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Journal

Journal of Ultrasound in Medicine, 41(6)

Authors

Kumar, Andre

Weng, Isabel

Graglia, Sally

et al.

Publication Date



2022-06-01


DOI

10.1002/jum.15818

Peer reviewed

Point-of-Care Ultrasound Predicts Clinical Outcomes in Patients With COVID-19

Andre Kumar, MD, MEd , Isabel Weng, MS, Sally Graglia, MD, MPH, Thomas Lew, MD, Kavita Gandhi, MD, PhD , Farhan Lalani, MD, David Chia, MD, Youyou Duanmu, MD, MPH, Trevor Jensen, MD, Viveta Lobo, MD, Jeffrey Nahn, MD, Nicholas Iverson, MD, Molly Rosenthal, MD, Alexandra June Gordon, MD, John Kugler, MD

 Supplemental material online at jtrultrasoundmed.org

Received April 5, 2021, from the Department of Medicine, Stanford University School of Medicine, Stanford, CA, USA (A.K., T.L., A.J.G., J.K.); Quantitative Sciences Unit, Stanford University, Stanford, CA, USA (I.W.); Department of Emergency Medicine, University of California San Francisco and Zuckerberg San Francisco General Hospital, San Francisco, CA, USA (S.G., J.N.); Department of Emergency Medicine, University of California San Francisco, San Francisco, CA, USA (K.G.); Department of Medicine, University of California San Francisco, San Francisco, CA, USA (F.L., D.C., T.J., N.I., M.R.); and Department of Emergency Medicine, Stanford University School of Medicine, Stanford, CA, USA (Y.D., V.L.). Manuscript accepted for publication August 16, 2021.

Address correspondence to Andre Kumar, MD, Stanford University School of Medicine, 300 Pasteur Drive, Stanford, CA 95401, USA.

E-mail: akumar3@stanford.edu

Abbreviations

CI, confidence interval; CT, computed tomography; ICU, intensive care unit; IQR, interquartile ranges; IRR, interrater reliability; OR, odds ratio; PASC, post-acute sequelae of COVID-19; POCUS, point-of-care ultrasound

doi:10.1002/jum.15818

Objectives—Point-of-care ultrasound (POCUS) detects the pulmonary manifestations of COVID-19 and may predict patient outcomes.

Methods—We conducted a prospective cohort study at four hospitals from March 2020 to January 2021 to evaluate lung POCUS and clinical outcomes of COVID-19. Inclusion criteria included adult patients hospitalized for COVID-19 who received lung POCUS with a 12-zone protocol.

Each image was interpreted by two reviewers blinded to clinical outcomes. Our primary outcome was the need for intensive care unit (ICU) admission versus no ICU admission. Secondary outcomes included intubation and supplemental oxygen usage.

Results—N = 160 patients were included. Among critically ill patients, B-lines (94 vs 76%; $P < .01$) and consolidations (70 vs 46%; $P < .01$) were more common. For scans collected within 24 hours of admission (N = 101 patients), early B-lines (odds ratio [OR] 4.41 [95% confidence interval, CI: 1.71–14.30]; $P < .01$) or consolidations (OR 2.49 [95% CI: 1.35–4.86]; $P < .01$) were predictive of ICU admission. Early consolidations were associated with oxygen usage after discharge (OR 2.16 [95% CI: 1.01–4.70]; $P = .047$). Patients with a normal scan within 24 hours of admission were less likely to require ICU admission (OR 0.28 [95% CI: 0.09–0.75]; $P < .01$) or supplemental oxygen (OR 0.26 [95% CI: 0.11–0.61]; $P < .01$). Ultrasound findings did not dynamically change over a 28-day scanning window after symptom onset.

Conclusions—Lung POCUS findings detected within 24 hours of admission may provide expedient risk stratification for important COVID-19 clinical outcomes, including future ICU admission or need for supplemental oxygen. Conversely, a normal scan within 24 hours of admission appears protective. POCUS findings appeared stable over a 28-day scanning window, suggesting that these findings, regardless of their timing, may have clinical implications.

Key Words—COVID-19; ICU; mortality; outcomes; POCUS; ultrasound

There is an urgent need to employ diagnostic modalities on the frontline of COVID-19 that are expedient, accurate, and cost-effective, especially as new outbreaks have shifted more toward resource-limited settings.¹ Current methods to evaluate the risk of adverse outcomes for COVID-19 encompass the use of blood or imaging tests to determine the likelihood of important clinical events, such as intubation or

death.²⁻⁶ These evaluations have been incorporated into scoring systems that can aid patient triage and provide risk stratification.²⁻⁶ However, such evaluations may be burdensome or time consuming, particularly in resource-limited settings where expedited access to clinical laboratories or imaging centers is not feasible.³

