Journal of Cardiothoracic and Vascular Anesthesia 34 (2020) 3197−3202

Contents lists available at ScienceDirect

Journal of Cardiothoracic and Vascular Anesthesia

journal homepage: www.jcvaonline.com

Special Article

Role of Ultrasound-Guided Evaluation of Dyspnea in the Coronavirus Disease 2019 Pandemic

Sara E. Neves, MD, Huma Fatima, MD, Daniel P. Walsh, MD, Feroze Mahmood, MD, Omar Chaudhary, MD, Robina Matyal, MD[1]

Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Harvard Medical School, Boston, MA

Key Words: Ultrasound; dyspnea; coronavirus; coronavirus disease-2019; COVID-19

THE NOVEL coronavirus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has led to a global pandemic termed as "coronavirus disease 2019 (COVID-19)", causing an unprecedented pressure on healthcare systems. Clinical care for COVID-19 patients varies widely in different parts of the world, with rapid evolution in diagnostic and therapeutic management. New insights into clinical imaging techniques are being acquired rapidly to reduce infection risk and maximize resource utilization. Previously, ultrasonography was established as an effective and inexpensive alternative imaging modality for the identification and monitoring of pneumonia and acute respiratory distress syndrome (ARDS).[1,2] Additional benefits of using bedside ultrasound in COVID-19 patients include the ability to evaluate cardiac function in real time and the reduction in the number of healthcare workers exposed during clinical management (both medical examination and imaging assessment can be performed by a single physician at the bedside). The existing data on integration of ultrasound imaging in COVID-19 care pathways are scarce. Although initial reports showed predilection of this virus for the lungs, emerging reports demonstrate cardiac involvement as well.[3] Thus, it is imperative to have a basic understanding of lung and cardiac ultrasonography to differentiate between cardiac and respiratory involvement because both can present clinically as dyspnea. In this article, 3 case scenarios that highlight the clinical feasibility of using ultrasonography and a discussion on a training model implemented by the authors' team to educate the existing workforce on the principles of lung and cardiac point-of-care ultrasound in patients with COVID-19 are presented.

Case 1

A 61-year-old man, with history of chronic obstructive pulmonary disease and hypertension (HTN), was admitted with 4 days of shortness of breath and fever. On admission, he was placed on 8 L of oxygen with a respiratory rate (RR) of 25/min, blood pressure of 100/60 mmHg, and heart rate of 95/min. A nasopharyngeal swab was performed with a positive result for SARS-CoV-2 on real-time reverse transcriptase−polymerase chain reaction assay. Bedside transthoracic echocardiography (TTE) and lung ultrasound were performed to evaluate his high oxygen requirement and fragile hemodynamics. Imaging demonstrated discrete, thick B-line artifacts (hyperechoic, vertical lines that arise from the pleural line) on lung ultrasound and normal ventricular functions on TTE. Over the next few hours, the patient became increasingly hypotensive, requiring norepinephrine and vasopressin infusions to maintain mean arterial pressures >65 mmHg. The fraction of inspired oxygen requirements increased, and despite trials of high-flow nasal cannula and awake prone positioning, the patient soon required intubation and mechanical

[1]*Address reprint requests to* Robina Matyal, MD, Department of Anesthesia, Critical Care and Pain Medicine, Beth Israel Deaconess Medical Center, Harvard Medical School, 1 Deaconess Road, Boston, MA, 02215.

E-mail address: rmatyal1@bidmc.harvard.edu (R. Matyal).

https://doi.org/10.1053/j.jvca.2020.07.005

ventilator support. Serial lung ultrasonography suggested diffuse and coalesced B-lines bilaterally, with small consolidations and an irregular, thickened pleural line (Video 1). Repeat TTE revealed no pleural effusion and continued normal cardiac function. The findings supported his diagnosis of ARDS. Over the next 48 hours, the patient's lung compliance decreased, with increased peak and plateau pressures. Blood gas analysis showed a partial pressure of carbon dioxide of 40 mmHg and partial pressure of oxygen of 50 mmHg. D-dimer was increased to 30,000. Follow-up lung examination with ultrasound showed extensive B-lines and consolidations bilaterally and new development of pleural effusion. Serial TTE revealed a dilated right ventricle (RV) and severe tricuspid regurgitation (Video 2). The patient was started on heparin infusion for possible pulmonary embolism and suspicion of coagulopathy related to COVID-19. On day 4 of admission, the patient's clinical course deteriorated further, with hypoxia necessitating increased positive end-expiratory pressure (PEEP) and eventual cardiac arrest. The patient was pronounced dead after prolonged resuscitation attempts failed to achieve return of spontaneous circulation.

