Original Article

Lung ultrasound correlates with radiographic severity and pattern in COVID-19 pneumonia: a preliminary study

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Background: Coronavirus Disease 2019 (COVID-19) was outbreaking in late 2019 and a proportion of patients developed to pneumonia. Although chest CT is a pivotal diagnostic tool for COVID-19 pneumonia, CT is expensive and also radiological burden for patients. There is urgent to investigate the role of lung ultrasound (LUS) in diagnosing and monitoring COVID-19 pneumonia.

Methods: A total of 8 patients with confirmed cases of COVID-19 pneumonia in Shantou Central Hospital from January 2020 to February 2020 were retrospectively studied. All participants underwent chest HRCT and LUS examination; both were independently performed within 1 day of the other. The radiological patterns were reviewed by 2 radiologists who were blind to the clinical information. A senior ultrasound physician, blind to HRCT results and clinical data, performed bedside LUS in the isolation ward. The CT score was used (a semi-quantitative scoring system) to assess radiographic severity and extent. A B-lines score denoting the extent and severity of sonographic lesion was calculated by summing the number of B-lines on 18 scanning sites.

Results: B-lines (100%), pleural irregularities (25%), consolidation (25%), and pleural effusion (25%) were the main findings of LUS examination. Interstitial abnormalities, ground-glass opacities (GGO), consolidations and local or bilateral patchy shadowing were the main findings of HRCT examination. The findings of LUS and HRCT were compared point to point and high consistency was found between the 2 measurements. A significant correlation was also found between the B-lines score and CT score [r=0.96, 95% confidence interval (CI): 0.81 to 0.99, P=0.0001].

Conclusions: Both LUS patterns and B-lines score are significantly correlated with HRCT findings and score, respectively, supporting its role in assessing COVID-19 pneumonia severity, screening, and following up dynamic changes of pneumonia.

Keywords: Lung ultrasound (LUS); B-lines; high resolution computed tomography (HRCT); severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2); COVID-19 pneumonia

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Introduction

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) is a newly emerging zoonotic agent that appeared in December 2019 and causes the coronavirus disease 2019 (COVID-19) (1). A proportion of COVID-19 patients will progress to develop pneumonia, which is significantly associated with worse prognosis and higher mortality (2,3). The mechanism leading to acute lung injury in COVID-19 has not yet been fully elucidated. Until now, Chest computed tomography (CT) has been a pivotal diagnostic tool for COVID-19 pneumonia, which can identify early lung inflammation, stratify patients based on imaging manifestations, and closely follow up pulmonary lesion modification (2,3). Typical CT features of COVID-19 pneumonia comprise interstitial abnormalities, ground-glass opacities (GGO), and local or bilateral patchy shadowing, mostly subpleural and predominantly involving lower lobes and posterior segments of the lungs. The sensitivity of chest CT regarding COVID-19 pneumonia has been shown to be 97%, with reverse transcription-polymerase chain reaction (RT-PCR) results as gold standard for diagnosis (4). However, the specificity of CT diagnosis is discounted. In addition, CT scan has high cost and presents radiological burden, which limits its application for close monitoring of pneumonia. Furthermore, considering the highly contagious nature of SARS-CoV-2, transporting patients from the isolation ward to the radiology room could increase the risk of medical device contamination and nosocomial spreading of the virus, and infectious contagion of health-care workers (5). Finally, there is a need to minimize radiological exposure for some special patient groups, especially children and pregnant woman (6,7).

In the past decades, lung ultrasound (LUS) has been successfully applied as a diagnostic and monitoring tool for many thoracic diseases, including pulmonary edema, pneumonia, pneumothorax, interstitial lung diseases, and acute respiratory distress syndrome (ARDS) (8). Recently, a few studies based on small case series have shown that point-of-care LUS is an important diagnostic and monitoring tool for COVID-19 patients (9). The findings of LUS in COVID-19 patients include pleural thickening, multifocal B-lines, and bilateral subpleural consolidation, which reflect the abnormalities detected by CT scans (10). Compared with CT, LUS is cheaper, more convenient, and free of radiation. However, the correlation between LUS and CT has yet to be clearly determined.

In this preliminary study, we depicted the major radiological and sonographic patterns and assessed the correlations between LUS B-lines score and HRCT score in 8 patients with COVID-19 pneumonia. It is the investigation to find out the correlation between LUS and CT in patients with COVID-19 pneumonia. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/apm-21-1731).