Point-of-care ultrasound (POCUS) has garnered substantial interest as a potential modality to expediently diagnose COVID-19 and its complications.⁷ POCUS devices are cheaper than traditional imaging equipment, such as X-ray or computed tomography (CT) machines, which makes POCUS ideal for surge scenarios and resource-limited settings.⁸ Since providers using POCUS are concomitantly at the bedside assessing patients, POCUS permits an immediate and augmented evaluation of the patient. It can reduce personal protective equipment usage by radiology technicians as well as the need to decontaminate larger radiographic equipment.^{9,10} POCUS has also been successfully used in the diagnosis and management of COVID-19.^{11,12} Previously described pulmonary manifestations of COVID-19 include pulmonary edema, lung consolidation, and pleural-line irregularities.^{13,14} POCUS can diagnose these pathological states with similar accuracy to CT and with higher sensitivity than X-ray.¹⁵⁻¹⁷ The sonographic manifestations of COVID-19 pneumonia include bilateral B-lines, consolidations, and pleural thickening/irregularity (Figure 1).^{18,19} Descriptions of these findings, their underlying pathologies, and their correlates with CT imaging could be found in Figure 1 and in online supplemental Appendix 1.¹⁸⁻²⁰

Although lung ultrasound abnormalities are more common in patients who experience adverse outcomes with COVID-19,^{12,14} few studies have examined whether scans performed early in the hospitalization can provide meaningful risk stratification.²¹ Furthermore, few scoring tools predict the need for oxygen on discharge, which represents a limited resource in many settings. In this study, we examine whether early pulmonary POCUS findings correlate with important clinical outcomes, such as intensive care admission or need for supplemental oxygen. We also examine whether these findings, if detected early, are predictive of future clinical outcomes in the subsequent hospital course or after discharge.

Materials and Methods

Participants and Setting

This was a prospective cohort study conducted at four tertiary care centers in the United States from March 2020 to January 2021 based on a previously described study protocol.¹⁴ Our inclusion criteria included the following: 1) adults hospitalized with a primary diagnosis of COVID-19 and 2) these patients were under direct care of the physician researchers of this study. The diagnosis of COVID-19 was based on symptomatology²² and a confirmatory nasopharyngeal polymerase chain reaction for SARS-CoV-2 on admission. All patients who met inclusion criteria were scanned during their initial evaluation by the physician researchers, regardless of their clinical condition unless explicitly declined by the patient. The frequency of declined scans was not tracked at all sites.

Physician researchers were permitted to perform a follow-up scan if there was a perceived change in clinical status (eg, worsening hypoxia, tachypnea, hypotension). The frequency of follow-up scans was tracked. Follow-up scans were included in the calculation of the frequency of POCUS findings (Table 1). As this study focused primarily on the utility of initial scans, all follow-up scans were excluded in analyses examining the predictive utility of POCUS and patient outcomes (Table 2). This study was approved by the Institutional Review Boards of Stanford University and the University of California, San Francisco. A waiver of consent was obtained by both institutions.

Outcomes

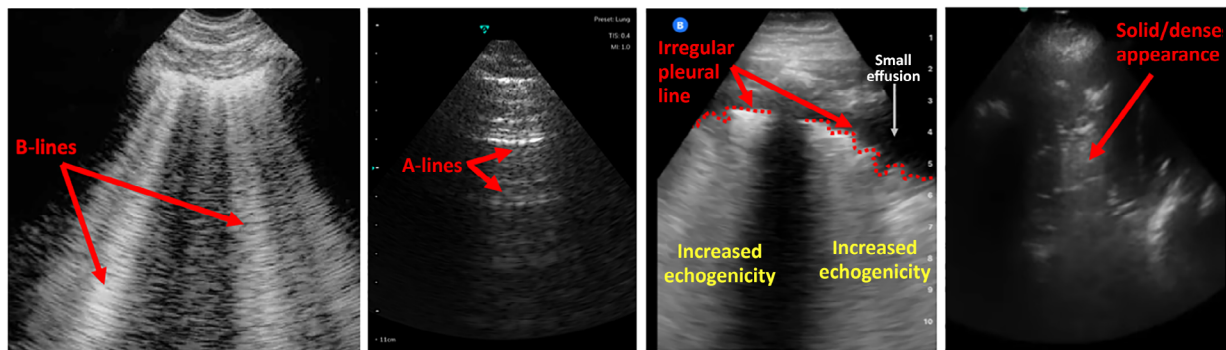
In this analysis, previously described POCUS features for COVID-19 were compared with primary and secondary outcomes of clinical interest. Our primary outcome was the need for intensive care unit (ICU) admission. Secondary outcomes included the incidence of intubation, supplemental oxygen usage during the hospitalization or discharge, and 30-day readmission.

Scanning Protocol and Interpretation

Physicians were instructed to use a 12-zone scanning protocol for pulmonary views (Figure 1) and save 6 second clips of each lung zone.²³ If a 12-zone protocol could not be performed due to the patient's

Figure 1. Scanning protocol and lung ultrasound findings in COVID-19 patients. This study utilized a 12-zone protocol (6 zones per each hemithorax), which we have previously described.^{14,28} If a 12-zone protocol could not be obtained, then an 8-zone protocol (which excludes zones 5–6) was obtained. This figure contains an overview of the observed ultrasound findings based on previously described terminology.^{14,28} Common pathological findings with COVID-19 on ultrasound include B-lines, consolidations, and patchy A-lines. B-lines are vertically oriented hyperechoic artifacts that arise from the pleura. They are caused by thickened interlobular septa due to alveolar–interstitial disorders, such as pneumonia, cardiogenic edema, acute respiratory distress syndrome, or abnormal collagen deposition (eg, idiopathic pulmonary fibrosis).¹⁴ Consolidations manifest as dense, echogenic lung parenchyma with occasional air bronchograms. Consolidations may affect more distal airways first (resulting in sub-pleural consolidations) and eventually result in lobar collapse with more substantial involvement (eg, translobar consolidation).¹⁴ A-lines represent a reverberation artifact arising from the pleura and represent normal lung parenchyma. AAL, anterior axillary line; PAL, posterior axillary line; ISM, inferior scapular margin.