Case 2

A 72-year-old man, with a history of coronary artery disease, HTN, and type 2 diabetes mellitus, presented to the emergency department with shortness of breath, cough, and fever. On admission due to suspicion for COVID-19, a nasopharyngeal swab was performed, resulting in a positive result for SARS-CoV-2 on real-time reverse transcriptase−polymerase chain reaction assay. In the emergency room, he bacame increasingly hypoxic and tachypneic, with an RR of 40; the patient was intubated and transferred to the intensive care unit. For improved intravenous access, a central line was placed using ultrasound guidance in the left internal jugular vein. Three hours after line placement, the patient's blood pressure decreased to 50/20 mmHg. Point-of-care TTE showed a hyperdynamic left ventricle and RV collapse. A left lung ultrasound also was performed and revealed absence of lung sliding; absent B-line artifacts; presence of prominent A-lines (hyperechoic, equidistant, horizontal lines); and lung point, all consistent with left-sided pneumothorax (Video 3). At that time, the patient went into cardiac arrest and an electrocardiogram showed narrow complex pulseless electrical activity; advanced cardiovascular life support was initiated. Emergency needle decompression led to return of spontaneous circulation and immediate improvement of hemodynamics and hypoxia. Subsequently, a chest tube was placed for definitive management of the pneumothorax.

Case 3

A 45-year-old woman, with history of HTN and type 2 diabetes mellitus, presented with acute onset of abdominal pain and fever. Testing was positive for SARS-CoV-2 on real-time reverse transcriptase−polymerase chain reaction assay. She became hypoxic and tachypneic, with an RR of 30. Supplemental oxygen via high-flow nasal cannula and therapy with remdesivir and hydroxychloroquine were initiated per hospital protocols at that time. Lung ultrasound showed multifocal B-lines bilaterally and small consolidations, suggesting the development of pulmonary edema. After 8 hours, the patient experienced worsening hypoxia and failure to improve with awake prone positioning, resulting in intubation and mechanical ventilation. Serial lung ultrasound showed additional progression of pulmonary edema (Video 4). Lung ultrasound findings were confirmed with chest x-ray (Fig 1). Aggressive diuresis was initiated. Improvement in oxygenation and ventilator support with reduction of PEEP were observed with continued diuresis over the next few days. The patient's condition improved, and she was extubated after 10 days and subsequently discharged home.

COVID-19−Specific Characteristics and Applications of Lung Ultrasound

Although only 3 cases are described here, the authors have observed similar lung ultrasound findings in many COVID-19 patients. More than 300 COVID-19 patients have been admitted to and treated at the authors' center, and ultrasound use was dependent on provider choice. Typical characteristics seen on lung ultrasound in the authors' COVID-19 patient population with ARDS include regions with diffuse, coalescent B-line artifacts; a thickened, irregular pleural line; and small consolidations. B-line artifacts are formed by the juxtaposition of alveolar air and septal thickening, caused by fluid trapping or fibrosis, and appear as laser beam−like vertical lines arising from the pleural line (Video 5). The pleural line also is known as the visceroparietal pleural interface, found approximately 0.5 cm below the ribs, and is a bright hyperechoic line. Lung sliding occurs as the visceral and parietal pleura slide on one another during respiration, creating a shimmering appearance. The shred sign, specific for lung consolidation, occurs at a boundary between the consolidated lung and resembles a solid parenchyma and the underlying aerated lung (Fig 2). As the

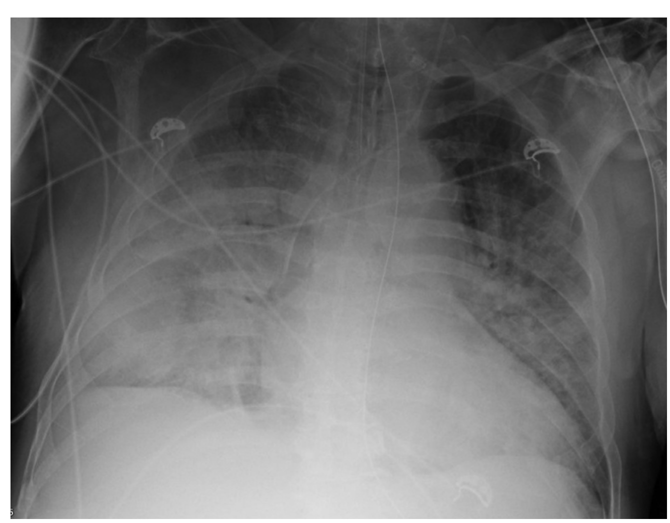

Fig 1. Chest x-ray shows diffuse pulmonary edema bilaterally as demonstrated by opacification of both lung fields in case 3.

