Prospective Longitudinal Evaluation of Point-of-Care Lung Ultrasound in Critically Ill Patients With Severe COVID-19 Pneumonia

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Objectives—To perform a prospective longitudinal analysis of lung ultrasound findings in critically ill patients with coronavirus disease 2019 (COVID-19).

Methods—Eighty-nine intensive care unit (ICU) patients with confirmed COVID-19 were prospectively enrolled and tracked. Point-of-care ultrasound (POCUS) examinations were performed with phased array, convex, and linear transducers using portable machines. The thorax was scanned in 12 lung areas: anterior, lateral, and posterior (superior/inferior) bilaterally. Lower limbs were scanned for deep venous thrombosis and chest computed tomographic angiography was performed to exclude suspected pulmonary embolism (PE). Follow-up POCUS was performed weekly and before hospital discharge.

Results—Patients were predominantly male (84.2%), with a median age of 43 years. The median duration of mechanical ventilation was 17 (interquartile range, 10–22) days; the ICU length of stay was 22 (interquartile range, 20.2–25.2) days; and the 28-day mortality rate was 28.1%. On ICU admission, POCUS detected bilateral irregular pleural lines (78.6%) with accompanying confluent and separate B-lines (100%), variable consolidations (61.7%), and pleural and cardiac effusions (22.4% and 13.4%, respectively). These findings appeared to signify a late stage of COVID-19 pneumonia. Deep venous thrombosis was identified in 16.8% of patients, whereas chest computed tomographic angiography confirmed PE in 24.7% of patients. Five to six weeks after ICU admission, follow-up POCUS examinations detected significantly lower rates (P < .05) of lung abnormalities in survivors.

Conclusions—Point-of-care ultrasound depicted B-lines, pleural line irregularities, and variable consolidations. Lung ultrasound findings were significantly decreased by ICU discharge, suggesting persistent but slow resolution of at least some COVID-19 lung lesions. Although POCUS identified deep venous thrombosis in less than 20% of patients at the bedside, nearly one-fourth of all patients were found to have computed tomography–proven PE.

Key Words—acute respiratory failure; chest computed tomography; COVID-19 pneumonia; point-of-care lung ultrasound; pulmonary embolism

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Lung ultrasound (US) has been used in coronavirus disease 2019 (COVID-19) evaluations since the beginning of the COVID-19 outbreak in China, North America, and...
Europe.\textsuperscript{1–6} Lung US was suggested to be particularly useful during the COVID-19 pandemic because of its ability to identify subtle lung parenchymal changes early in the course of disease, monitor the evolution of pulmonary lesions in hospitalized patients, and guide mechanical ventilation therapy in critically ill patients with acute respiratory failure and acute respiratory distress syndrome.\textsuperscript{7–10} Although the role of traditional portable chest radiography, especially in this era of crisis and resource limitations, cannot be unheeded, lung US could represent a flexible diagnostic solution in COVID-19 pneumonia.\textsuperscript{11,12} Unlike lung US, some reports indicate the sensitivity of chest radiography for COVID-19 pneumonia to be as slow at 20%.\textsuperscript{13} Lung US is a portable bedside imaging tool, which has been previously used in the diagnosis and monitoring of acute respiratory distress syndrome in the intensive care unit (ICU).\textsuperscript{14–22}

Chest computed tomography (CT) rapidly became the mainstream imaging method in the diagnosis and monitoring of COVID-19 pneumonia by identifying the typical pattern of ground glass opacities with variable infiltrates and consolidations, while showing a high correlation with laboratory detection of the virus by real-time polymerase chain reaction (RT-PCR) assays.\textsuperscript{23–30} Compared to CT, point-of-care ultrasound (POCUS) still has limited evidence supporting its diagnostic utility in COVID-19 but could be helpful with proper expertise. Since most lung parenchymal lesions in COVID-19 are distributed peripherally, these lesions should theoretically be detected by POCUS.\textsuperscript{23–30} Hence, in this study, the primary end point was to analyze the lung US findings in critically ill patients with severe COVID-19 pneumonia or admission to the ICU longitudinally throughout their disease course.

