain information that may alter medical management [13]. The current study also shows that the sensitivity of lung US to detect abnormalities

TABLE 1: Lung Ultrasound (US) Findings in Patients Classified by Duration of Symptoms

Lung US Finding	Early ($n = 9$)	Intermediate ($n = 9$)	Late ($n = 10$)	Total ($n = 28$)
A-lines[a]	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
B-lines	9 (100.0)	9 (100.0)	10 (100.0)	28 (100.00)
Thickened pleural line	1 (11.1)	6 (66.7)	10 (100.0)	17 (60.7)
Pulmonary consolidation	6 (66.7)	6 (66.7)	7 (70.0)	19 (67.9)
Pleural effusion	1 (11.1)	0 (0.0)	0 (0.0)	1 (3.6)

Note—The duration of symptoms from initial onset to lung US was classified as early (< 20 days), intermediate (20–30 days), or late (> 30 days). Data are reported as number (%) of patients.
[a]Only A-lines were visualized.

TABLE 2: Lung Ultrasound (US) Findings in Patients Classified by Disease Severity

Lung US Finding	Moderate (*n* = 13)	Severe (*n* = 15)	Total (*n* = 28)
A-lines[a]	0 (0.0)	0 (0.0)	0 (0.0)
B-lines	13 (100.0)	15 (100.0)	28 (100.0)
Thickened pleural line	8 (61.5)	9 (60.0)	17 (60.7)
Pulmonary consolidation	6 (46.2)	13 (86.7)	19 (67.9)
Pleural effusion	1 (7.7)	0 (0.0)	1 (3.6)

Note—Patients were classified on the basis of disease severity into one of the following four disease severity types according to [10]: mild, moderate, severe, or critical. Because all study participants were inpatients, no patients were classified as having mild disease. In addition, severe and critical cases were merged into the severe disease group because of the small numbers of cases in each individual category. Data are reported as number (%) of patients.
[a]Only A-lines were visualized.

in patients with COVID-19 is high and comparable to that of chest CT. The most common lung US findings were B-lines, which are caused by the reverberation of the US beam between slightly decreased alveolar air and increased interstitial fluids. On lung US, the B-lines are visualized as multiple vertical echogenic reverberation artifacts extending from the lung surface. Previous studies have shown high interobserver variability for assessment of B-lines, with percentage of agreement ranging from 92.2% to 95.1% [14, 15]. However, the detection of B-lines does not allow clinicians to differentiate among different causes, such as cardiogenic edema, acute respiratory distress syndrome, pulmonary fibrosis, or viral pneumonia [12]. No negative control cases were included in the current study, but the specificity of lung US in patients with suspected COVID-19 is expected to be very low at initial presentation.

B-lines were present in all patients in our study regardless of disease duration and severity. However, our results showed that the frequencies of a thickened pleural line were related to the time course of COVID-19: US showed a thickened pleural line in higher percentages of patients as the duration of disease increased. Like interlobular and intralobular septa thickening visualized on chest CT, a thickened pleural line on US is thought to reflect pulmonary fibrosis and a longer disease duration. Recognizing changes in lung US findings not only enables us to understand the pathophysiology and nature history of COVID-19, but also helps us to predict disease progression.

In addition to providing early diagnosis of COVID-19, chest CT can be used to evaluate the severity of the disease [16–18]. Similar to what has been observed with chest CT, our study shows that pulmonary consolidation depicted on lung US may serve as an alert in patient management. Pulmonary consolidation is visualized on lung US as tissuelike hypoechoic regions, which reflect highly reduced air flow and increased quantity of inflammatory cellular exudate. Lung US can provide an objective evaluation to identify which patients with COVID-19 have the severe and critical forms of the disease. US is repeatable in critically ill patients, which ensures that monitoring of the severity of the disease and the effects of therapies can be easily carried out. This capability is particularly important in situations in which chest CT is not available, such as in isolation wards and ICUs. Although portable radiography could be just as useful as US in terms of evaluation of consolidation, a bedside portable, handheld US system or even a robot-assisted tele-US system (a unique technique for physicians to remotely scan patients) [19] further minimizes the number of health care workers and medical devices exposed to COVID-19 compared with radiography.

This retrospective study has several limitations. First, the sample size was small with only 28 patients, and series repeated lung US studies were not performed to confirm its ability to evaluate either disease progression or treatment efficacy. Second, no patients with a negative RT-PCR result for COVID-19 were included to calculate the specificity of lung US. However, we believe that it is impossible to effectively confirm or rule out the diagnosis of COVID-19 simply on the basis of lung US findings. Third, the mean time interval between the onset of initial symptoms and lung US was longer (26.8 ± 13.3 days) than that of CT studies. In addition, patients with symptom duration of less than 4 days were not included in this study. The sensitivity of lung US for patients in the early phase of COVID-19 may not be as high as that shown in the current study. Fourth, our study fails to quantitatively evaluate disease severity. As with the CT severity score suggested by Yang et al. [17], a lung US severity score should be proposed to more accurately illustrate disease severity and facilitate comparison in follow-up studies. Finally, like other US techniques, lung US is operator-dependent and may not be as effective in inexperienced hands.

In conclusion, lung US was highly sensitive for detecting abnormalities in patients with COVID-19, and B-lines, a thickened pleural line, and pulmonary consolidation were the most commonly observed features. A thickened pleural line was more frequently observed on US in patients with longer time intervals after the initial onset of symptoms. Finally, pulmonary consolidation may be helpful in identifying patients with severe and critical forms of COVID-19.

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