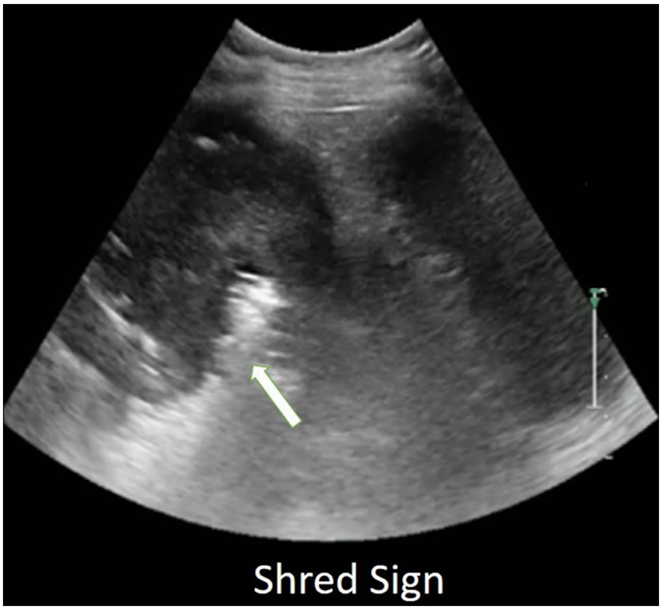

Fig 2. The shred sign *(white arrow)* is a marker of lung consolidation and occurs at a boundary between the consolidated lung, which resembles a solid parenchyma, and the underlying aerated lung.

disease progresses, B-lines increase in frequency and distribution, involving upper and anterior areas of the lungs along, with increases in the size and number of consolidations (Fig 3).[4]

Central line placements often are required in COVID-19 patients admitted to the intensive care unit for infusion of pressors and for increased intravenous access in this patient population requiring significant supportive therapy. As seen in case 2, central line placement poses a risk of iatrogenic pneumothorax. The risk of central line placement complications may be increased in this patient population due to increased personal protective equipment (PPE) requirements, high PEEP requirements, and a frequent inability to optimize positioning (severe hypoxia limiting the ability to tolerate the Trendelenburg position). It has been shown that lung ultrasound has high sensitivity for diagnosing pneumothorax.[5] The authors suggest that in addition to the use of ultrasound for central line placement, standard use of lung ultrasound immediately postprocedure to confirm the absence of pneumothorax should be incorporated. This method has the advantage of limiting additional personnel exposure to COVID-19 patients because the ultrasound equipment already will be in the room from line placement. Furthermore, the authors occasionally have observed delay in the ability to obtain chest x-ray due to high demand for radiography and an increase in the time it takes for radiology personnel to don PPE and prepare equipment to enter a COVID-19 isolation room. With this method, point-of-care lung ultrasound is available immediately.

Sonographic characteristics of pneumothorax include absence of lung sliding, prominent A-lines, absent B-lines, absent lung pulse, and presence of lung point (Fig 4). A-lines are artifacts formed by the reflection of ultrasound waves from either pleura or air. They are observed in normal lungs, certain diseases (asthma and chronic obstructive pulmonary disease), and pneumothorax (Video 6). Lung pulse is a rhythmic motion of the pleura in synchrony with cardiac rhythm. The movement of the heart cannot be detected with the presence of air between visceral and parietal pleura; therefore, as with lung sliding, the presence of lung pulse rules out pneumothorax. Lung point is defined as the junction between sliding lung and absent sliding, and its identification is 100% specific for pneumothorax (Video 7).[6]