Methods

Participants

For this retrospective, single-center study, 8 patients diagnosed with COVID-19 were recruited from January to February 2020, at Shantou Central Hospital. This study was conducted in accordance with the principles of the Declaration of Helsinki (as revised in 2013), and the Ethics Committee of Shantou Central Hospital waived written informed consent on account of its retrospective and emergent nature and evaluation of only the imaging and clinical data of patients, involving no potential risk for confidentiality. The ethical approval was obtained by ethics committee of Shantou Central hospital (2020-Scientific Research NO.010). Patients with heart and renal failure, and previous pulmonary diseases, including chronic obstructive pulmonary disease (COPD), interstitial lung disease (ILD), lung cancer, and tuberculosis, were excluded. Detailed demographic, clinical, and laboratory information were extracted from the electronic medical record system. All patients were recovered from COVID-19 pneumonia and discharged within 2 months.

Chest CT protocol and evaluation

All CT examinations were performed with a 128-slice scanner (Ingenuity Core 128 CT, Philips Healthcare, Amsterdam, Netherlands). The CT scan parameter settings were as follows: 120 kV; automatic tube current (100–400 mAs); iterative reconstruction technique level 5; rotation time 0.75 second; section thickness, 1 mm; collimation, 0.625 mm; pitch, 0.99; and matrix, 512×512. The CT dose index volume (CTDIvol) and dose-length product (DLP) during scans were recorded. The estimated effective dose (ED) was derived from DLP and a conversion coefficient k, ED = DLP × k, where k is the conversion coefficient for the chest (k=0.014 mSv mGy^{-1} cm^{-1}) (11).

The major CT findings were described using internationally standard nomenclature defined by the

Table 1 Laboratory findings of patients

Biochemical parameters	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8
White blood cell count ($\times10^9$/L) (normal range, 3.5–9.5$\times10^9$/L)	6	6.8	8.9	5.2	5	5.7	5.5	4.5
Neutrophil count ($\times10^9$/L) (normal range, 1.8–6.3$\times10^9$/L)	4.2	5.1	7.5	2.6	2.2	3.4	3.0	1.3
Lymphocyte count($\times10^9$/L) (normal range, 1.1–3.2$\times10^9$/L)	1.2	1.3	0.5	1.9	2.4	1.6	1.5	2.7
CRP (mg/L) (normal range, 0–8mg/L)	2.04	97.67	7.31	5.8	1.43	15.3	5.61	<0.499
PCT (ng/mL) (normal range, 0–0.05 ng/mL)	0.02	0.054	0.22	<0.1	<0.02	0.038	0.13	NA
D-dimer (normal range, 0–550 μg/L)	980	1950	2850	370	510	2110	150	NA
Total protein (g/L) (normal range, 65–85 g/L)	74.8	70.4	62.3	67.6	63.2	75.2	78.3	68.4
Albumin (g/L) (normal range, 40–55 g/L)	45.1	33.4	35.3	33.3	32.8	39.7	39.6	36.7
A-G ratio (normal range, 1.2–2.4)	1.52	0.9	1.31	0.97	1.08	1.12	1.02	1.16

CRP, C reactive protein; PCT, procalcitonin; A-G ratio, albumin and globulin ratio; NA, not applicable.

Fleischner Society glossary, using terms including GGO, reticulation, consolidation, and so on (12).

We used a semi-quantitative scoring system to quantitatively estimate the pulmonary involvement of all these abnormalities on the basis of the area involved (13). Each of the 5 lung lobes was visually scored from 0 to 5 as follows: 0, no involvement; 1, <5% involvement; 2, 5–25% involvement; 3, 26–49% involvement; 4, 50–75% involvement; 5, >75% involvement. The total CT score was the sum of the individual lobar scores and ranged from 0 to 25 (no involvement to maximum involvement).

The distribution of lung abnormalities was recorded as predominantly subpleural (involving mainly the peripheral one-third of the lung), random (without predilection for subpleural or central regions), or diffuse (continuous involvement of all lung segments).

All image analyses were performed using the institutional digital database system (NEUPACS Version 5.5, Neusoft, Shenyang, China) by 2 senior chest radiologists with 10–15 years of experience, and final scores were determined by consensus of the 2 senior chest radiologists.