Scanning protocol



| B-lines | Normal lung | Subpleural consolidation | Translobar consolidation |
|---|---|---|---|
| Vertically oriented lines that fulfill the following criteria: 1) extend from the pleural surface to the maximum depth of the image (at least 13–16 cm) and 2) move in conjunction with lung sliding, and 3) erasure of A-lines as they move over them. | Normal lung is characterized by horizontal lines called A-lines, which represent sonographic artifacts of normal pleura | Characterized by a broken/highly irregular pleural line and associated increased echogenicity below the pleural line. An effusion may be rarely present, as shown in the image. | Characterized by a dense (“hepaticized”) lung that appears more solid. A large effusion may be present (not shown). |

Table 1. Patient Demographics and Scans

| Characteristic | All COVID-19 Patients | Non-ICU Patients | ICU Patients | P |
|----------------------------------|-----------------------|------------------|------------------|-----------------|
| Number of patients | 160 | 106 (66%) | 54 (34%) | – |
| No. of scans | 201 | 132 (66%) | 69 (34%) | – |
| Early scans (<24 h) | 101 | 79 | 22 | – |
| Mechanical ventilation | 24 (15%) | – | 24 (44%) | – |
| Death | 7 (4%) | – | 7 (13%) | – |
| Median age (IQR) | 58 (45–71) | 55 (46–69) | 60 (43–71) | .85 |
| Female | 65 (41%) | 46 (43%) | 19 (35%) | .45 |
| Median BMI (IQR) | 28.9 (25–34) | 28 (25–34) | 31 (26–36) | .2 |
| Supplemental oxygen usage | 102 (64%) | 48 (64%) | 54 (100%) | <.001 |
| Discharged on oxygen | 37 (42%) | 15 (27%) | 22 (65%) | <.001 |
| Symptoms to triage, days (IQR) | 6 (3–9) | 7.0 (3.0, 10.0) | 6.0 (3.3, 8.8) | .60 |
| Symptoms to scan, days (IQR) | 9 (5–14.5) | 9.0 (5.0, 12.0) | 11.0 (5.6, 17.0) | .08 |
| Triage to first scan, days (IQR) | 0.9 (0.3–2.9) | 0.8 (0.3–1.8) | 2.5 (0.3–8.5) | .003 |
| No. of 12-zone scans | 115 (57%) | 77 (58%) | 38 (55%) | – |
| Anterior zone scans | 198 (99%) | 130 (98%) | 68 (99%) | – |
| Lateral zone scans | 188 (94%) | 121 (92%) | 67 (97%) | – |
| Posterior zone scans | 115 (57%) | 77 (58%) | 38 (55%) | – |
| Normal lung POCUS | 31 (15%) | 27 (20%) | 4 (6%) | .01 |
| Majority A-line pattern | 65 (32%) | 51 (39%) | 14 (20%) | .01 |
| B-lines | 165 (82%) | 100 (76%) | 65 (94%) | <.01 |
| Bilateral | 124 (62%) | 71 (54%) | 53 (77%) | <.01 |
| Anterior | 121 (61%) | 68 (52%) | 53 (78%) | <.01 |
| Lateral | 132 (70%) | 82 (68%) | 50 (74%) | .41 |
| Posterior | 84 (72%) | 51 (66%) | 33 (85%) | .06 |
| Consolidation | 108 (54%) | 60 (46%) | 48 (70%) | <.01 |
| Bilateral | 61 (30%) | 31 (24%) | 30 (44%) | <.01 |
| Anterior | 53 (54%) | 21 (39%) | 32 (71%) | <.01 |
| Lateral | 69 (68%) | 32 (55%) | 37 (84%) | <.01 |
| Posterior | 56 (82%) | 39 (87%) | 17 (74%) | .33 |

Bold items denote findings of statistical significance ($P < .05$). Early scans are those defined as being collected within 24 h of initial emergency department triage and prior to ICU admission.

IQR, interquartile range; BMI, body mass index; ICU, intensive care unit.

