Application of Lung Ultrasound During the Coronavirus Disease 2019 Pandemic: A Narrative Review

David Convissar, MD, Lauren E. Gibson, MD, Lorenzo Berra, MD, Edward A. Bittner, MD, PhD, and Marvin G. Chang, MD, PhD

This review highlights the ultrasound findings reported from a number of studies and case reports and discusses the unifying findings from coronavirus disease (COVID-19) patients and from the avian (H7N9) and H1N1 influenza epidemics. We discuss the potential role for portable point-of-care ultrasound (PPOCUS) as a safe and effective bedside option in the initial evaluation, management, and monitoring of disease progression in patients with confirmed or suspected COVID-19 infection. (Anesth Analg XXX;XXX:00–00)

Glossary

ARDS = acute respiratory distress syndrome; COVID-19 = coronavirus disease 2019; PEEP = positive end-expiratory pressure; POCUS = point-of-care ultrasound; PPOCUS = portable point-of-care ultrasound; \( \text{SaO}_2 \) = XXX

Amid the recent coronavirus disease (COVID-19) outbreak and resulting pandemic, there has been a growing necessity to determine novel ways of safely evaluating patients who are suspected to be infected with the virus. Given the limited supply, cost, and often slow turnaround time of available assays, testing every patient who presents with symptoms or with recent exposure is currently not a viable option. It has been cited that early computed tomography scanning of patients may be beneficial, because infected patients may demonstrate radiologic findings before the onset of severe clinical symptoms. However, the American College of Radiology recommends that computed tomography not be used to screen for or diagnose COVID-19 and that it be used sparingly in hospitalized, symptomatic patients given the risk of infection transmission posed to staff and subsequent patients.

There is evidence that lung point-of-care ultrasound (POCUS) may be comparable to chest radiography and to computed tomography in terms of its ability to detect parenchymal and pleural pathology and to monitor response to therapies. Historically, ultrasound was found to be an important tool for the rapid evaluation and assessment of pulmonary status in patients during the 2013 avian influenza A (H7N9) epidemic. Similarly, lung ultrasound may aid in the identification and subsequent monitoring of suspected COVID-19 infections, perhaps even before the onset or progression of respiratory symptoms. Here, we review the ultrasound findings reported from a number of studies and case reports and discuss the unifying findings from COVID-19 patients and from the avian (H7N9) and H1N1 influenza epidemics. We also discuss the potential role for portable POCUS as a safe and effective bedside option in the initial evaluation, management, and monitoring of disease progression in patients with confirmed or suspected COVID-19 infection.

POCUS FINDINGS IN COVID-19: A REVIEW OF AVAILABLE STUDIES AND CASE REPORTS

Since the outbreak, multiple studies and case reports have emerged in the literature and social media evaluating the use of lung ultrasound in patients with confirmed COVID-19 infections. Table 1 shows the characteristics and lung ultrasound findings that have been associated with COVID-19. Huang et al utilized lung ultrasound to evaluate peripulmonary lesions of 20 noncritical COVID-19 patients at Xi’an Chest Hospital in China. The authors...
Table 1. POCUS Examinations Performed on COVID-19 Patients

| Source        | Location                        | No. of Patients | Patient Characteristics | Ultrasound Device | Ultrasound Scanning Protocol | Lung Ultrasound Findings                                                                 |
|---------------|---------------------------------|----------------|-------------------------|-------------------|------------------------------|-----------------------------------------------------------------------------------------|
| Huang et al⁷  | Xi’an Chest Hospital (Shaanxi, China) | 20             | Noncritical COVID-19–confirmed patients. Average age 27–81 y, median 45 y (3 cases >65 y) with fever, radiographic features of pneumonia by computed tomography, and normal or decreased white blood cell count | SonoScape P50     | 12 Zone Method                | Posterior and inferior lung field lesions. Large number of B lines ("Waterfall Sign"), at times fused and fixed ("White Lung Sign"). Rough pleural lines. Subpleural pulmonary consolidations. Decreased blood flow. Air bronchograms. |
| Jin et al¹    | Xiangya Hospital (Hunan, China)  | 20             | COVID-19–confirmed patients (age, sex, acuity not mentioned) | Not identified     | 12 Zone Method                | Thickening of pleural line and irregularities. B lines in various patterns. Multiple patterns of consolidation including multifocal small, nontranslobar and translobar with mobile air bronchograms. A lines during recovery. Pleural effusions uncommon. Pleural irregularities. Subpleural consolidations. Areas of thick, confluent B lines as well as spared areas. |
| Buonsenso et al⁹ | Agostino Gemelli University Hospital (Rome, Italy) | 1              | Noncritical COVID-19–confirmed patient, 52-y-old man presenting after 7 d of fever and flu-like symptoms, found to have perihilar infiltrates on chest radiograph and lymphopenia | Unidentified portable ultrasound | 12 Zone Method                | Pleural thickening. Subpleural consolidations. Areas of thick, confluent B lines as well as spared areas. |
| Chen⁶ (2020)  | Hospital Universitario La Paz (Madrid, Spain) | 1              | Noncritical COVID-19–confirmed patient, 35-y-old emergency room physician who performed ultrasound scan self on days 1–9 after COVID-19 diagnosis | Butterfly iQ       | Not reported                  | Small bilateral pleural effusions with a thickened pleural line. Basal B lines. Presence and spread of subpleural consolidations. Normal lung ultrasound initially. Ultrasound findings occur in the absence of shortness of breath/dyspnea and occur before malaise. |
| Thomas et al⁸ | Victoria General Hospital (British Columbia, Canada) | 1              | Critical COVID-19–confirmed patient, 64-y-old health care worker presenting 10 d after symptom onset with fevers, hypoxemia (SaO₂ 88%), and bilateral infiltrates on chest radiograph | Not identified     | Not reported                  | Pleural thickening. Subpleural consolidations, ("skip lesions"). Multifocal B lines. |

