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Application of Lung Ultrasound during the COVID-19 Pandemic: A Narrative Review

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Glossary of Terms

Acute Respiratory Distress Syndrome (ARDS)

Positive End-Expiratory Pressure (PEEP)

Point-of-Care Ultrasound (POCUS)

Abstract

This review highlights the ultrasound findings reported from a number of studies and case reports and discusses the unifying findings from COVID-19 patients as well as 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.

Keywords: Point of care ultrasound; COVID-19; coronavirus; lung ultrasound; ultrasound; POCUS

Introduction

Amidst the recent 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 turn-around 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, as infected patients may demonstrate radiologic findings before the onset of severe clinical symptoms[1]. 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[2].

There is evidence that lung point-of-care ultrasound (POCUS) may be comparable to chest radiography as well as to computed tomography in terms of its ability to detect parenchymal and pleural pathology as well as to monitor response to therapies[3]. 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[4,5]. Similarly, lung ultrasound may aid in the identification and subsequent monitoring of suspected COVID-19 infections, perhaps even prior to the onset or progression of respiratory symptoms. Here, we review the ultrasound findings reported from a number of studies and case reports[1,6-8] and discuss the unifying findings from COVID-19 patients as well as from the avian (H7N9) and H1N1 influenza epidemics. We also discuss the potential role for portable point-of-care ultrasound 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[1,6-9]. Table 1 shows the characteristics and lung ultrasound findings that have been associated with COVID-19.

Huang et al.[7] utilized lung ultrasound to evaluate peri-pulmonary lesions of 20 non-critical COVID-19 patients at Xi'an Chest Hospital in China. The authors 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[7]. 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.

Peng et al.[1] 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 as well as to trend their disease progression and guide eventual respiratory weaning.

Dr. Yale Tung Chen, 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. Chen 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 (Figures 1D and 1F; Supplemental Digital Content 3 and 5, Videos 3 and 5, http://links.lww.com/AA/D96, http://links.lww.com/AA/D98)[1,6,7], (2) individual and confluent B lines (Figures 1B and 1C; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97)[1,6-9], (3) signs of air bronchograms, especially peripherally (Figure 1F; Supplemental Digital Content, Video 5, http://links.lww.com/AA/D98)[1,7-9], and (4) thickened or irregular pleural lines (Figures 1B, 1C, and 1E; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97)[1,6-9]. Some of these findings are consistent with viral pneumonias from prior epidemics, including the subpleural consolidations described on ultrasound in influenza A (H1N1) and subpleural consolidations and B lines described in avian influenza A (H7N9)[5,6,9]. In contrast, normal lungs have an A-line pattern (Figure 1A; Supplemental Digital Content 1, Video 1, http://links.lww.com/AA/D94).

The Use of Lung POCUS in Prior Epidemics: What's the Same?

During the 2009 influenza A (H1N1) pandemic, in which patients' conditions rapidly deteriorated from self-limited febrile illness to an aggressive pneumonia, chest radiographs often failed to identify early interstitial lung disease[10]. A cross-sectional study demonstrated abnormal ultrasound patterns showing interstitial syndrome in 15 of 16 patients who presented with normal chest radiographs, 63% of whom were subsequently diagnosed with viral (H1N1) pneumonia and 38% of whom were diagnosed with bacterial pneumonia[9]. Overall, lung ultrasound was found to have 94% sensitivity and 89% specificity, or a positive predictive value of 86% and a negative predictive value of 96%, and outperformed chest radiography for the detection of viral pneumonia in symptomatic patients[5].

The avian influenza A (H7N9) epidemics of 2013-2014 and 2016 saw large regional infection in China with a documented 1,222 infections and a death rate of 40%[11]. Serial lung ultrasounds of these patients demonstrated the effectiveness of POCUS in the early identification of pneumonia secondary to the H7N9 virus[4,5]. In both patients who eventually developed acute respiratory distress syndrome (ARDS) as a result of the infection, serial lung ultrasound examinations showed B lines, pleural effusions, and small subpleural consolidations. These findings are consistent with previously documented findings in viral pulmonary infections such as measles and H1N1[4,5].