Table 2. Outcomes by POCUS Findings Based on Early Scans

| Characteristic | ICU Admission | | Intubation | | Required Supplemental O ₂ OR | | Discharged on O ₂ OR [95% CI] | |
|-----------------|----------------|----------------|----------------|----------------|---|----------------|--|----------------|
| | OR [95% CI] | P | OR [95% CI] | P | [95% CI] | P | O ₂ OR [95% CI] | P |
| Normal LUS | 0.3 [0.1–0.8] | <.01 | 0.3 [0.03–1.3] | .13 | 0.3 [0.1–0.6] | <.01 | 0.6 [0.2–1.6] | .29 |
| Majority A-line | 0.4 [0.2–0.8] | <.01 | 0.5 [0.2–1.4] | .19 | 0.9 [0.4–2.0] | .79 | 0.7 [0.3–1.5] | .35 |
| B-lines | 4.4 [1.7–14.3] | <.01 | 3.8 [0.9–35.1] | .07 | 3.7 [1.6–8.6] | <.01 | 1.6 [0.6–4.4] | .35 |
| Bilateral | 2.6 [1.4–5.2] | <.01 | 1.0 [0.4–2.5] | .98 | 1.6 [0.8–3.4] | .19 | 1.6 [0.8–3.6] | .21 |
| Anterior | 3.0 [1.6–5.9] | <.01 | 3.1 [1.2–10.3] | .02 | 2.9 [1.4–6.3] | <.01 | 1.9 [0.9–4.4] | .10 |
| Lateral | 1.3 [0.7–2.6] | .41 | 0.8 [0.3–2.0] | .56 | 2.2 [1.0–4.8] | .046 | 1.3 [0.6–3.0] | .57 |
| Posterior | 2.4 [1.0–6.8] | .07 | 1.9 [0.5–10.3] | .34 | 1.4 [0.5–4.2] | .53 | 1.4 [0.4–4.5] | .62 |
| Consolidation | 2.5 [1.4–4.7] | <.01 | 2.2 [0.9–5.7] | .08 | 1.9 [0.9–4.1] | .11 | 2.2 [1.0–4.7] | .047 |
| Bilateral | 2.4 [1.3–4.4] | <.01 | 2.1 [0.9–4.9] | .09 | 1.9 [0.8–5.3] | .16 | 3.3 [1.4–8.1] | <.01 |
| Anterior | 3.8 [1.7–9.2] | <.01 | 6.4 [1.8–34.0] | <.01 | 2.7 [0.8–9.7] | .10 | 2.9 [0.9–9.8] | .08 |
| Lateral | 3.7 [1.5–10.1] | <.01 | 2.8 [0.8–14.7] | .13 | 2.4 [0.6–8.5] | .19 | 2.9 [0.8–11.7] | .10 |
| Posterior | 0.5 [0.1–1.6] | .21 | 0.6 [0.1–3.3] | .48 | 0.8 [0.1–5.0] | .82 | 1.5 [0.3–10.9] | .64 |

Scans (N = 102) were analyzed if they were collected within 24 hours of emergency department triage and prior ICU admission to examine the predictive utility of early POCUS scans (expressed as odds ratios and 95% confidence intervals). Majority A-lines were defined as a A-line only finding in at least 50% of sampled lung fields. Bold items denote findings of statistical significance ($P < .05$).

ICU, intensive care unit; OR, odds ratio; LUS, lung ultrasound; CI, confidence interval; POCUS, point-of-care ultrasound.

condition (eg, the posterior lung zones were not accessible due to intubation), then a modified 8-zone protocol capturing the anterior and lateral lung fields was performed.²³ This study utilized several POCUS devices, including Butterfly IQ™, Vave™, Lumify™, Mindray™, GE™, and Sonosite™, which represent the commercially available portable machines at our institutions. All devices used a phased array probe and were set to the “lung” preset.

The POCUS scans were obtained by physicians credentialed in POCUS for patient care at their respective institutions. The physicians involved in scanning completed a 30-minute orientation to review the scanning protocol. A core group of researchers at each site interpreted the archived images based on consensus guidelines for lung ultrasound (LUS) developed by the researchers (online supplemental Appendix 1).^{23–25} A full description of the credentials and experience of the scanners and image interpreters can be found in the online supplemental Appendix 1. The researchers were blinded to patient information and outcomes when interpreting the images.

Previous investigations have demonstrated moderate-to-excellent interrater reliability (IRR) for LUS across different experience levels and probe types.^{26,27} Nonetheless, we conducted our own IRR analysis within the context of COVID-19 and LUS. We found that LUS has moderate-to-substantial IRR for LUS among COVID-19 for the findings included in this study.²⁸ Based on our IRR findings, we developed an interpretation protocol. First, two researchers would independently apply the consensus guidelines (online supplemental Appendix 1) to create a standardized approach to image interpretation. Next, they would input their findings into separate electronic forms. The researchers would then meet to compare their interpretations. If there was disagreement in interpretation, the two researchers would attempt to reach a consensus. If no consensus could be reached, then the data were excluded from the final database.

Analysis

Our calculated sample size for this study was 94 patients based on reasonable assumptions (15% event rate, 80% power, α .05). Event rates were based on internal data from our hospitals at the time of study design. For the main analysis comparing ICU admission with no ICU admission, the unit of analysis

was on each scan. Therefore, the analytical set could include multiple scans for one patient that met inclusion criteria. Subgroup analysis was limited to the initial scan per patient. Chi-square and Fisher exact testing were performed for categorical variables and *t*-tests for continuous variables. Mann–Whitney tests were performed for non-normal distributed continuous variables instead of *t*-tests with median and interquartile ranges (IQR) reported. Odds ratios (ORs), corresponding 95% confidence intervals (CIs), and *P* values from the models were reported. For POCUS features with low or high rates (<5%, >95%) of events, we performed Firth logistic regressions instead of obtaining more reliable estimates. Poisson regression models were performed for POCUS ultrasound count features. All analyses were performed with R statistical programming languages, version 4.0.3 (Vienna, Austria).

