Outcomes of Simplified Lung Ultrasound Exam in COVID-19
Implications for Self-Imaging

Bruce J. Kimura, MD ©, Rujing Shi, DO, MAS, Eric M. Tran, DO, Samantha R. Spierling Bagsic, PhD, MSE, Pamela M. Resnikoff, MD, MPH

Objectives—Lung ultrasound B-lines represent interstitial thickening or edema and relate to mortality in COVID-19. As B-lines can be detected with minimal training using point-of-care ultrasound (POCUS), we examined the frequency, clinical associations, and outcomes of B-lines when found using a simplified POCUS method in acutely ill patients with COVID-19.

Methods—In this retrospective cohort study, hospital data from COVID-19 patients who had undergone lung imaging during standard echocardiography or POCUS were reviewed for an ultrasound lung comet (ULC) sign, defined as the presence of ≥3 B-lines from images of only the antero-apex of either lung (ULC +). Clinical risk factors, oximetry and radiographic results, and disease severity were analyzed for associations with ULC +. Clinical risk factors and ULC + were analyzed for associations with hospital mortality or the need for intensive care in multivariable models.

Results—Of N = 160 patients, age (mean ± standard deviation) was 64.8 ± 15.5 years, and 46 (29%) died. ULC + was present in 100/160 (62%) of patients overall, in 81/103 (79%) of severe-or-greater disease versus 19/57 (33%) of moderate-or-less disease (P < .0001) and was associated with mortality (odds ratio [OR] = 2.4 [95% confidence interval [CI]: 1.1–5.4], P = .02) and the need for intensive care (OR = 5.23 [95% CI: 2.42–12.40], P < .0001). In the multivariable models, symptom duration and severe-or-greater disease were associated with ULC +, and ULC +, diabetes, and symptom duration were associated with the need for intensive care.

Conclusions—B-lines in the upper chest were common and related to disease severity, intensive care, and hospital mortality in COVID-19. Validation of a simplified lung POCUS exam could provide the evidence basis for a self-imaging application during the pandemic.

Key Words—COVID-19; lung ultrasound; pneumonia; point-of-care ultrasound; prognosis

COVID-19 has resulted in greater than 3 million deaths worldwide and more than 550,000 deaths in the United States within its first year alone. Most of the mortality has been due to respiratory failure that usually begins 10 days after exposure, with the progression of the viral infection from the nasopharynx to the lungs. Methods to identify those patients in whom disease will progress have medical and social implications for quarantine, triage, and early treatments. Notably, once disease progresses to the lungs, point-of-care
ultrasound (POCUS) can readily detect B-lines, an ultrasound artifact presumably generated by the visceral pleura or neighboring interstitium thickened from infection and edema. Outcome studies in COVID-19 have demonstrated that a comprehensive lung B-line score relates to a worse prognosis.

Earlier during the pandemic, healthcare professionals who were infected with COVID-19 were able to image their own lungs and demonstrate the development of B-lines using small POCUS devices while isolating at home. Although few data exist to guide how to image one’s self, a small study has shown that the upper chest is a region that is easily accessed and amenable to the simplified imaging that could facilitate self-imaging by patients, family members, or caregivers. However, before a patient self-imaging strategy can be studied, B-lines detected at the upper chest will first need to show a significant prevalence and a relationship to COVID-19 disease severity and outcomes. Therefore, we sought to determine the frequency, clinical associations, and mortality of a simple B-line finding from only the upper chest sites across a clinical spectrum of acutely infected patients who tested positive for COVID-19.

Materials and Methods

This retrospective cohort study took place at a 300-bed community teaching medical center utilizing data from April 2020 to March 2021 and was approved by the Scripps Institutional Review Board (Scripps Health, San Diego, #20-7691) with waiving of patient consent. At this hospital, two lung ultrasound antero-apical views in the second or third intercostal space in the mid-clavicular line, previously shown to have prognostic value, had been incorporated before the pandemic into the institution’s routine echo imaging protocol using standard echocardiographs (SS-1MHz, Phillips iE33; Phillips Healthcare, Andover, MA) and were also a part of routine POCUS bedside examination using one of many pocket-sized U.S. Food and Drug Administration-approved POCUS devices, including Lumify (S4-1MHz transducer, Phillips Healthcare), Vave (4 MHz transducer, Vave Health, Santa Clara, CA), and Vscan (1.7–3.8 MHz transducer, GE Healthcare, Wauwatosa, WI) in use at the institution. All patients, who had tested positive for COVID-19 by polymerase chain reaction testing via nucleic acid amplification (Hologic, San Diego, CA) and had received echo or lung POCUS, had their antero-apical images noted for an ultrasound lung comet (ULC) sign, defined as the presence or coalescence of three or more vertical ring-down linear B-line artifacts in a single image in either lung (Figure 1). Patients were considered ULC+ if either lung showed a comet sign with images confirmed by an expert physician reviewer with over a decade of experience in interpretation and acquisition of lung images who was blinded to patient outcome.