LUS

Commercially available ultrasound equipment with a 5–14 MHz wide-band linear array transducer and another 2–5 MHz convex array transducer were used (Toshiba Medical Systems, APlio 500, Tokyo, Japan) in this study. A senior ultrasound physician who was blind to radiographic and clinical information conducted the LUS. The LUS was performed with participants in a seated position, and 18 lung areas were scanned (including the upper part, middle part, and lower part of the midclavicular line, anterior axillary line, and posterior axillary line, on both the left and right side. These areas were marked as L1–L9 and R1–R9, respectively, according to the Essential Image Acquisition Protocols for Thoracic Ultrasonography (Toma and Volpicelli, 2020). All ultrasound patterns and the total number of B-lines across the 18 scanning sites were recorded in detail. The sum of B-lines yielded a score reflecting interstitial pneumonia severity (14).

Statistical analysis

Statistical analyses were performed using the statistical software IBM SPSS (version 22; IBM, Armonk, NY, USA). Quantitative data were presented as mean ± standard deviation (minimum-maximum) and the counting data were presented as a percentage of the total. Correlations among total B-lines number and CT score were assessed with Pearson's correlation index. A P value of <0.05 was defined as statistical significance.

Results

Clinical and laboratory findings

A total of 8 patients including 4 male and 4 female, with ages ranging from 12 to 69 years (43±17.5) were enrolled in this study. The most common symptoms were cough, sore throat and fever. Other symptoms included mild headache and dizziness. The patients' laboratory data are shown in *Table 1*.

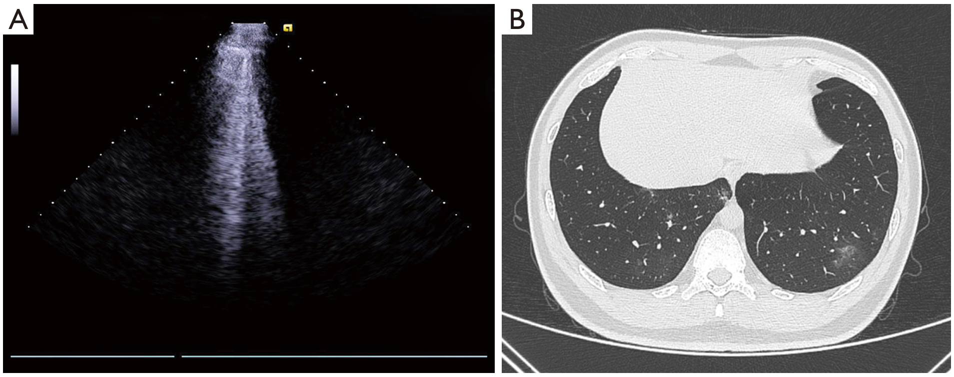

Figure 1 Imaging findings in mild COVID-19 pneumonia. (A) Lung ultrasound reveals patchy areas of coalescent B-lines (lower part of posterior axillary line, in the left side). (B) Computed tomography scan reveals subpleural ground-glass opacities.

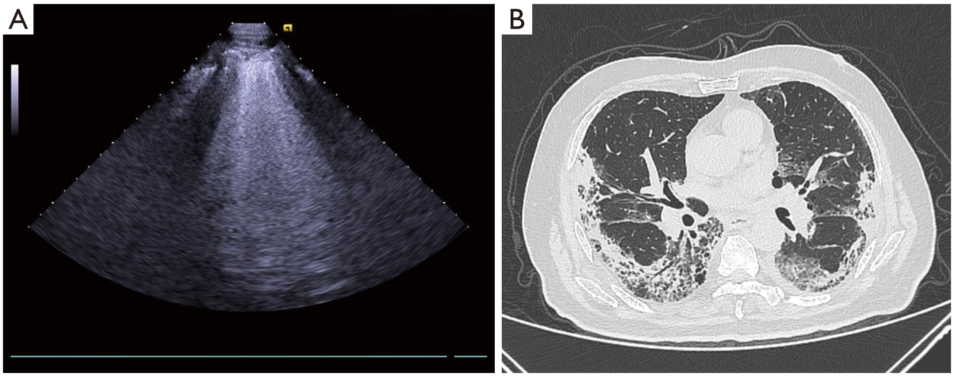

Figure 2 Imaging findings in severe COVID-19 pneumonia. (A) Lung ultrasound reveals confluent B-lines (the "white lung" sign) and pleural irregularly thickening (lower part of posterior axillary line, in the right side). (B) Computed tomography scan reveals ground-glass opacities, subpleural consolidation, reticulation and honeycombing.