Results

Patients and Scans

The study was sufficiently powered to analyze the primary outcome. There were $N = 160$ patients ($N = 201$ scans) included in the study (Table 1). $N = 54$ patients ($N = 69$ scans) were admitted to the ICU, while $N = 106$ patients ($N = 132$ scans) were not admitted. Approximately $N = 32$ patients received multiple LUS scans on separate days, which accounts for the greater number of LUS scans than patients. The timing of scans from symptom onset, emergency department (ED) triage, and ICU admission are listed in Table 1. All scans ($N = 201$) were collected with a median 0.9 days (IQR 0.3–2.9) after initial triage in the ED (Table 1).

Primary Outcome: ICU Admission and Prediction With Early Scanning

Several LUS features were more common in patients who experienced ICU admission (Table 1). To assess the predictive utility of early POCUS for ICU admission, we analyzed scans collected within 24 hours of ER triage and before ICU admission ($N = 101$ scans). Scans ($N = 22$) from critically ill patients were acquired a median 0.9 days (IQR 0.6–1.2) prior to ICU admission. All scans analyzed for this

subanalysis were acquired at least 6 hours before ICU admission.

Several early POCUS features were again associated with ICU admission (Table 2). These included the absolute presence of B-lines (OR 4.41 [95% CI: 1.71–14.30]; $P < .01$) or consolidation (OR 2.49 [95% CI: 1.35–4.86]; $P < .01$). The presence of either bilateral, anterior, or lateral B-lines or consolidations was similarly associated with ICU admission (Table 2). Protective factors against ICU admission included the presence of a normal lung scan (OR 0.28 [95% CI: 0.09–0.75]; $P < .01$) or the presence of an A-line pattern in the majority of sampled lung fields (OR 0.42 [95% CI: 0.21–0.81]; $P < .01$). Importantly, none of the patients who had an initially normal LUS within 24 hours of ED evaluation were admitted to the ICU in the subsequent 28 days.

Secondary Outcomes: Intubation, Oxygen Usage, Readmission

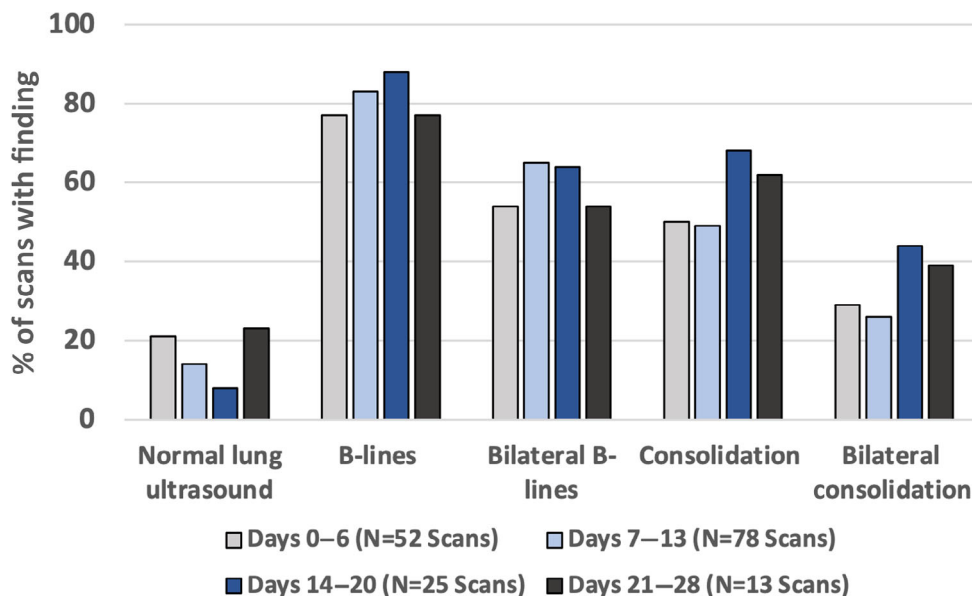
To assess the predictive utility of POCUS on secondary outcomes, scans that were collected within 24 hours of ER triage or before ICU admission were analyzed (N = 101 scans). Early LUS findings

(Table 2) associated with intubation included anterior B-lines (OR 3.10 [95% CI: 1.15–10.27]; $P = .02$) and anterior consolidation (OR 6.40 [95% CI: 1.80–34.01]; $P < .01$). Supplemental oxygen usage during the hospitalization was associated with B-lines at triage (OR 3.74 [95% CI: 1.63–8.63]; $P < .01$), while a normal LUS at the time of triage was protective against oxygen usage for the hospitalization (OR 0.26 [95% CI: 0.11–0.61]; $P < .01$). Consolidations present on triage scans were associated with the need for oxygen at discharge (OR 2.16 [95% CI: 1.01–4.70]; $P = .047$). No POCUS findings were significantly associated with 30-day readmission (online supplemental Appendix 1).