Figure 1. Composite of lung imaging: abnormal study with ≥3 B-lines (arrows), ULCs+; inset, example of probe placement on upper anterior chest, intercostal space #2.
categorize COVID-19 disease severity at the time of ultrasound evaluation as follows:

1. **Asymptomatic or pre-symptomatic infection**: Individuals who tested positive for the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) using a virologic test, but who had no symptoms that were consistent with COVID-19;

2. **Mild illness**: Individuals who had any of the various signs and symptoms of COVID-19 (e.g., fever, cough, sore throat, malaise, headache, muscle pain, nausea, vomiting, diarrhea, loss of taste, and smell) but who did not have shortness of breath, dyspnea, or abnormal chest imaging;

3. **Moderate illness**: Individuals who showed evidence of lower respiratory disease during clinical assessment or imaging and who had a saturation of oxygen (SpO2) ≥ 94% on room air at sea level;

4. **Severe illness**: Individuals who had SpO2 < 94% on room air at sea level, or, for patients with chronic hypoxemia, a decrease from baseline of >3%, a ratio of arterial partial pressure of oxygen to fraction of inspired oxygen (PaO2/FiO2) < 300 mmHg, respiratory rate > 30 breaths/min, or lung infiltrates >50%, or;

5. **Critical illness**: Individuals who had respiratory failure, septic shock, and/or multiple organ dysfunction.

Two clinical outcomes, mortality and the need for intensive care, were considered. Mortality was defined by patient death or disposition to hospice during hospitalization. The need for intensive care was present if the patient was transferred to the intensive care unit or had critical disease severity.

**Statistical Analysis**

Continuous raw data are expressed as a mean ± standard deviation. Based upon the need for significant hospital resources (i.e., supplemental oxygen and intravenous therapies) in the severe-or-greater categories, data from the severe and critical categories were grouped and compared to a moderate-or-less category group, defined as the combination of the asymptomatic, mild, and moderate categories, for outcome analysis. Clinical risk factors (age ≥ 65 years, gender, diabetes, hypertension, obesity defined as a body mass index >30, and time from symptom onset to the imaging study of >10 days), clinical test results (abnormal chest X-ray/CT, SpO2 < 94%, or requiring supplemental oxygen), and disease severity category were analyzed for univariable associations with ULC+, reported as odds ratios (ORs) with 95% confidence intervals [95% CIs]. Clinical risk factors and ULC+ were analyzed for associations with the two outcomes in reduced multivariable models using backward elimination. P-values were considered significant when ≤.05. All data were analyzed using R version 4.0.3 (2020).

**Figure 2.** Bar graph of ULC+ frequency and inpatient mortality (%) versus disease severity category. The ULC frequency and mortality were significantly lower between moderate-or-less versus severe-or-greater groups (see text). ASx, asymptomatic.
Results

Of N = 160 patients, age was 64.8 ± 15.5 years, 64% were male, and 94% were hospital admissions while 6% were discharged from the emergency department. ULC+ was present in 100/160 (62%) of patients overall and in 81/103 (79%) of severe-or-greater disease versus 19/57 (33%) of moderate-or-less disease (P < .0001) (Figure 2). In the 100 patients who were ULC+, the duration of symptoms before ULC detection was <24 hours in 8%, <5 days in 37%, and ≤10 days in 61%. Patients with shorter symptom durations had less significant disease severity (Figure 3). Of 19 patients who were in the moderate-or-less group and ULC+, only 1/19 (5%) had hypoxemia due to reasons not directly attributed to COVID-19 disease and most, 16/19 (84%), had demonstrated ULC+ within 10 days of symptom onset. Age ≥ 65 years, a history of hypertension, symptom duration >10 days, SpO2 < 94%, abnormal chest X-ray/CT, and severe-or-greater disease severity (Table 1) were associated with ULC+. In the multivariable analysis, ULC+ was best related to severe-or-greater disease (OR = 6.43 [95% CI: 3.11–13.71], P < .0001) and duration of symptoms >10 days (OR = 2.66 [95% CI: 1.13–6.68], P = .03).