Thus, ultrasonography has repeatedly proven to be an effective imaging modality to aid in both diagnosing and monitoring the progression of viral pneumonias. Its safety, in terms of lack of radiation exposure and relative ease of equipment sterilization to reduce the spread of infection, and accessibility to resource-limited settings make it an ideal choice during epidemics. Computed tomography, while reliable in providing good diagnostic quality imaging, is costly and carries the disadvantages of radiation exposure, lack of portability, and heightened risk of infectious spread[4,5].

The Use of Lung POCUS in Today's Pandemic: What's 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 upwards of $150,000, prohibiting access to hospitals and care centers that are resource-limited[12]. 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 $2,000 and $2,500[13]. 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 patient and/or the use of disposable probe covers can further help to reduce the risk of infectious spread from portable devices[13].

The use of portable ultrasound for evaluating lung tissue is already common practice in many clinical settings, including emergency departments and intensive care units[12]. Additional advantages include the ability to synchronize with current electronic medical records, the integration of artificial intelligence into the recognition of specific ultrasound findings, and the ability to integrate into social media, such as demonstrated by Dr. Chen on Twitter[6], to promote information sharing [8,12,14]. This could create a large crowdsourced index from which clinicians and scientists could continue to identify and share common findings in COVID-19 patients. Many ultrasound platforms also include video learning platforms to teach examination skills on demand, allowing for increased adoption among clinicians with limited ultrasound experience[14]. Tele-guidance further assists novice users by allowing them to leverage the skills of a remote expert user[14,15].

Recommendations for the Use of Lung Ultrasound in the COVID-19 Pandemic

Based on available data from prior epidemics and recent case reports, lung ultrasound may be preferred over chest radiography or computed tomography in the diagnosis and monitoring of COVID-19 patients due to its ease of bedside use, low associated cost, and reduced risk of infectious spread.[1,4] Lung ultrasound can help clinicians to differentiate between a possible pneumonia and alternative causes of dyspnea while awaiting confirmatory testing or in areas where molecular assays are unavailable.

After the initial assessment, serial lung ultrasound exams may be helpful to track the clinical trajectory of a seemingly unpredictable disease course and guide suitable treatment options and timing of interventions. For example, detection of a new consolidation with dynamic air bronchograms may suggest the development of a superimposed bacterial pneumonia. In addition to other clinical parameters, such ultrasound findings would support a decision to initiate antibiotics[14]. Consolidations that are more posterior may advocate for early prone positioning in the appropriate clinical context. Similarly, increasing B lines suggests a trend towards deterioration in a patient who may benefit from titration of positive end-expiratory pressure (PEEP) in order to improve aeration. Atelectasis on lung ultrasound may suggest the need for additional PEEP and recruitment maneuvers. Although less common in viral pneumonia, the size, location, and appearance of any pleural effusions can be assessed by lung ultrasound to determine the need for drainage.

Serial lung ultrasounds may be particularly useful in assessing the clinical response to the above interventions and guiding the appropriateness for de-escalation of care. Exams 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[15]. In this way, ultrasound can help predict responders and non-responders to interventions, such as prone positioning and ventilation changes[16,17]. 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 post viral cardiomyopathy[18] and who may have weaning failure that is of cardiovascular origin[19].

Conclusion

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.

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Figure Legends

Figure 1. Lung ultrasound examination of COVID-19 patients may reveal normal lungs with A lines (Panel A; Supplemental Digital Content 1, Video 1, http://links.lww.com/AA/D94) during the earliest stage of the infection, isolated B lines (Panel B; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97), confluent B lines (Panel C; Supplemental Digital Content 2, Video 2, http://links.lww.com/AA/D95), thickened and irregular pleural lines (Panel D; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97), thickening and jagged pleural lines (Panel E; Supplemental Digital Content 4, Video 4, http://links.lww.com/AA/D97) and/or subpleural consolidation with air bronchograms (Panel F; Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/D98)[20].