Materials and Methods

Study Design
We prospectively enrolled consented patients with confirmed COVID-19 pneumonia admitted to a polyvalent ICU (King Saud Medical City) throughout May 2020. Inclusion criteria were age older than 18 years, ICU admission, and serious COVID-19 pneumonia. The latter was defined as acute respiratory failure: dyspnea, a respiratory rate of 30 breaths per minute or higher, blood oxygen saturation of 93% or less, a partial arterial pressure of oxygen–to–fractional inspired concentration of oxygen ratio of less than 300, development of bilateral pulmonary infiltrates within 24 to 48 hours, or a combination thereof.\textsuperscript{30–35} Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection was determined by RT-PCR assays on throat swab samples using a QuantiNova Probe RT-PCR kit (Qiagen, Hilden, Germany) in a Light-Cycler 480 real-time PCR system (Roche, Basel, Switzerland).\textsuperscript{36–42} Exclusion criteria were patients with COVID-19 who did not undergo a POCUS examination (reasons included unavailability of operators on the patient’s admission and transfer to other COVID-19–targeted hospitals per the Saudi Ministry of Health surge plan) and 2 consecutive negative RT-PCR test results for SARS-CoV-2 taken at least 24 hours apart. The study was conducted according to the principles of the Declaration of Helsinki and approved by our Institutional Review Board.\textsuperscript{43} Written informed consent was obtained from patients or their legal representatives.

Point-of-Care US Examination and Data Acquisition
On ICU admission, a POCUS examination was performed with phased array (2–4-MHz), convex (2-6-MHz), and linear (10–15-MHz) transducers connected to portable US machines assigned exclusively to the study of patients with COVID-19, (Figure 1). The US examination was performed by a single operator with the assistance of a single ICU nurse. Both entered the ICU isolation room wearing personal protective equipment adhering to preventive infection control measures for respiratory, droplet, and contact isolation in COVID-19 as detailed elsewhere.\textsuperscript{44–46} All transducers were placed inside sterile sheaths, and US machines were dressed in sterile covers to perform each examination. At the end of the examination, machines and transducers were sterilized in a designated isolation room and were placed into new sterile covers.\textsuperscript{44–46} The thorax was scanned in 12 lung areas in total: anterior-superior and anterior-inferior, lateral-superior and lateral-inferior, and posterior-superior and posterior-inferior bilaterally.\textsuperscript{14–22} Ultrasound examinations targeted detection of B-lines, lung consolidations, and pleural line abnormalities in each lung (Figure 2).\textsuperscript{14–22} Due to the high risk of
thromboembolic disease in ICU patients with COVID-19, during the POCUS session, a vascular US examination of the lower limbs was performed in search of potential deep venous thrombosis (DVT). \(^6,47,48\) Per hospital policy and regardless of POCUS results, all patients with COVID-19 who had a high suspicion of pulmonary embolism (PE; ie, elevated d-dimer levels or refractory hypoxia for >48 hours) underwent chest computed tomographic angiography (CCTA) to exclude PE. \(^49-55\) The incidence of acute kidney injury, as defined per the “risk,” “injury,” and “failure” criteria, and the prevalence of comorbidities were documented. \(^56\) Data regarding invasive mechanical ventilation and oxygen therapy by means of a high-flow nasal cannula (HFNC), which has shown promise in the management of serious COVID-19 pneumonia, were tracked. \(^57\) Outcome measures such as the duration of mechanical ventilation, ICU length of stay, and raw (not adjusted for disease severity) mortality on day 28 after ICU admission were recorded. Follow-up POCUS examinations were performed weekly in all patients and once before hospital discharge in survivors. All POCUS examinations were performed by experienced operators. Point-of-care US images were electronically stored and analyzed. Medical records were used to obtain demographic, clinical, and laboratory data for enrolled patients with COVID-19.