In outcome analysis, patient mortality was 29% (46/160) overall and 42% (43/103) in the severe-or-greater group versus 5% (3/57) in the moderate-or-less group (P < .0001). ULC+ was associated with mortality, present in 76% (35/46) of those who died vs. 57% (65/114) in survivors (OR = 2.4 [95% CI: 1.1–5.4], P = .02). In the multivariable model that included ULC+ and clinical risk factors, mortality was best related to age ≥65 years (OR = 3.06 [95% CI: 1.43–6.97], P = .0053), male gender (OR = 2.71 [95% CI: 1.22–6.44], P = .02), and symptom duration >10 days (OR = 1.86 [95% CI: 1.33–6.23], P = .007). ULC+ was associated with the need for intensive care (OR = 5.23 [95% CI: 2.42–12.40], P < .0001), which occurred in 57/160 (36%) patients, 28 of whom had transferred from an initial ward admission. In the multivariable model, the need for intensive care was best related to ULC+ (OR = 3.88 [95% CI: 1.69–9.61], P = .002), diabetes (OR = 4.04 [1.86–9.32], P = .0006), and symptom duration >10 days (OR = 3.35 [95% CI: 1.52–7.63], P < .003).

Discussion

This study, by analyzing a clinical cross-section of patients with COVID-19, demonstrated that a simple sign of 3 B-lines found while imaging the upper chest was common and associated with disease severity, intensive care, and hospital mortality. Notably, in the subgroup with non-severe illness, nearly a third of
patients demonstrated the ULC+ sign at this site, without hypoxemia and usually within 10 days of symptom onset. The findings of this study provide the evidence basis for simplified imaging at easily accessible upper chest sites and have implications for increasing the application of POCUS in assessing prognosis, disease progression, triage, and early therapies in COVID-19 disease.

In alveolar-interstitial syndromes, ultrasound imaging of the lung has been shown to produce a specific reverberation or “ring-down” artifact, called the B-line, presumably generated from surface interfaces on the lung that have been thickened by inflammation, edema, or fibrosis.\(^9,24\) Since the early description of lung ultrasound imaging over 20 years ago,\(^9\) the antero-apical lung region has been repeatedly recognized as a distinct imaging zone for B-lines.\(^22,24,27\) In a retrospective analysis of outcomes in N = 486 hospitalized patients referred for echo,\(^21\) using the same antero-apical site as the current study, ULC+ had a frequency of 29% and was associated with an 11% in-hospital mortality before the pandemic, as compared to the current study of 63% frequency and 29% mortality in similarly-referred COVID-19 patients. The increased frequency and mortality of B-lines in COVID-19 is supported by reports of postmortem pathology, which commonly demonstrates edematous lungs and findings of diffuse alveolar damage with hyaline membranes and type 2 pneumocyte hyperplasia, consistent with widespread virus-induced acute lung injury.\(^28\)

The current findings are consistent with recent lung ultrasound outcome studies in COVID-19\(^10\)–\(^16\) that have demonstrated a relationship of patient mortality with complex lung ultrasound scores involving B-line and pleural abnormalities over the entirety of both lungs. However, the current investigation is unique in its validation of a simple POCUS sign in only the antero-apical lung zones and by using outcomes across the full spectrum of COVID-19 severity.