Supplemental Video Legends

Supplemental Video 1. Normal lung ultrasound with A lines[14]

Supplemental Video 2. Lung ultrasound with confirmed COVID-19 infection with thick irregular pleural line, confluent and isolated B lines and A lines[14]

Supplemental Video 3. Lung ultrasound with confirmed COVID-19 infection with scattered B lines and a thickened and irregular pleural line with small subpleural consolidations[20]

Supplemental Video 4. Lung ultrasound with confirmed COVID-19 infection with isolated B lines and irregular, thick and discontinuous pleural line (skip lesions)[20]

Supplemental Video 5. Lung ultrasound with confirmed COVID-19 infection with a subpleural consolidation and air bronchograms[20]

Tables

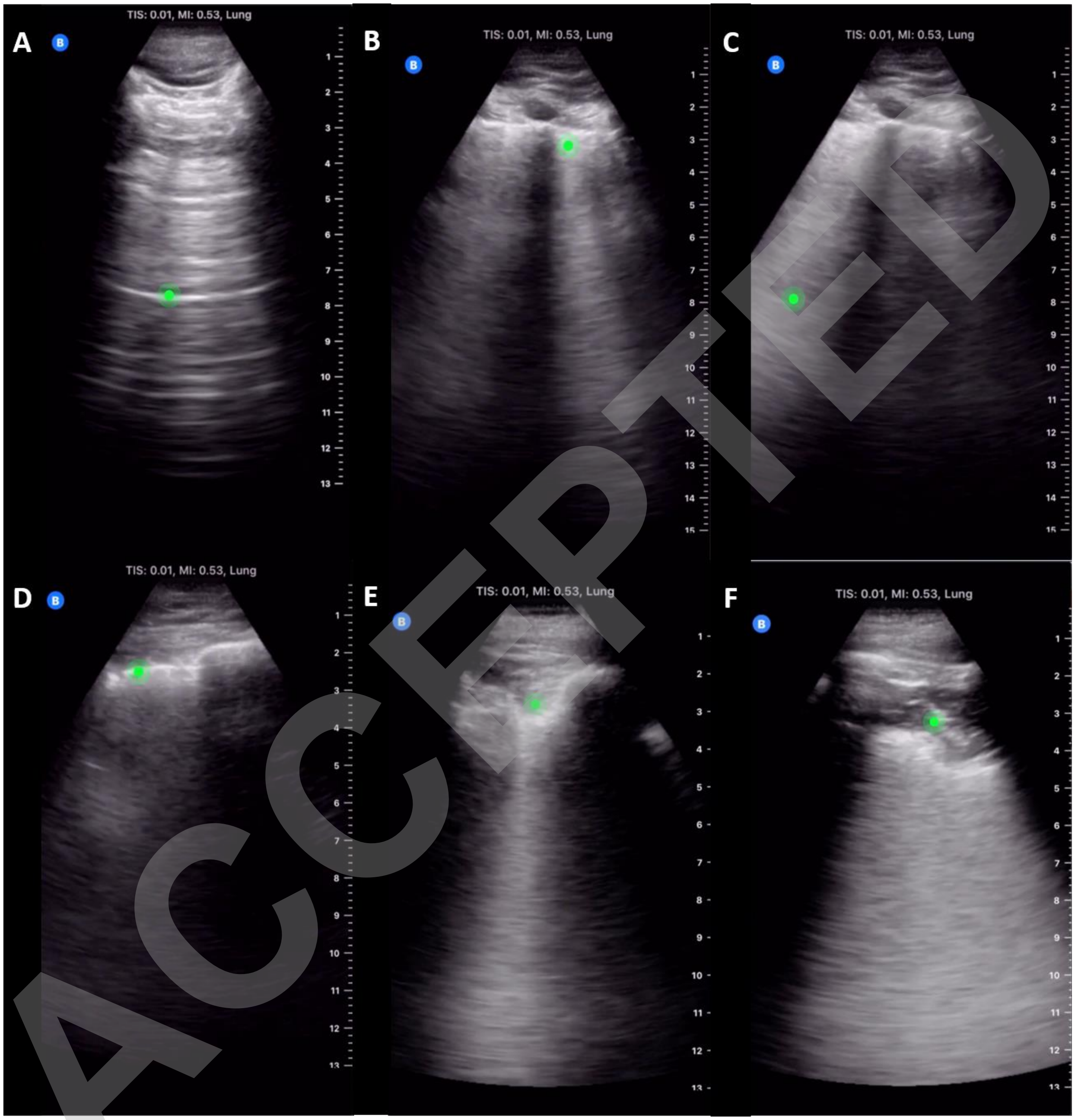
Source	Location	# of Patients	Patient Characteristics	Ultrasound Device	Ultrasound Scanning Protocol	Lung Ultrasound Findings
Huang et al. (Feb 2020)[7]	Xi'an Chest Hospital (Shaanxi, China)	20	Non-critical COVID-19 confirmed patients. Average age 27-81 years, median 45 years (3 cases > 65 years) with 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
Peng et al. (March 2020)[1]	Xiangya Hospital (Hunan, China)	20	COVID-19 confirmed patients (age, gender, 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, non-translobar and translobar with mobile air bronchograms - A lines during recovery - Pleural effusions uncommon
Buonsenso et al. (March 2020)[9]	Agostino Gemelli University Hospital (Rome, Italy)	1	Non-critical COVID-19 confirmed patient, 52-year-old man presenting after 7 days of fever and flu-like symptoms, found to have peri-hilar infiltrates on chest radiograph and lymphopenia	Unidentified portable ultrasound	12 Zone Method	- Pleural irregularities - Subpleural consolidations - Areas of thick, confluent B lines as well as spared areas
@yaletung on Twitter (March 2020)[6]	Hospital Universitario La Paz (Madrid, Spain)	1	Non-critical COVID-19 confirmed patient, 35-year-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 prior to malaise
Thomas et al. (April 2020)[8]	Victoria General Hospital (British Columbia, Canada)	1	Critical COVID-19 confirmed patient, 64-year-old healthcare worker presenting 10 days after symptom onset with fevers, hypoxemia (SaO_2 88%), and bilateral infiltrates on chest radiograph	Not identified	Not reported	- Pleural thickening - Subpleural consolidations, ("skip lesions") - Multifocal B lines