Figure 1. Scanning with different transducers in 4 critically ill patients with COVID-19: irregular pleural line with associated subpleural consolidation, B-lines, and hyperechoic parenchymal consolidation in the posterior-inferior area of the left lung depicted by a phased array (2.5-MHz) transducer (A); beam line artifact in the inferior-anterior area of the right lung depicted by a linear (15-MHz) transducer (B); beam line artifact in the lateral-inferior area of the right lung depicted by a phase array (2.5-MHz) transducer (C); and beam line artifact and hyper-echoic consolidations depicted by a convex (3.5-MHz) transducer in the inferior-anterior area of the right lung (D, panoramic view integrating 3 intercostal spaces).
Statistical Analyses
Continuous variables were expressed as medians with interquartile ranges (IQR). Categorical variables were expressed as proportions. A power analysis suggested that a minimum sample size of 80 patients would be required with a significance level of 5% to achieve power of 80%. The Fisher exact test was used to compare differences between proportions. A 2-tailed significance level of .05 was regarded statistically significant. All data were stored on a spreadsheet (Excel 2011; Microsoft Corporation, Redmond, WA), and analyses were performed with a commercially available statistical package (SPSS version 24; IBM Corporation, Armonk, NY).

Results
Patient Population
One hundred consecutive patients with COVID-19 were admitted to the ICU during the study period. Eleven patients were excluded from study enrolment because of transfer to other COVID-19 centers according to the Saudi Ministry of Health surge plan. Eighty-nine consented patients with COVID-19 were finally enrolled. All patients had portable chest radiography, which was performed in the emergency department. Ten of 89 patients (11.2%) had admission chest CT scans. All recruited patients underwent POCUS examinations on study enrollment.

Table 1 summarizes main baseline parameters and outcome measures of the study population. Most of the patients with COVID-19 were male (84.2%) with a median age of 43 (IQR, 32.1–53.9) years. Table 2 summarizes patient symptoms and comorbidities before hospital admission. The most common symptoms were cough (100%), fever (84.2%), and dyspnea (47.1%). On ICU admission, 84.2% of patients were intubated, and 15.7% were receiving oxygen via an HFNC with median flow of 60 L/min and a median fraction of inspired oxygen of 40%. However, after 48 hours, all patients were intubated and mechanically ventilated.

A high admission Sequential Organ Function Assessment score was documented (9.4 [IQR, 8.9–10.5]). Venovenous extracorporeal membrane oxygenation was attempted in 5 cases (5.6%), of which 2 patients died. All patients received acute respiratory distress syndrome net ventilation, prone positioning, lung recruitment, and empiric therapy for COVID-19 with lopinavir/ritonavir, ribavirin, and interferon β1b for 14 days, dexamethasone for 7 days,

Figure 2. Scanning with a linear high-frequency (12-MHz) transducer in the superior-anterior area of the left lung in a critically ill patient with COVID-19 depicting (white arrows) irregularities of the pleural line with associated B-lines (A) and subpleural consolidations (B).
prophylactic anticoagulation, and ICU supportive care per current recommendations for the treatment of severe COVID-19 pneumonia.35,36,58

**Computed Tomography, Laboratory Results, and Illness Severity**

Twenty-five patients were screened for PE by CCTA within the first 48 hours of ICU admission because of resistant hypoxemia. Twenty-two of 89 (24.7%) patients were found to have positive results for PE by CCTA (Table 1). Acute kidney injury was documented in 11 cases (12.3%), of which 3 received continuous renal replacement therapy, as they had anuria,