### Table 1. Clinical Risk Factors and Tests and Their Association with ULC+

| N = 160 | n (% of Total) | COMETS (+) n = 100 | COMETS (−) n = 60 | OR [95% CI] | P Value (Univariable) |
|---------|----------------|--------------------|------------------|------------|----------------------|
| Age ≥ 65 years | 90 (56.3%) | 63 (63%) | 27 (45%) | 2.08 (1.09–4.02) | .0273 |
| Gender (% male) | 102 (63.8%) | 68 (68%) | 34 (56.7%) | 1.63 (0.84–3.16) | .1500 |
| Diabetes | 90 (56.3%) | 62 (62%) | 28 (46.7%) | 1.86 (0.98–3.59) | .0596 |
| Hypertension | 112 (70%) | 76 (76%) | 36 (60%) | 2.11 (1.06–4.24) | .0340 |
| Obesity (BMI > 30) | 67 (41.9%) | 46 (46%) | 21 (35%) | 1.58 (0.82–3.09) | .1730 |
| Time from onset of symptoms > 10 days | | | | | |
| 0 | 22 (13.8%) | 8 (8%) | 14 (23.3%) | | |
| 1–4 | 50 (31.3%) | 29 (29%) | 21 (35%) | | |
| 5–10 | 40 (25%) | 24 (24%) | 16 (26.7%) | | |
| >10 | 48 (30%) | 39 (39%) | 9 (15%) | | |
| SpO2 < 94% | 102 (63.8%) | 80 (80%) | 22 (36.7%) | 6.91 (3.42–14.45) | <.0001 |
| Abnormal chest X-ray or CT | 127 (79.4%) | 90 (90%) | 37 (61.7%) | 5.68 (2.44–14.14) | .0001 |
| Severity classification | | | | | |
| Asymptomatic | 24 (15%) | 7 (7%) | 17 (28.3%) | 7.36 (3.63–15.52) | <.0001* |
| Mild | 10 (6.3%) | 2 (2%) | 8 (13.3%) | | |
| Moderate | 23 (14.4%) | 10 (10%) | 13 (21.7%) | | |
| Severe | 57 (35.6%) | 43 (43%) | 14 (23.3%) | | |
| Critical | 46 (28.8%) | 38 (38%) | 8 (13.3%) | | |

BMI, body-mass index; CI, confidence interval, CT, computed tomography; OR, odds ratio.

*relates to the P-value of the Severity Classification where OR 7.36 (3.63–15.52) <.0001. P-value for Severity classification derived from univariable logistic regression model with aggregated categories: Severe/critical relative to asymptomatic/mild/moderate.
were used in previous ultrasound investigations. In comparison with a study using 8 imaging zones that examined disease severity in 106 consecutive COVID-19 patients, the prevalence of B-lines was 31% in mild disease and 70% in severe-or-greater disease, which is similar to the 33 and 79% found in the current study using only the 2 apical zones. Our data show a surprisingly high prevalence of a simple upper lobe finding often in the absence of hypoxemia, which may represent an early phase of a progressive infection. Self-inoculation or tracheobronchial spread to the upper lungs from a virus-laden nasopharynx infection could be plausible explanations, given that the upper lung regions have been modeled to have a higher deposition and dispersion of submicrometer particles, are suspected to have delayed lymphatic drainage, and are subject to inflammatory oxidative stress from oxygen-free radicals. Lung ultrasound findings in this infection have been associated with interleukin 6 levels and may herald a stage of cytokine activation. In the current study, the reported duration of symptoms of ≤10 days in the majority of ULC+ patients is consistent with the time-course of initial lung involvement observed in COVID-19.

Importantly, our data validate an imaging site for patients to self-image remotely in COVID-19. The rationale for studying a simplified lung ultrasound protocol during the pandemic is to ultimately increase the availability of outpatient ultrasound examination by making it easier for nonexpert users to apply the technique in the community. Searching for comets in the upper chest is one of the simplest ultrasound maneuvers to learn and perform. The imaging process described does not require patients to undress and takes less than a minute. In a recent feasibility study using a single page of patient instruction, the same lung imaging technique employed in the current study was successfully taught to patients with cardiac disease, unexplained dyspnea, and COVID-19 pneumonia. Over 85% of patients under 78 years of age obtained adequate images on themselves and overall accuracy was 88% compared to expert imaging. In conjunction with the current findings, our data would project the superiority of ultrasound to self-monitor initial COVID-19 infection over other methods, as SpO2 assessment would identify a later, more severe stage of disease and chest X-ray, which is less sensitive than ultrasound, would require transport to a medical facility. In a quick-look POCUS application using smartphone devices, the appearance of upper lobe B-lines could result in immediate quarantine and serum testing of the individual with minimal or atypical symptoms, identify outpatients who may benefit from immunologic therapies, and assist in triage of acutely ill patients arriving at the hospital. More data are needed to validate a self-imaging telemedicine pathway, confirm the timing and location of initial lung involvement, and investigate whether B-lines represent higher airborne infectivity. In the future, proof-of-concept studies with simplified imaging protocols, patient-friendly instruction, and artificial intelligence could usher in a novel public telehealth methodology for various diseases and extend ultrasound imaging to nonphysician personnel in homes and hard-to-reach, resource-poor communities.