Table 1: POCUS examinations performed on COVID-19 patients

Summary of POCUS Exam Findings on COVID-19 Patients
Posterior and inferior lung field lesions[7]
Confluent and isolated B lines (Figures 1B and 1C; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97)[1,6-9]
Thickened and/or Irregular Pleural Lines (Figures 1B, 1C, and 1E; Supplemental Digital Content 2-4, Videos 2, 3, and 4, http://links.lww.com/AA/D95, http://links.lww.com/AA/D96, http://links.lww.com/AA/D97)[1,6-9]
Presence of Subpleural Consolidations (Figures 1D and 1F; Supplemental Digital Content 3 and 5, Videos 3 and 5, http://links.lww.com/AA/D96, http://links.lww.com/AA/D98)[1,6-9]
Air Bronchograms (Figure 1F; Supplemental Digital Content 5, Video 5, http://links.lww.com/AA/D98)[1,7]

Table 2: POCUS examination findings from COVID-19 patients

Figure 1


A
TIS: 0.01, MI: 0.53, Lung
B
TIS: 0.01, MI: 0.53, Lung
C
TIS: 0.01, MI: 0.53, Lung
D
TIS: 0.01, MI: 0.53, Lung
E
TIS: 0.01, MI: 0.53, Lung
F
TIS: 0.01, MI: 0.53, Lung