**Table 1.** Baseline Parameters and Outcome Measures of the Study Population (n = 89)

| Parameter/Outcome Measure | Value |
|---------------------------|-------|
| Age, y                    | 43 (32.1–53.9) |
| Male, %                   | 84.2 |
| Body mass index, kg/m²    | 26.5 (20.4–31.1) |
| Symptoms onset to ICU admission, d | 9.5 (6.5–12.1) |
| SOFA score on ICU admission | 9.4 (8.9–10.5) |
| Intubated and mechanically ventilated, % | 84.2 |
| Mechanically ventilated and receiving VV-ECMO, % | 5.6 |
| Nonintubated and receiving an HFNC, % | 15.7 |
| Pao₂/FiO₂ ratio on ICU admission | 175 (125.5–235.5) |
| Lymphocyte count, ×10⁹/L (normal range, 1.1–3.2) | 0.8 (0.52–1.1) |
| C-reactive protein, mg/L (normal range, 0–5) | 82.3 (61.2–99.8) |
| Total bilirubin, µmol/L (normal range, 0–26) | 292 (18.5–35.2) |
| Alanine aminotransferase, U/L (normal range, 9–50) | 96.5 (72.3–101.2) |
| Aspartate aminotransferase, U/L (normal range, 40.2–88.3) | 56.9 |
| Serum lactate, mmol/L (normal range, 1.0–2.5) | 3.2 (1.4–5.9) |
| Creatinine, mg/dL (normal range, 0.6–1.2) | 1.4 (0.9–1.9) |
| Lactate dehydrogenase, U/L (normal range, 100–190) | 426.5 (278.4–573.4) |
| Ferritin, ng/mL (normal range, 23–336) | 733 (699–858) |
| D-Dimers, µg/mL (normal values, <1) | 6.4 (3.9–12.7) |
| Acute kidney injury, % | 12.3 |
| Confirmed PE by CCTA, % | 24.7 |
| Duration of mechanical ventilation, d | 17 (10–22) |
| ICU length of stay, d | 22 (20.2–25.2) |
| Patients discharged from the hospital, % | 71.9 |
| Mortality on day 28, % | 28.1 |

Values are medians (IQRs) where applicable. Pao₂/FiO₂ ratio indicates partial arterial pressure of oxygen–to–fractional inspired concentration of oxygen ratio; SOFA, Sequential Organ Function Assessment; and VV-ECMO, venovenous extracorporeal membrane oxygenation.

**Table 2.** Study Population Symptoms and Comorbidities on Admission

| Presenting Symptom | Incidence, % | Comorbidity | Incidence, % |
|--------------------|--------------|-------------|--------------|
| Cough              | 100          | Hypertension| 50.5         |
| Fever              | 84.2         | Diabetes    | 44.9         |
| Dyspnea            | 47.1         | Cardiovascular disease | 13.4 |
| Sputum production  | 34.8         | End-stage renal disease | 10.1 |
| Nausea and vomiting| 15.9         |             |              |
| Diarrhea           | 11.2         |             |              |
| Altered consciousness | 10.1       |             |              |

**Table 3.** Point-of-Care US Findings in ICU Patients With COVID-19

| US Finding                          | Incidence of Findings on ICU admission in Patients (n = 89), % | Incidence of Findings on Hospital Discharge (After 5–6 wk) in Survivors (n = 64), % |
|-------------------------------------|-----------------------------------------------------------------|----------------------------------------------------------------------------------|
| B-lines                             | 100                                                             | 15.6<sup>a</sup>                                                                |
| Anterior-superior                   | 78.6                                                            | 9.3<sup>a</sup>                                                                |
| Anterior-inferior                   | 78.6                                                            | 12.5<sup>a</sup>                                                               |
| Lateral-superior                    | 78.6                                                            | 9.3<sup>a</sup>                                                                |
| Lateral-inferior                    | 67.4                                                            | 12.5<sup>a</sup>                                                               |
| Posterior-superior                  | 84.2                                                            | 12.5<sup>a</sup>                                                               |
| Posterior-inferior                  | 84.2                                                            | 12.5<sup>a</sup>                                                               |
| Bilateral                           | 78.6                                                            | 12.5<sup>a</sup>                                                               |
| Confluent B-lines                   | 78.6                                                            | 9.3<sup>a</sup>                                                                |
| Separated B-lines                   | 67.4                                                            | 12.5<sup>a</sup>                                                               |
| Pleural line irregularities in >6 lung areas | 78.6                                                            | 15.6<sup>a</sup>                                                               |
| Consolidations                      | 61.7                                                            | 12.5<sup>a</sup>                                                               |
| Anterior-superior                   | 39.3                                                            | 9.3<sup>a</sup>                                                                |
| Anterior-inferior                   | 39.3                                                            | 12.5<sup>a</sup>                                                               |
| Lateral-superior                    | 39.3                                                            | 12.5<sup>a</sup>                                                               |
| Lateral-inferior                    | 39.3                                                            | 12.5<sup>a</sup>                                                               |
| Posterior-superior                  | 49.4                                                            | 9.3<sup>a</sup>                                                                |
| Posterior-inferior                  | 49.4                                                            | 9.3<sup>a</sup>                                                                |
| Bilateral                           | 49.4                                                            | 12.5<sup>a</sup>                                                               |
| Pleural effusions                   | 22.4                                                            | 1.5<sup>a</sup>                                                                |
| Pericardial effusions               | 13.4                                                            | 1.5<sup>a</sup>                                                                |
| DVT                                 | 16.8                                                            | 12.5<sup>a</sup>                                                               |