Abbreviations: COVID-19, coronavirus disease 2019; POCUS, point-of-care ultrasound; SaO₂, XXX.

conclude that computed tomography may be inferior to lung ultrasound in detecting smaller peripulmonary lesions and effusions in COVID-19 patients. Lung ultrasound in these patients demonstrated (1) posterior and inferior lung field lesions, (2) B lines, (3) distorted pleural lines, (4) subpleural pulmonary consolidations, and (5) air bronchograms. While these findings may not be specific to COVID-19 compared to other viral pneumonias, identification of these patterns during a pandemic could certainly assist providers in determining individuals who are likely to be infected.

Jin et al¹ performed lung ultrasound on 20 confirmed COVID-19 patients from Xiangya Hospital and Peking Union Medical College Hospital in China. Their early findings demonstrated that the use of ultrasound provided similar results to those of computed tomography and superior results to those of standard chest radiographs.¹ Their findings included (1) thickening of the pleural line with irregularity, (2) B lines, (3) consolidation, (4) the appearance of A lines during recovery, and (5) the absence of pleural effusions.¹ They concluded that ultrasound was an effective way to assess the severity of a patient’s pulmonary disease and to trend their disease progression and guide eventual respiratory weaning.

Dr Yale Tung Chen,⁶ an emergency physician from the Hospital Universitario La Paz in Spain, was recently found to be positive for COVID-19. He took it upon himself to ultrasound his own lungs and share his findings on Twitter as his disease progressed.⁶ His ultrasound findings were (1) small bilateral pleural...
effusions with a thickened pleural line, (2) basal B lines, and (3) the presence and spread of subpleural consolidations.6 Using a portable ultrasound device in concert with a social media platform has allowed Dr Chen5 to demonstrate, in near real time, the utilization of lung ultrasonography as it applies to the COVID-19 threat.

Table 2 summarizes the ultrasound findings from the studies and case reports discussed above and includes (1) subpleural lesions in the inferior and posterior regions of the lung, which seems to be highly consistent with other cases of viral pneumonia (Figure D and F; Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/D96 and Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/D98); (2) individual and confluent B lines (Figure B and C; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95; Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/D96; and Supplemental Digital Content 4, Video 4, http://links.lww.com/AA/D97); and (3) signs of air bronchograms, especially peripherally (Figure F; Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/D98), and (4) thickened or irregular pleural lines (Figure B, C, and E; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95; Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/D96; and Supplemental Digital Content 4, Video 4, http://links.lww.com/AA/D97).

Communication and education are key in preparing for pandemics, and today’s devices provide powerful platforms on which to share and integrate data quickly. The use of lung POCUS in today’s pandemic: what is different?

Today, we have access to more affordable and portable ultrasound devices that far exceed the imaging capabilities of devices from even a decade ago. These devices may serve as an invaluable tool for the rapid diagnosis and day-to-day monitoring of suspected COVID-19 patients. In addition, today’s devices provide powerful platforms on which to share and integrate data quickly.