Stability of Lung Ultrasound Findings Over Time

The following analysis examined whether lung POCUS findings dynamically change over 28 days from symptom onset. Patient scans (N = 201) were stratified into quartiles by time since symptom onset to their scan (days 0–6, 7–13, 14–20, and 21–28). Notably, POCUS findings did not significantly change over the 28-day period (Figure 2). This stability was also observed for patients who experienced ICU admission or not (online supplemental Appendix 1).

Figure 2. Persistence of lung ultrasound findings over time. Lung findings were stratified by days from symptom onset to the ultrasound scan into quartiles (0–6 days, 7–13 days, 14–20 days, and 21–28 days). There was no significant difference in the frequency of findings across the time periods or when comparing early (0–6 days) versus late (21–28 days) scanning periods.



Similarly, there was no difference when comparing early (days 0–7) versus late (days 21+) scans (online supplemental Appendix 1).

Discussion

In this prospective cohort study conducted at four medical centers of patients hospitalized with COVID-19, we found that lung ultrasounds collected within 24 hours of emergency department triage were predictive of important clinical outcomes in the subsequent hospital course, including ICU admission, intubation, supplemental oxygen usage, and the need for oxygen at discharge. Ultrasound findings associated with an adverse clinical course included B-lines and consolidations (particularly in the anterior and lateral lung fields), while a normal ultrasound on triage was protective against adverse outcomes. Notably, ultrasound findings did not dynamically change over a 28-day window after symptom onset, suggesting that the presence of B-lines or consolidations, regardless of when they are detected, may be important clinical predictors.

Previous investigations have demonstrated that lung POCUS findings (such as B-lines or consolidations) are associated with critical illness and intubation for COVID-19.¹² Our study expands on these observations by demonstrating that scans collected within 24 hours of ED triage may predict outcomes for the entire hospital course, including future supplemental oxygen usage and the need for oxygen on discharge. This information may substantially aid frontline providers in resource-limited settings experiencing patient surges.²⁹ In such scenarios, POCUS could augment admission or discharge decisions for providers.²⁹ More broadly, POCUS could represent one of several tools to identify patients at-risk for adverse outcomes.^{3,6,12,30} Other authors have demonstrated the utility of laboratory tests (eg, ferritin, c-reactive protein) or radiographic findings for risk stratification.^{2,3,31} POCUS may have potential advantages over these other methods in that it is more expedient, low cost and does not expose the patient to ionizing radiation.³² Future studies are needed to directly compare POCUS with other scoring systems that utilize laboratory or radiological findings.

A criticism of POCUS is that it requires expertise to conduct and may therefore not be accessible to a

wide array of providers.³³ We have noted others have created prognostic tools for COVID-19 that incorporate extensive POCUS scanning protocols and complex scoring systems,^{5,6,12} which may further relegate POCUS to the hands of only highly motivated users. We disagree with such an approach and believe that the promise of POCUS lies in its simplicity and inherent expediency. Importantly, our findings suggest that the high-risk features for COVID-19 are located primarily in the anterior or lateral lungs, which can be rapidly assessed by providers with limited POCUS experience.³⁴ Several of the findings we observed have excellent interrater reliability and can be expediently learned.^{28,35,36} In contrast to more complex protocols, the results of this study suggest that a rapid assessment of the anterior lungs could provide meaningful risk stratification and warrants further investigation.

In this study, we observed that POCUS findings remained stable over the 28-day scanning period, which is consistent with previous observations for POCUS and COVID-19.^{14,37–39} There are two implications of these findings. First, the detection of B-lines or consolidations at any time point may warrant close clinical observation, while a normal scan may be reassuring. For an otherwise stable patient who presents with a normal lung ultrasound, a provider may be reassured for discharge, especially since POCUS findings for COVID-19 may remain stable over time.^{14,38,39} This practice may be supported by CT data that demonstrate pulmonary opacities often appear before symptomatology or clinical deterioration, suggesting that imaging findings can predict whether a patient will clinically worsen, even before becoming symptomatic.⁴⁰ The second implication of our findings is that POCUS may aid in the evaluation of post-acute sequelae of COVID-19 (PASC), an increasingly recognized complication of SARS-CoV-2 that is characterized by long-term symptomatology (including dyspnea) following seroconversion.^{39,41} COVID-19 can lead to chronic fibroproliferative histologic changes of the lungs,^{13,39} which can be readily detected by POCUS.³² Such an approach may avoid ionizing radiation from serial CT scans and further investigations are needed to demonstrate the utility of POCUS for PASC.