<sup>a</sup>P < .05 by Fisher exact test.
acidosis, and hyperkalemia. Table 1 summarizes laboratory abnormalities identified. All other infectious and systemic disease screening results were negative.

The duration of mechanical ventilation was 17 (IQR, 10–22) days, and the ICU length of stay was 22 (IQR, 20.2–25.2) days. Raw (not adjusted for

Figure 3. Confluent (A) and separate (B) B-lines detected by a phased array (2.5-MHz) transducer in the inferior-anterior area of the right lung in a critically ill patient with COVID-19.

Figure 4. Panoramic views integrating 3 intercostal spaces by a convex (3.5-MHz) transducer depicting separate B-lines in the inferior-anterior area of the right lung (A) and beam line artifacts with hyperechoic consolidations in the inferior-posterior area of the right lung (B) in 4 critically ill patients with COVID-19.
disease severity) mortality on day 28 after ICU admission was 28.1% (25 of the 89 patients died). Finally, SARS-CoV-2 RNA, assayed by RT-PCR, became negative in the 64 survivors by 30 (IQR, 25–35) days after ICU admission.

**Point-of-Care US Findings in Patients With COVID-19**

A total of 452 POCUS examinations were performed during the study period. The POCUS examinations lasted approximately 27 (IQR, 24–30) minutes. The main POCUS findings are summarized in Table 3. On ICU admission, all patients with COVID-19 had an abnormal aeration pattern (B-lines). In most cases, coexistent confluent and separated B-lines were documented (Figure 3). Bilateral involvement and pleural line irregularities in more than 6 lung areas were evident in most cases (Table 3). However, the right lung (73%) was more frequently affected compared to the left lung (61.7%). Confluent B-lines originating from regular pleural lines, previously characterized as “beam line” or “waterfall” (Figure 4) artifacts and suggested to represent an early stage of actively spreading COVID-19 pneumonia alternating with areas of normal lung parenchyma, were observed only in a minority of cases (31.4%). Of note, the aforementioned sign was best visualized with the convex transducer because of its large scanning surface and low frequency (Figure 4).

In contrast, confluent and separate B-lines originating from irregular pleural lines were evident in most cases (69.6%), which may reflect a late stage of COVID-19 pneumonia. Variable consolidations, which were mainly identified in the posterior lung areas, were recorded (Table 3). A “starry sky” pattern

![Figure 5](image1.png)

**Figure 5.** Bright hyperechoic (starry sky) consolidation and pleural effusion depicted by a convex (3.5-MHz) transducer in the superior-lateral area of the right lung (A) and lung hepatization consolidation floating in a large pleural effusion in the inferior-lateral area of the right lung depicted by a phases array (2.5-MHz) transducer (B) in 2 critically ill patients with COVID-19.