Traditional ultrasound has a number of limitations that portable ultrasound may be able to solve. The
cost of an ultrasound machine can vary from $30,000 to upward of $150,000, prohibiting access to hospitals and care centers that are resource limited. Transport of these large devices to remote areas also creates added cost. These machines must be thoroughly sterilized after each use to prevent the spread of infection. Meanwhile, portable ultrasounds are available for between $2000 and $2500. A single handheld probe can be easily sterilized, while complete sterilization of the knobs, buttons, screens, and carts of traditional machines can be difficult and time consuming, if not impossible. Allotment of an ultrasound probe to each

Figure. Lung ultrasound examination of COVID-19 patients may reveal normal lungs with A lines (A; Supplemental Digital Content 1, Video 1, http://links.lww.com/AA/D94) during the earliest stage of the infection, isolated B lines (B; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95; Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/D96; Supplemental Digital Content, Video 4, http://links.lww.com/AA/D97), confluent B lines (C; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95), thickened and irregular pleural lines (D; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95; Supplemental Digital Content 3, Video 3, http://links.lww.com/AA/D96; Supplemental Digital Content 4, Video 4, http://links.lww.com/AA/D97), thickening and jagged pleural lines (E; Supplemental Digital Content 4, Video 4, http://links.lww.com/AA/D97), and/or subpleural consolidation with air bronchograms (F; Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/D98). COVID-19 indicates coronavirus disease 2019.
Serial lung ultrasounds may be particularly useful in assessing the clinical response to the above interventions and guiding the appropriateness for deescalation of care. Examinations should be performed in a standardized manner, such as by using a 12- or 14-zone method to cover all lung areas and incorporating a scoring system, as proposed by Soldati et al, to assist in the classification of findings. In this way, ultrasound can help predict responders and nonresponders to interventions, such as prone positioning and ventilation changes. Reduction in B lines, the reappearance of A lines, and the resolution of consolidations suggest recovery and would support a decision to wean respiratory support. Although beyond the scope of this article, it is important to note that cardiac ultrasound can also play a major role in optimizing the management of COVID-19 patients who may develop postviral cardiomyopathy and who may have weaning failure that is of cardiovascular origin.

CONCLUSIONS
The COVID-19 pandemic has presented many new challenges for the medical community. As clinicians, we must embrace innovations that could make a difference in containing the disease. Lung ultrasound has the potential to improve the management of COVID-19 patients, with key advantages over other imaging modalities. The advent of affordable, portable ultrasound devices with advanced capabilities such as information sharing, video learning, and teleguidance may further increase patient and provider safety and improve patient care.

DISCLOSURES
Name: David Convissar, MD.
Contribution: This author helped write the manuscript.
Name: Lauren E. Gibson, MD.
Contribution: This author helped write the manuscript.
Name: Lorenzo Berra, MD.
Contribution: This author helped write the manuscript.
Name: Edward A. Bittner, MD, PhD.
Contribution: This author helped write the manuscript.
Name: Marvin G. Chang, MD, PhD.
Contribution: This author helped write the manuscript.

This manuscript was handled by: Thomas M. Hemmerling, MSc, MD, DEAA.

ACKNOWLEDGMENTS
We are thankful and grateful to Butterfly Network, Inc for allowing us to use their deidentified videos of coronavirus disease 2019–confirmed patients in this article.

REFERENCES
1. Jin YH, Cai L, Cheng ZS, et al; for the Zhongnan Hospital of Wuhan University Novel Coronavirus Management and Research Team, Evidence-Based Medicine Chapter of China International Exchange and Promotive Association for Medical and Health Care (CPAM). A rapid advice guideline
Application of Lung Ultrasound in COVID-19

1. World Health Organization. Human infection with avian influenza A (H7N9) virus – China. 2017.
2. Patrick Lindsay M, Lauren G, Bittner EA, Chang MG. Portable point of care ultrasound (PPOCUS): an emerging technology for improving patient safety. Anesthesia Patient Safety Foundation. 2020;35.
3. Cheung JC, Lam KN. POCUS in COVID-19: pearls and pitfalls. Lancet Respir Med. 2020.
4. Tsung JW, Kessler DO, Shah VP. Prospective application of clinician-performed lung ultrasonography during the 2009 H1N1 influenza A pandemic: distinguishing viral from bacterial pneumonia. Crit Ultrasound J. 2012;4:416.
5. Prat G, Guinard S, Bizien N, et al. Can lung ultrasonography predict prone positioning response in acute respiratory distress syndrome patients? J Crit Care. 2016;32:36–41.
6. Wang XT, Ding X, Zhang HM, Chen H, Su LX, Liu DW; Chinese Critical Ultrasound Study Group (CCUSG). Lung ultrasound can be used to predict the potential of prone positioning and assess prognosis in patients with acute respiratory distress syndrome. Crit Care. 2016;20:385.
7. Arentz M, Yim E, Klaff L, et al. Characteristics and outcomes of 21 critically ill patients with COVID-19 in Washington State. JAMA. 2020.
8. Routsi C, Stanopoulos I, Kokkoris S, Sideris A, Zakynthinos S. Weaning failure of cardiovascular origin: how to suspect, detect and treat—a review of the literature. Ann Intensive Care. 2019;9:6.