There are several limitations to this study. The authors of the study, who were also the treating physicians, attempted to scan all COVID-19 patients in

their care, but time and resource constraints resulted in self-selecting patients for inclusion in the study and performing the scans without blinding. Therefore, there may be substantial selection bias resulting in a potential convenience sample. Certain patient conditions, such as intubation or patient mobility, prevented the provider from acquiring all 12 zones, particularly the posterior zones. Therefore, not all patients received a 12-zone scan, which limits the generalizability of the findings' frequencies by location. We did not control for patient conditions that may have confounded the sonographic findings (eg, interstitial lung disease), although these diseases had low prevalence in our population (online supplemental Appendix 1). We did not serially perform scans on most patients over time. Therefore, the persistence of findings over the 28-day scanning window should be interpreted with caution. Finally, our population was limited to patients hospitalized for COVID-19. Consequently, our findings may not be generalizable to outpatient or triage settings, although other studies have examined the utility of POCUS in these venues.^{6,7}

In conclusion, we found that lung ultrasounds from COVID-19 patients collected within 24 hours of emergency department triage were predictive of important clinical outcomes in the subsequent hospital course, including ICU admission, intubation, supplemental oxygen usage, and the need for oxygen at discharge. None of the patients who had an initially normal LUS within 24 hours of ED evaluation were admitted to the ICU, required supplemental oxygen in the subsequent hospitalization, or experienced readmission in 30 days. Lung ultrasound findings remained stable over a 28-day scanning period from symptom onset, suggesting that the presence of B-lines or consolidations, regardless of when they are detected, warrant close clinical observation. Future studies should determine whether POCUS can be utilized to appropriate triage or discharge patients with COVID-19, especially if a simplified protocol capturing the anterior or lateral lungs is used.

References

1. Katz IT, Weintraub R, Bekker L-G, Brandt AM. From vaccine nationalism to vaccine equity - finding a path forward. *N Engl J Med* 2021; 384:1281–1283.
2. Chon Y, Kim JY, Suh YJ, et al. Adverse initial CT findings associated with poor prognosis of coronavirus disease. *J Korean Med Sci* 2020; 35:e316.
3. Liang W, Liang H, Ou L, et al. Development and validation of a clinical risk score to predict the occurrence of critical illness in hospitalized patients with COVID-19. *JAMA Intern Med* 2020; 180: 1081–1089. <https://doi.org/10.1001/jamainternmed.2020.2033>.
4. Lanza E, Muglia R, Bolengo I, et al. Quantitative chest CT analysis in COVID-19 to predict the need for oxygenation support and intubation. *Eur Radiol* 2020; 30:6770–6778. <https://doi.org/10.1007/s00330-020-07013-2>.
5. Lu X, Zhang M, Qian A, Tang L, Xu S. Lung ultrasound score in establishing the timing of intubation in COVID-19 interstitial pneumonia: a preliminary retrospective observational study. *PLoS One* 2020; 15:e0238679.
6. Lichter Y, Topilsky Y, Taieb P, et al. Lung ultrasound predicts clinical course and outcomes in COVID-19 patients. *Intensive Care Med* 2020; 46:1873–1883. <https://doi.org/10.1007/s00134-020-06212-1>.
7. Calvo-Cebrián A, Alonso-Roca R, Rodríguez-Contreras FJ, Rodríguez-Pascual M d LN, Calderín-Morales MDP. Usefulness of lung ultrasound examinations performed by primary care physicians in patients with suspected COVID-19. *J Ultrasound Med* 2020; 40:741–750. <https://doi.org/10.1002/jum.15444>.
8. Reynolds TA, Amato S, Kulola I, Chen C-JJ, Mfinanga J, Sawe HR. Impact of point-of-care ultrasound on clinical decision-making at an urban emergency department in Tanzania. *PLoS One* 2018; 13:e0194774.
9. Fox S, Dugar S. Point-of-care ultrasound and COVID-19. *Cleve Clin J Med* 2020. <https://doi.org/10.3949/ccjm.87a.ccc019>.
10. Mongodi S, Orlando A, Arisi E, et al. Lung ultrasound in patients with acute respiratory failure reduces conventional imaging and health care provider exposure to COVID-19. *Ultrasound Med Biol* 2020; 46:2090–2093.
11. Haak SL, Renken IJ, Jager LC, Lameijer H, van der Kolk BBY. Diagnostic accuracy of point-of-care lung ultrasound in COVID-19. *Emerg Med J* 2020; 38:94–99. <https://doi.org/10.1136/ememed-2020-210125>.
12. Boero E, Rovida S, Schreiber A, et al. The COVID-19 Worsening Score (COWS)-a predictive bedside tool for critical illness. *Echocardiography* 2021; 38:207–216.
13. Grillo F, Barisione E, Ball L, Mastracci L, Fiocca R. Lung fibrosis: an undervalued finding in COVID-19 pathological series. *Lancet Infect Dis* 2020; 21:E72. [https://doi.org/10.1016/S1473-3099\(20\)30582-X](https://doi.org/10.1016/S1473-3099(20)30582-X).
14. Kumar A, Weng Y, Duanmu Y, et al. Lung ultrasound findings in patients hospitalized with COVID-19. *J Ultrasound Med* 2021. <https://doi.org/10.1002/jum.15683>.
15. Alzahrani SA, Al-Salamah MA, Al-Madani WH, Elbarbary MA. Systematic review and meta-analysis for the use of ultrasound versus radiology in diagnosing of pneumonia. *Crit Ultrasound J* 2017; 9:6.