![Figure 6](image2.png)

**Figure 6.** Zoomed-in image of a bright hyperechoic (starry sky) consolidation and associated pleural effusion in the inferior-posterior area of the right lung depicted by a phased array (2.5-MHz) transducer in a critically ill patient with COVID-19.
of consolidation (bright infiltrates) was evident in most cases (49.4%; Figures 5 and 6). Less-prevalent consolidation patterns were subpleural consolidations (26.9%) and lung parenchymal hepatization pattern (22.4%). Pleural and pericardial effusions were observed less frequently (Table 3). Small pneumothoraces were detected by lung US in the first week of hospitalization in 3 cases (3.37%), although the median positive end-expiratory pressure used in this study was relatively low: 10 (IQR, 8–12) cm H\textsubscript{2}O (Figure 7).

**Figure 7.** Small pneumothorax (white arrow indicates lung point) detected by a linear (15-MHz) transducer in the inferior-anterior area of the right lung in a critically ill patient with COVID-19.

**Figure 8.** Contrast chest CT scans depicting (red arrowheads) upper and middle segmental right pulmonary artery nonobstructive emboli (A) and tiny filling defects suggestive of microemboli of the distal subsegmental branches of the right pulmonary artery (B) in 2 critically ill patients with COVID-19.
On ICU admission, DVT was detected in 16.8% of cases compared to the confirmed rate of PE (Figure 8) by CCTA (24.7%) in this study. The follow-up POCUS examinations in the upcoming weeks (weeks 1–4) showed an initial increase of the incidence of lung US findings in weeks 1 to 2, followed by a gradual decrease of these finding in weeks 3 and 4 after ICU admission (Table 4). Ten patients died in the first week, 9 in the second week, 3 in the third week, and 3 in the fourth week of hospitalization. The 64 survivors were examined again before hospital discharge, approximately 32 (IQR, 26–40) days after ICU admission. At that time, lung abnormalities were still present (Tables 3 and 4). However, the incidence of lung abnormalities on hospital discharge was significantly lower (P < .05, 2-tailed Fisher exact test) compared to baseline findings (Table 3).

**Discussion**

Due to the sudden and rapid onset of the COVID-19 pandemic with its disruptive effect on medical systems, prospective data regarding POCUS use on critically ill patients has been slow to emerge. Our study provides additional important data on the utility of POCUS in the population of critically ill patients with COVID-19. We found that POCUS effectively detected lung abnormalities such as B-lines, pleural line abnormalities, variable consolidations, and pleural effusions. Additionally, our standardized POCUS