This retrospective analysis of “front-line” care during the COVID-19 pandemic is subject to multiple limitations and biases. Nonconsecutive patients with COVID-19 who were referred for echo or underwent POCUS were categorized by disease severity, but still likely represented a clinically heterogeneous group, as data may reflect more severe and complicated disease in those referred for echo or lesser disease in others who had been routinely imaged due to the POCUS capabilities of their examining physician. Our unadjusted overall mortality rate of 29% for patients who had been imaged with ultrasound suggests a modest effect of selection bias, as this rate is high but comparable to that of unselected patients in similar-sized U.S. hospitals during the initial wave of the pandemic and similar to other COVID-19 ultrasound outcome studies of older patients. Concomitant cardiogenic pulmonary edema was not excluded and virus-induced heart failure exacerbation may have been a significant and prevalent comorbidity, which was nonetheless considered attributable to the COVID-19 infection. As a single-center study, our findings represent the prevalence and virulence of cases encountered by a hospital in the downtown San Diego region which has a high proportion of admissions from the surrounding Hispanic community and an underserved homeless population and occurred before widespread vaccination, the appearance of the delta variant, and the development of any standardized outpatient treatments.
In conclusion, a ULC sign consisting of 3 B-lines, observed upon scanning the upper chest, was common, related to disease severity, intensive care treatment, and patient mortality in COVID-19. Future studies may clarify the utility of simplified lung ultrasound imaging in staging and monitoring COVID-19 infection, potentially using data obtained early by affected individuals from within the community.

References

1. Johns Hopkins University & Medicine. Coronavirus Resource Center. https://coronavirus.jhu.edu. Accessed April 19, 2021.
2. Wiersinga WJ, Rhodes A, Cheng AC, Peacock SJ, Prescott HC. Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review. JAMA 2020; 324:782–793.
3. Gandhi RT, Lynch JB, Del Rio C. Mild or moderate Covid-19. N Engl J Med 2020; 383:1757–1766.
4. Volpicelli G, Gargani L, Perlini S, et al. Lung ultrasound for the early diagnosis of COVID-19 pneumonia: an international multicenter study. Intensive Care Med 2021; 47:444–454.
5. Kumar A, Weng Y, Duannu Y, et al. Lung ultrasound findings in patients hospitalized with COVID-19. J Ultrasound Med 2021. https://doi.org/10.1002/jum.15683. Online ahead of print.
6. Brenner DS, Liu GY, Omron R, Tang O, Garibaldi BT, Fong TC. Diagnostic accuracy of lung ultrasound for SARS-CoV-2: a retrospective cohort study. Ultrasound J 2021; 13:12.
7. Tung-Chen Y, Algora-Martín A, Llamas-Fuentes R, et al. Point-of-care ultrasound in the initial characterization of patients with COVID-19. Med Clin (Barc) 2021; 156:477–484.
8. Sahu AK, Mathew R, Bhoi S, Sinha TP, Nayer J, Aggarwal P. Lung sonographic findings in COVID-19 patients. Am J Emerg Med 2021; 45:324–328.
9. Lichtenstein D, Mézière G, Biderman P, Gepner A, Barré O. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997; 156:1640–1646.
10. Ji L, Cao C, Gao Y, et al. Prognostic value of bedside lung ultrasound score in patients with COVID-19. Crit Care 2020; 24:700.
11. de Alencar JCG, Marchini JFM, Marino LO, et al. Lung ultrasound score predicts outcomes in COVID-19 patients admitted to the emergency department. Ann Intensive Care 2021; 11:6.
12. Mafort TT, Rufino R, da Costa CH, et al. One-month outcomes of patients with SARS-CoV-2 infection and their relationships with lung ultrasound signs. Ultrasound J 2021; 13:19.
13. 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.
14. Recinella G, Marasco G, Tufoni M, et al. Clinical role of lung ultrasound for the diagnosis and prognosis of coronavirus disease pneumonia in elderly patients: a pivotal study. Gerontology 2021; 67:78–86.
15. Veronezi N, Sbrogiò LG, Valle R, Marin L, Fiore EB, Tiozzo A. Prognostic value of lung ultrasonography in older nursing home residents affected by COVID-19. J Am Med Dir Assoc 2020; 21:1384–1386.
16. Rojatti M, Regli IB, Zanforlin A, et al. Lung ultrasound and respiratory pathology in mechanically ventilated COVID-19 patients—an observational trial. SN Compr Clin Med 2020; 1–8. Online ahead of print.
17. Tung-Chen Y. Lung ultrasound in the monitoring of COVID-19 infection. Clin Med (Lond) 2020; 20:e62–e65.
18. Pivetta E, Girard E, Locascio F, Lupia E, Martin JD, Stone M. Self-performed lung ultrasound for home monitoring of a patient positive for coronavirus disease 2019. Chest 2020; 158:e93–e97.
19. Aminlari A, Quenzer F, Hayden S, Stone J, Murchison C, Campbell C. A Case of Covid-19 Diagnosed at home with portable ultrasound and confirmed with home serology test. J Emerg Med 2021; 60:399–401.
20. Resnikoff PM, Shi R, Spierling Bagic SR, Kimura BJ. The novel concept of patient self-imaging: success in COVID-19 and cardiopulmonary disorders. Am J Med 2021; 134:e360–e361.
21. Garibyan VN, Amundson SA, Shaw DJ, et al. The prognostic value of lung ultrasound findings in hospitalized patients undergoing echocardiography. J Ultrasound Med 2018; 37:1641–1648.
22. Kimura BJ, Shaw DJ, Amundson SA, Phan JN, Blanchard DG, DeMaria AN. Cardiac limited ultrasound exam techniques to augment the bedside cardiac physical. J Ultrasound Med 2015; 34:1683–1690. https://doi.org/10.7863/ultra.15.14.09002.
23. Centers for Disease Control and Prevention. Return to Work Criteria for Healthcare Workers. https://www.cdc.gov/coronavirus/2019-ncov/hcp/return-to-work/definitions. Accessed April 17, 2021.
24. Volpicelli G, Elbarbary M, Blaivas M, et al. International evidence-based recommendations for point-of-care lung ultrasound. Intensive Care Med 2012; 38:577–591.
25. Picano E, Frassati F, Agricola E, Gligorova S, Gargani L, Mottola G. Ultrasound lung comets: a clinically useful sign of extravascular lung water. J Am Soc Echocardiogr 2006; 19:356–363.
26. Volpicelli G, Mussa A, Garofalo G, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. Am J Emerg Med 2006; 24:689–696.
27. Liteplo AS, Marill KA, Villen T, et al. Emergency thoracic ultrasound in the differentiation of the etiology of shortness of breath (ETUDES): sonographic B-lines and N-terminal pro-brain-natriuretic peptide in diagnosing congestive heart failure. Acad Emerg Med 2009; 16:201–210.
28. Borczuk AC, Tomevich SP, Seshan SV, et al. COVID-19 pulmonary pathology: a multi-institutional autopsy cohort from Italy and new York City. Mod Pathol 2020; 33:2156–2168.
29. Wong HYF, Lam HYS, Fong AH, et al. Frequency and distribution of chest radiographic findings in patients positive for COVID-19. Radiology 2020; 296:E72–E78.