16. Lichtenstein DA. BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill. *Chest* 2015; 147:1659–1670.
17. Grifoni S, Olivetto I, Cecchini P, et al. Utility of an integrated clinical, echocardiographic, and venous ultrasonographic approach for triage of patients with suspected pulmonary embolism. *Am J Cardiol* 1998; 82:1230–1235.
18. Fiala MJ. Ultrasound in COVID-19: a timeline of ultrasound findings in relation to CT. *Clin Radiol* 2020; 75:553–554.
19. Ottaviani S, Franc M, Ebstein E, et al. Lung ultrasonography in patients with COVID-19: comparison with CT. *Clin Radiol* 2020; 75:E877.E1–E877.E6. <https://doi.org/10.1016/j.crad.2020.07.024>.
20. Dini FL, Bergamini C, Allegrini A, et al. Bedside wireless lung ultrasound for the evaluation of COVID-19 lung injury in senior nursing home residents. *Monaldi Arch Chest Dis* 2020; 90:100–101. <https://doi.org/10.4081/monaldi.2020.1446>.
21. Secco G, Delorenzo M, Salinaro F, et al. Lung ultrasound presentation of COVID-19 patients: phenotypes and correlations. *Intern Emerg Med* 2021; 16:1317–1327. <https://doi.org/10.1007/s11739-020-02620-9>.
22. CDC. Coronavirus Disease 2019 (COVID-19). Centers for Disease Control and Prevention. 2020. <https://www.cdc.gov/coronavirus/2019-nCoV/hcp/clinical-criteria.html>. Accessed April 29, 2020.
23. Doerschug KC, Schmidt GA. Intensive care ultrasound: III. Lung and pleural ultrasound for the intensivist. *Ann Am Thorac Soc* 2013; 10:708–712.
24. Reuss J. Sonography of the pleura. *Ultraschall Med* 2010; 31:8–22.
25. Lobo V, Weingrow D, Perera P, Williams SR, Gharahbaghian L. Thoracic ultrasonography. *Crit Care Clin* 2014; 30:93–117. v–vi.
26. Gomond-Le Goff C, Vivalda L, Foligno S, Loi B, Yousef N, De Luca D. Effect of different probes and expertise on the interpretation reliability of point-of-care lung ultrasound. *Chest* 2020; 157:924–931.
27. Vieira JR, de Castro MR, de Paula Guimarães T, et al. Evaluation of pulmonary B lines by different intensive care physicians using bedside ultrasonography: a reliability study. *Rev Bras Ter Intensiva* 2019; 31:354–360.
28. Kumar A, Weng Y, Graglia S, et al. Interobserver agreement of lung ultrasound findings of COVID-19. *J Ultrasound Med* 2021. <https://doi.org/10.1002/jum.15620>.
29. Glomb N, D'Amico B, Rus M, Chen C. Point-of-care ultrasound in resource-limited settings. *Clin Pediatr Emerg Med* 2015; 16:256–261.
30. Knight T, Edwards L, Rajasekaran A, Clare S, Lasserson D. Point-of-care lung ultrasound in the assessment of suspected COVID-19: a retrospective service evaluation with a severity score. *Acute Med* 2020; 19:192–200.
31. Carubbi F, Salvati L, Alunno A, et al. Ferritin is associated with the severity of lung involvement but not with worse prognosis in patients with COVID-19: data from two Italian COVID-19 units. *Sci Rep* 2021; 11:4863.
32. Kumar A, Liu G, Chi J, Kugler J. The role of Technology in the Bedside Encounter. *Med Clin North Am* 2018; 102:443–451.
33. Moore CL, Copel JA. Point-of-care ultrasonography. *N Engl J Med* 2011; 364:749–757.
34. Lim JS, Lee S, Do HH, Oh KH. Can limited education of lung ultrasound be conducted to medical students properly? A pilot study. *Biomed Res Int* 2017; 2017:8147075.
35. Shumbusho JP, Duanmu Y, Kim SH, et al. Accuracy of resident-performed point-of-care lung ultrasound examinations versus chest radiography in pneumothorax follow-up after tube thoracostomy in Rwanda. *J Ultrasound Med* 2020; 39:499–506.
36. Kumar A, Weng Y, Wang L, et al. Portable ultrasound device usage and learning outcomes among internal medicine trainees: a parallel-group randomized trial. *J Hosp Med* 2020; 15:e1–e6.
37. Zhang Y, Xue H, Wang M, He N, Lv Z, Cui L. Lung ultrasound findings in patients with coronavirus disease (COVID-19). *AJR Am J Roentgenol* 2020; 216:1–5.
38. Alharthy A, Faqih F, Abuhamdah M, et al. Prospective longitudinal evaluation of point-of-care lung ultrasound in critically ill patients with severe COVID-19 pneumonia. *J Ultrasound Med* 2021; 40:443–456.
39. Writing Committee for the COMEBAC Study Group, Morin L, Savale L, et al. Four-month clinical status of a cohort of patients after hospitalization for COVID-19. *JAMA* 2021; 325:1525–1534.
40. Inui S, Fujikawa A, Jitsu M, et al. Chest CT findings in cases from the cruise ship diamond princess with coronavirus disease (COVID-19). *Radiol Cardiothoracic Imaging* 2020; 2:e200110.
41. Carfi A, Bernabei R, Landi F. Gemelli against COVID-19 post-acute care study group. Persistent symptoms in patients after acute COVID-19. *JAMA* 2020; 324:603–605.