| US Finding | On ICU Admission, Patients (n = 89), % | Week 1, Patients (n = 79), % | Week 2, Patients (n = 70), % | Week 3, Patients (n = 67), % | Week 4, Patients (n = 64), % | On Hospital Discharge, Survivors (n = 64), % |
|------------|--------------------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|---------------------------------------------|
| B-lines    | 100                                  | 100                         | 100                         | 74.6                        | 37.5                        | 15.6                                        |
| Anterior-superior | 78.6                           | 87.3                        | 85.1                        | 52.2                        | 23.4                        | 9.3                                         |
| Anterior-inferior | 78.6                         | 87.3                        | 85.1                        | 52.2                        | 23.4                        | 12.5                                        |
| Lateral-superior | 78.6                        | 87.3                        | 85.1                        | 52.2                        | 23.4                        | 9.3                                         |
| Lateral-inferior | 67.4                         | 82.2                        | 78.7                        | 52.2                        | 23.4                        | 12.5                                        |
| Posterior-superior | 84.2                        | 91.1                        | 87.1                        | 58.2                        | 26.5                        | 12.5                                        |
| Posterior-inferior | 84.2                        | 91.1                        | 87.1                        | 58.2                        | 26.5                        | 12.5                                        |
| Bilateral   | 78.6                                  | 87.3                        | 87.1                        | 52.2                        | 23.4                        | 12.5                                        |
| Confluent B-lines | 78.6                         | 87.3                        | 71.4                        | 52.2                        | 23.4                        | 9.3                                         |
| Separated B-lines | 67.4                         | 82.2                        | 71.4                        | 52.2                        | 29.8                        | 12.5                                        |
| Pleural line irregularities in >6 lung areas | 78.6                        | 87.3                        | 71.4                        | 52.2                        | 18.7                        | 15.6                                        |
| Consolidations | 61.7                          | 75.9                        | 571                         | 32.8                        | 18.7                        | 12.5                                        |
| Anterior-superior | 39.3                         | 63.2                        | 50                          | 22.3                        | 18.7                        | 9.3                                         |
| Anterior-inferior | 39.3                         | 63.2                        | 50                          | 22.3                        | 18.7                        | 12.5                                        |
| Lateral-superior | 39.3                         | 63.2                        | 50                          | 22.3                        | 18.7                        | 12.5                                        |
| Lateral-inferior | 39.3                         | 63.2                        | 50                          | 22.3                        | 18.7                        | 12.5                                        |
| Posterior-superior | 49.4                         | 69.6                        | 50                          | 22.3                        | 18.7                        | 9.3                                         |
| Posterior-inferior | 49.4                         | 69.6                        | 50                          | 26.8                        | 18.7                        | 9.3                                         |
| Bilateral   | 48.4                                  | 69.6                        | 50                          | 26.8                        | 18.7                        | 12.5                                        |
| Pleural effusions | 22.4                        | 15.1                        | 11.4                        | 5.9                         | 3.1                         | 1.5                                         |
| Pericardial effusions | 13.4                        | 12.6                        | 5.7                         | 2.9                         | 1.5                         | 1.5                                         |

Percentages were derived from the total numbers of patients examined at each point in time on admission, during follow-up, and on discharge. Ten patients died in the first week, 9 in the second week, 3 in the third week, and 3 in the fourth week of hospitalization. The total number of survivors who were examined in the fifth to sixth weeks before hospital discharge was 64.
approach identified other critical conditions such as pericardial effusions and DVT in critically ill patients with COVID-19.

Early depictions of COVID-19 lung US findings have suggested that the extent of lung involvement and typical appearances of patient lungs differ from one patient population to another. Descriptions of lung US findings on emergency department presentation, including scattered areas of pleural involvement adjacent to normal lung, are less common among patients seen by ICU providers and represent an earlier stage of COVID-19 development. In our study, lung US examinations, performed on ICU admission, identified bilateral lung abnormalities mainly in the posterior lung areas for most of the patients studied.\textsuperscript{1–6} In most of our patients, severe COVID-19 pneumonia had already evolved, as their clinical picture and lung US findings suggested (Figure 9). The beam line artifact (integrating a pattern of regular pleural lines with accompanying confluent B-lines), which has been reported in publications focused on patient populations with early stages of active COVID-19 pneumonia, was noted only in a minority of our cases, again supporting a steady progression of US findings as disease severity progresses.\textsuperscript{1–6,59,60} Our patient group showed rather extensive lung parenchymal involvement on POCUS examinations on ICU admission (Table 3).

Depicting the natural course of the disease process in the ICU population with lung US is an important task. Our weekly follow-up scans of all patients showed that an increasing number of lung abnormalities were observed in weeks 1 and 2 after ICU admission (Figure 10). A gradual improvement of the lung