COVID-19–Specific Characteristics and Applications of Echocardiography

Focused point-of-care cardiac ultrasound includes assessment of hemodynamic status to guide fluid replacement, ventricular functional assessment, and identification of the deterioration of preexisting structural cardiovascular pathologies. Parasternal long-axis, parasternal short-axis, apical 4-chamber, subxiphoid 4-chamber, and inferior vena cava views are recommended. Inferior vena cava diameter and its collapsibility can be used to determine volume status. Evaluation of left ventricular systolic function can rule out the presence of

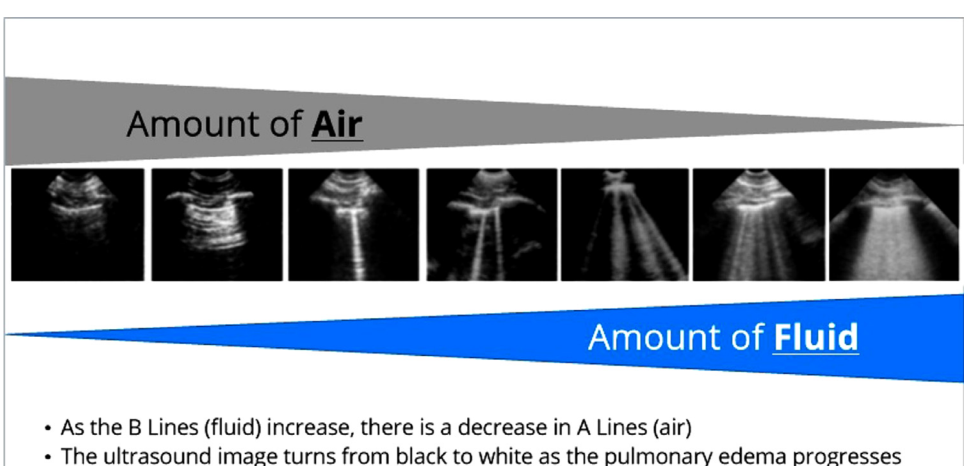

Fig 3. Lung ultrasound imaging findings with progression of pulmonary edema are denoted by a corresponding increase in B-lines and a decrease in A-lines, as shown.