LUS findings, correlation between LUS and HRCT

All 8 participants presented with at least 1 of the following abnormalities: all participants presented with an increase in B-lines, 2 presented with coalescent B-lines (<3 mm) (*Figure 1*), and 4 presented with a wide distance between B-lines (>7 mm) and the lung rockets sign; 2 participants showed the "white lung" sign (*Figure 2*), pulmonary consolidation, the comorbidity of pleural thickening and small amounts of pleural effusion, and none presented with the comorbidity of pneumothorax. The average time for LUS examination was about 8 minutes.

Distribution of lung lesions: All cases had multiple lung lesion distributions and bilateral lung involvement. The LUS found a total of 102 regions with lung involvement among the 8 participants, including L1 (62.5%, 5/8), L2 (87.5%, 7/8), L3 (87.5%, 7/8), L4 (62.5%, 5/8), L5 (62.5%, 5/8), L6 (87.5%, 7/8), L7 (37.5%, 3/8), L8 (87.5%, 7/8), L9 (100%, 8/8), and R1 (25%, 2/8), R2 (100%, 8/8), R3 (87.5%, 7/8), R4 (25%, 2/8), R5 (50%, 4/8) , R6 (100%, 8/8), R7 (25%, 2/8), R8 (87.5%, 7/8), and R9 (100%, 8/8), which indicated that the lesions were distributed mainly in the subpleural and peripheral pulmonary zones, with the lower lobe and the dorsal region having a greater tendency for involvement.

We found higher values of B-lines and CT score in the COVID-19 patients (*Table 2*). A significant linear correlation was found between the B-lines and CT score (r=0.96, 95% CI: 0.81 to 0.99, P=0.0001) (*Figure 3*).

Discussion

Lung involvement is the clinical hallmark of COVID-19

Table 2 HRCT and LUS findings

Methods	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6	Patient 7	Patient 8
CT Scan								
Number of lobes affected	3	5	5	4	4	5	3	0
Predominant distribution	Peripheral	Peripheral	Neither	Peripheral	Peripheral	Peripheral	Peripheral	Neither
Opacity characteristics	GGO + consolidation (>50%)	GGO + consolidation (>50%)	GGO + consolidation (>50%)	GGO (>50%) + consolidation	GGO (>50%) + consolidation	GGO (>50%) + consolidation	GGO	No
Interstitial abnormalities	Yes	Yes	Yes	Yes	Yes	No	No	No
Pleural effusion	No	Yes	No	No	No	No	No	No
CT scoring value	7	18	23	8	4	13	3	0
Lung ultrasound								
Localization	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral	Bilateral
Pleural irregularities	No	Yes	Yes	No	No	No	No	No
B-lines	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Consolidation	No	Yes	Yes	No	No	No	No	No
Pleural effusion	No	Yes	Yes	No	No	No	No	No
Total B-lines scoring	58	114	212	81	48	104	27	8

HRCT, high resolution computed tomography; LUS, lung ultrasound; GGO, ground-glass opacities.

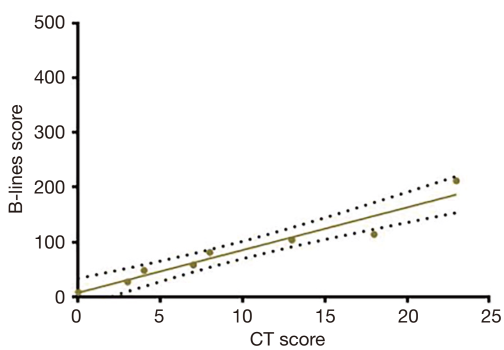

Figure 3 Correlation between the B-lines score and CT score. A significant correlation was found between the B-lines score and CT score (r=0.96, 95% CI: 0.81 to 0.99, P=0.0001).

infection, and is associated with significant morbidity and mortality (15). Early identification, prompt intervention, and close monitoring of the development of pneumonia is very important and could help improve patient prognosis.

Chest CT is a key component of diagnostic workup for patients with suspected infection. Typical CT findings included bilateral pulmonary parenchymal GGO, with or without consolidation, and with lower lobe and peripheral zone consolidation (16). Chest CT could comprehensively assess the extent and severity of pneumonia, and dynamically monitor lesion changes. Unfortunately, CT scanning is not available in all emergency departments. In addition, these CT findings are not specific to COVID-19 and could be also seen in other viral pneumonia, bacterial pneumonia, and inflammatory pneumonia. Furthermore, CT scan should not be routinely used in specific age groups, such as children and pregnant women. In this context, there is growing evidence supporting the use of LUS in detecting COVID-19 pneumonia.