30. Yang R, Li X, Liu H, et al. Chest CT severity score: an imaging tool for assessing severe COVID-19. Radiol Cardiothorac Imaging 2020; 2:e200047.

31. Song F, Shi N, Shan F, et al. Emerging 2019 novel coronavirus (2019-nCoV) pneumonia. Radiology 2020; 295:210–217.

32. Sarangapani R, Weder AS. The role of dispersion in particle deposition in human airways. Toxicol Sci 2000; 54:229–236.

33. Nemec SF, Bankier AA, Eisenberg RL. Upper lobe-predominant diseases of the lung. Am J Roentgenol 2013; 200:W222–W237.

34. Vallyathan V, Shi X. The role of oxygen free radicals in occupational and environmental lung diseases. Environ Health Perspect 1997; 105:165–177.

35. Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G. Evaluation of ultrasound lung comets by hand-held echocardiography. Cardiovasc Ultrasound 2006; 4:34.

36. Pare JR, Camelo I, Mayo KC, et al. Point-of-care lung ultrasound is more sensitive than chest radiograph for evaluation of COVID-19. West J Emerg Med 2020; 21:771–778.

37. Rosenthal N, Cao Z, Gundrum J, Sianis J, Safo S. Risk factors associated with in-hospital mortality in a US national sample of patients with COVID-19. JAMA Netw Open 2020; 3:e2029058.

38. Karagodin I, Carvalho Singulane C, Woodward GM, et al. Echocardiographic correlates of in-hospital death in patients with acute COVID-19 infection: the world alliance societies of echocardiography (WASE-COVID) study. J Am Soc Echocardiogr 2021;34:819–830.