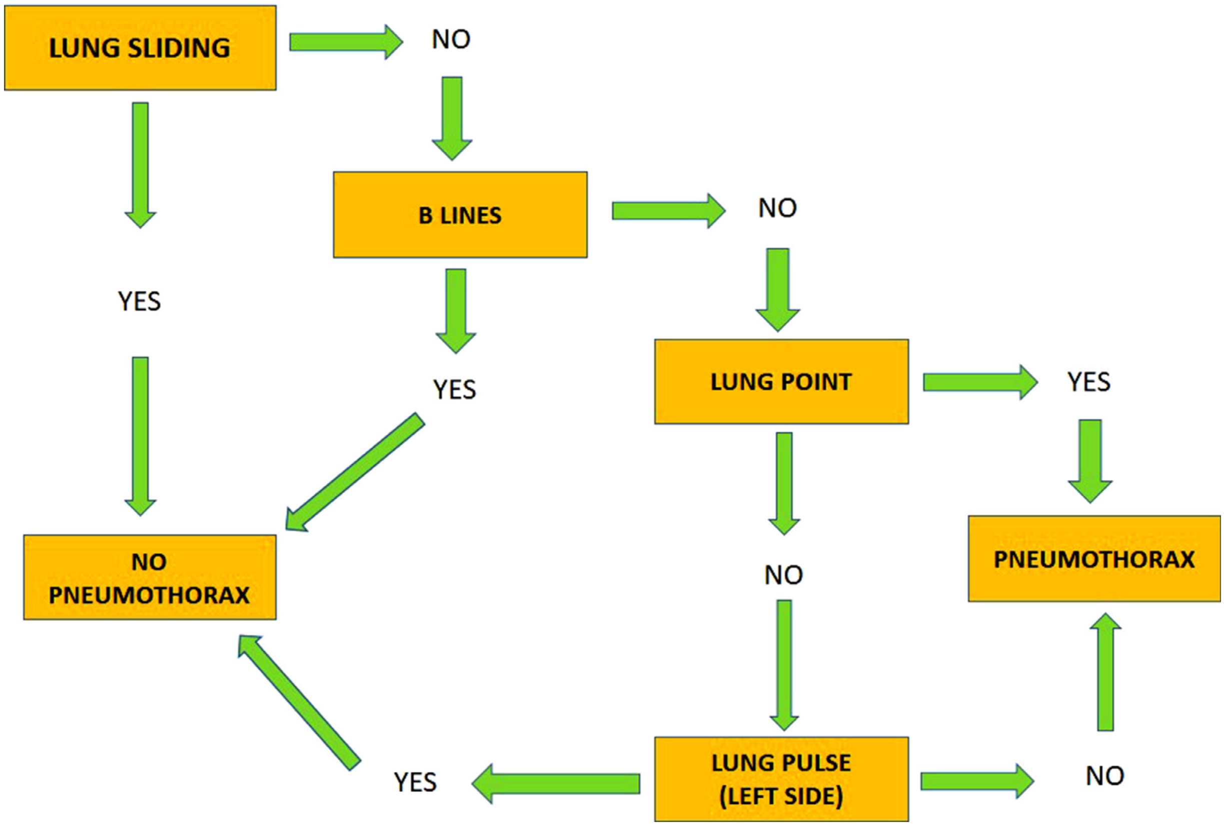

Fig 4. An algorithm for the evaluation of pneumothorax.

cardiomyopathy, myocarditis, and myocardial injury seen in patients with COVID-19.[7] In addition, evaluation of RV function can identify pulmonary HTN resulting from severe respiratory failure and provide support for suspected pulmonary embolism resulting from the prothrombotic state seen in some COVID-19 patients. Even though TTE cannot be used to diagnose pulmonary embolism, for unstable patients who are unable to be transported to obtain definitive imaging, TTE may offer some guidance for empirical management.

Identification of pulmonary HTN can be performed by estimation of systolic pulmonary artery pressure through tricuspid regurgitation jet velocity. Visualization of RV dilation and severe tricuspid regurgitation in case 1 assisted in differentiating between a right- and left-sided cause of hemodynamic deterioration and initiation of anticoagulation therapy. The pathophysiology underlying the prothrombotic risk in COVID-19 patients and the interplay between the deterioration of lung and cardiac function in these patients still are being explored.

Discussion

Current literature on the use of point-of-care cardiac and lung ultrasound and its effect on patient management, especially in COVID-19 patients, is limited to individual case reports and small studies. A recent meta-analysis and systematic review incorporated 7 studies and demonstrated the characteristic B-lines pattern as the most common abnormality.[8] A study by Huang et al. demonstrated characteristic lesions in 75% of a total of 20 COVID-19 patients on lung ultrasonography that were consistent with computed tomography (CT) findings.[9] Another study further supported the use of ultrasound as a superior modality to chest x-ray and comparable with CT in 20 COVID-19 patients.[10]

The case scenarios in the present study highlight the benefit of surface imaging techniques to evaluate lung and cardiac function and to quantify the level of involvement through serial examinations. The identification, interpretation, and quantification of sonographic characteristics facilitate monitoring of disease progression. The current modality of choice for lung evaluation is CT. The disadvantages of CT in the COVID-19 patient population include inability to move unstable patients and intubated patients with high ventilator requirements, excessive exposure of COVID-19 patients to other healthcare workers and hospital environment, requirement of extensive equipment sterilization, higher cost, and limited access in an over-capacity hospital during the pandemic. As an alternative, the authors advocate for the use of an ultrasound algorithm to guide diagnosis in symptomatic patients, followed by prognostic stratification using serial inspections to determine the evolution and extensions of specific patterns in intensive care units (Fig 5). Correlation of the clinical presentation with bedside sonographic findings can facilitate informed clinical decision-making in treatment initiation, escalation, or weaning in a patient population with novel disease. As seen in case 3, the progression of pulmonary edema identified with sonography-directed aggressive diuresis, resulting in improved lung function.