Peng *et al.* first described LUS findings in 20 patients with COVID-19 (10), and they reported that LUS features were significantly correlated with CT findings. The major patterns in LUS included the presence of B-lines (multifocal, discrete, or confluent), pleural line irregularity, and subpleural consolidation, whereas pleural effusion was rare. Similar findings were identified in our current study, wherein the B-lines pattern corresponded to interstitial pneumonia. The B-lines are sensitive features for the alveolar-interstitial syndrome (17), and different B-lines morphology may indicate different extra-vascular exudation (14). In addition, CT scanning showed that COVID-19 pneumonia was predisposed to involvement the peripheral area and pleura. Accordingly, pleural irregularity is a pivotal LUS sign to detect the lesion. In our study, pleural irregularity was found in 25% of participants.

Growing evidence demonstrates that most cases of COVID-19 pneumonia correspond to interstitial lung disease. Previous studies have shown that the number of B-lines is strongly associated with HRCT severity score, pulmonary function test parameters, and serum biomarker KL-6 levels in connective tissue disease-associated interstitial lung disease (CTD-ILD) (18-20). In this pilot study, total B-lines score of LUS and semi-quantitative score of HRCT denoted sonographic and radiological severity, respectively. Our results demonstrated that the B-lines score is significantly correlated with the HRCT score, indicating that LUS might be used as an imaging modality to assess and follow up the severity of COVID-19 pneumonia.

Participant 8 was a 12-year-old child who had recently travelled to Wuhan, and was admitted to our hospital with dry cough, but no fever, sore throat, or muscle pain. She had no history of lung disease. After admission, the nucleic acid of the SARS-CoV-2 was positive and chest CT scanning was normal. However, LUS examination identified a total of 8 B-lines, predominantly distributed at the inferior areas of the lung. The patient was isolated and was placed under medical observation for 2 weeks. Finally, her condition improved and she was discharged. Considering that LUS has good sensitivity to detect early lesions that are closed to peripheral area, and is radiation-free, it could represent an alternative to HRCT for identifying suspected COVID-19 pneumonia.

For COVID-19 patients who are children or pregnant women, LUS is more available to detect and follow up their viral pneumonia, owing to its inherent features of being radiation-free, non-invasive, real-time, repeatable, and feasible.

The SARS-CoV-2 is highly contagious, and has progressed rapidly into a worldwide pandemic, showing that humans are particularly susceptible to this novel coronavirus. Therefore, we believe that such a procedure as LUS could reduce health-care workers' risk of exposure and minimize patient movement from the isolation room to the radiology room. Considering the contagiousness of the virus and the need to reduce nosocomial outbreaks, we strongly suggest point-of-care LUS in this setting (5).

There were some limitations to this retrospective study. First, it is obvious that our sample size was very small, so the statistical power is limited. On account of the pandemic situation having being mitigated rapidly in Shantou, there were no further cases enrolled since the time of research initiation. Since COVID-19 pneumonia is a kind of respiratory infection disease, the most effective personal protective was vaccination and wearing mask. Fortunately, free vaccination is sweeping all of the word especially in China, and defeating COVID-19 pneumonia is at hand. Second, although LUS has good sensitivity in detecting early pneumonia, it could not distinguish COVID-19 from other types of pneumonia. Accordingly, prompt identification of the specific pathogen is very important. Third, due to the short observation time, it is not clear whether the extent and severity detected by LUS can predict the prognosis of COVID-19 pneumonia patients.

In conclusion, LUS patterns and B-lines score are significantly correlated with HRCT findings and CT score, respectively, supporting their use as measures of COVID-19 pneumonia severity at the bedside and as an effective diagnostic method for COVID-19 pneumonia. Further prospective, large sample, and multi-center studies are needed to confirm our results.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://dx.doi.org/10.21037/apm-21-1731

Data Sharing Statement: Available at https://dx.doi.org/10.21037/apm-21-1731

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://dx.doi.

org/10.21037/apm-21-1731). The authors have no conflicts of interest to declare.

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. Due to the retrospective design of the study, the requirement for written informed consent was waived, in compliance with the law. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The ethical approval was obtained by ethics committee of Shantou Central hospital (2020-Scientific Research NO.010)

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