\textbf{Figure 9.} Evolution of fulminant COVID-19 pneumonia in a 50-year-old diabetic patient. Panoramic views depicted by a convex (3.5-MHz) transducer scanning the superior-anterior area of the right lung: normal lung aeration pattern (A-lines; \textbf{A}, white arrow) while the patient was receiving an HFNC (day 1); appearance of the beam line artifact (\textbf{B} and \textbf{C}, white chevrons at the interface with the normal lung parenchyma) while the patient was receiving an HFNC (day 2); appearance of subpleural consolidation (\textbf{D}, white star) and separate B-lines derived from thickened pleural lines while the patient was intubated and receiving mechanical ventilation (day 4); and pleural line irregularities with hyperechoic consolidations and separate B-lines while the patient was receiving mechanical ventilation (day 7; \textbf{E}).
Parenchymal abnormalities was then observed in weeks 3 and 4 after ICU admission and before hospital discharge in survivors (>30 days after ICU admission). These findings were consistent with a previous study, which used a similar but less-detailed lung US scanning protocol. We have documented pleural line irregularities (in >6 lung areas) with accompanying B-lines in most our patients (Figure 11). Additionally, we found several consolidation patterns. The most prevalent one (starry sky pattern: bright infiltrates) could be a reflection of the severe lung parenchymal inflammation of COVID-19 pneumonia (Figure 10), which is also visualized on chest CT as ground glass opacities and infiltrates and was mainly distributed in peripheral and posterior lung zones.

Notably, on ICU admission, clinical and laboratory data showed a high Sequential Organ Function Assessment admission score, as well as lymphocytopenia, with elevated levels of C-reactive protein, lactate dehydrogenase, D-dimers, and ferritin, which are predictors of severe COVID-19 pneumonia, a cytokine storm, and death. Our findings regarding the ICU length of stay, days receiving mechanical ventilation, and the raw 28-day mortality were comparable to the published literature.

Of particular interest was the low rate of DVT identified as part of our POCUS evaluation: just 16.8%. This was in contrast to CCTA-confirmed PE in nearly one-fourth of our study population, at 24.7%. These rates were much lower compared to
findings reported by a previous study.6 The difference may be partially attributed to the fact that all of our patients received aggressive prophylactic anticoagulation per hospital policy. Furthermore, we speculate that in COVID-19, PE may be due to predominantly local growth of microthrombi within the lung vasculature, which may not necessarily be linked to DVT formation and could be another reason for our findings related to DVT and PE frequencies.49–55 The pathophysiologic mechanisms of lung microthrombosis in serious COVID-19 are highly complex and may be related to the development of cytokine release syndrome.61–65 Notwithstanding, lung abnormalities were still present on hospital discharge in a minority of patients, suggesting that lung US findings correlate with resolution of severe COVID-19 pneumonia in ICU patients. However, the lack of clearance of lung findings in all patients, even on hospital discharge, suggests that the resolution of lung parenchymal abnormalities depicted by imaging techniques in COVID-19 pneumonia requires considerable time. Moreover, lung parenchymal damage and changes may persist for a long time (lung tissue scarring), highlighting potentially chronic issues for long-term rehabilitation of survivors.

This prospective study had a number of limitations. The number of recruited patients was relatively small; hence, no meaningful subgroup analysis could be performed. We could not relate the US findings with pertinent laboratory findings and chest CT scans in all studied cases; however, that was not an end point of this study. Although it is an operator-dependent modality, the advantages of POCUS cannot be underestimated, even in contrast to CT scanning. Point-of-care US is a bedside diagnostic tool that could minimize the risk of cross-infection related to transport of patients with COVID-19. It is less resource intensive and delivers no ionizing radiation. More studies are clearly required to explore the role of POCUS in the diagnosis and treatment of critically ill patients with COVID-19, bearing in mind that the absence of imaging signs cannot entirely rule out the infection.

In conclusion, this study illustrated that POCUS may be an alternative imaging modality in the diagnosis and monitoring of critically ill patients with COVID-19. Lung US detected extensive lung involvement, featured by B-lines, pleural line irregularities, and variable consolidation patterns in patients with serious COVID-19 pneumonia. Lung involvement progression was successfully tracked with US as well as disease resolution on improvement. Our rate of confirmed PE by CCTA was high but could not be related to POCUS-detected DVT. Lung US confirmed the gradual improvement of COVID-19 pneumonia in survivors approximately 5 to 6 weeks after ICU admission. The putative correlation of POCUS to CT and laboratory findings in COVID-19 warrants further attention.

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