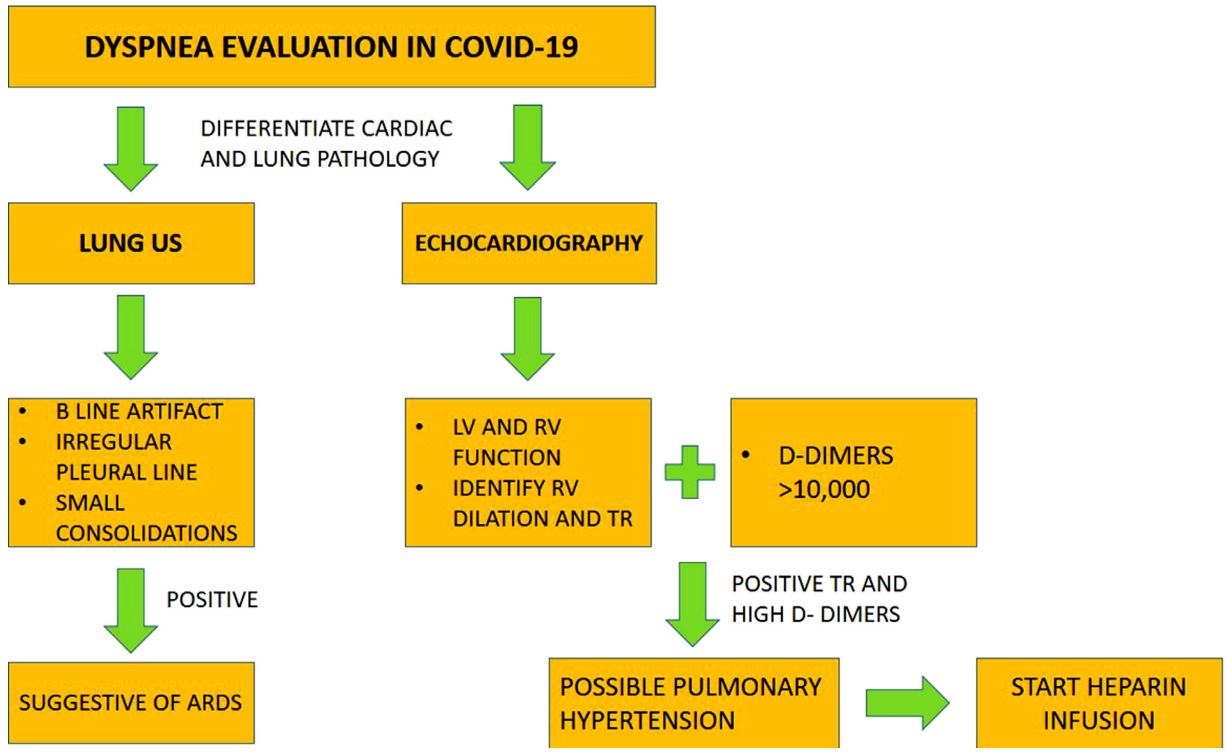

Fig 5. An algorithm for ultrasound-guided evaluation of dyspnea in coronavirus disease-2019 patients. ARDS, acute respiratory distress syndrome; COVID-19, coronavirus disease-2019; LV, left ventricle; RV, right ventricle; TR, tricuspid regurgitation; US, ultrasound.

Although most healthcare systems have several providers skilled in ultrasound imaging, an environment with increasing patient burden and limited resources necessitates efficient, effective, just-in-time training of providers previously unfamiliar with point-of-care ultrasound techniques. The authors of the present report devised an online web-based interactive teaching course on lung ultrasound and TTE. This innovative teaching tool provided educational training without the need for in-person training and use of limited PPE, enabling clinicians to uphold social distancing policy and reducing exposure.

The course was developed using the Articulate Storyline authoring tool (Articulate Global Inc, New York, NY). The modules included animations, illustrations, video clips, and in-module quizzes to engage the viewer. The target audience of this interactive course included multidisciplinary teams and individuals at multiple levels of training (midlevel providers, residents, and attending physicians) involved in the care of COVID-19 patients. The primary objectives of the course included review of basic ultrasound physics, probe handling, image optimization techniques, strategies to address suboptimal imaging, recognition of normal and pathologic imaging, illustration of specific sonographic characteristics of COVID-19 etiologies, and reporting of ultrasound imaging. The course was viewed by 250 of 350 individuals invited to participate over 2 weeks. In addition, to address contamination concerns and sterilization of ultrasound equipment, the authors suggest use of portable ultrasound devices, which have a smaller surface area; disposable plastic covers; and germicidal disposable wipes (Super Sani-Cloth disinfectant germicidal wipes) to clean the equipment and tablets after each use, per hospital protocol and guidance considerations.[11] In particular, it is necessary to wipe the probe, cable, and connector and allow the surfaces to remain wet for 2 minutes. Additional fresh wipes should be used to confirm contact time of 2 minutes, and equipment should be allowed to air dry. The authors' institution uses the Butterfly iQ handheld probe (Butterfly Network, Inc, Guilford, CT) and VScan Extend handheld ultrasound dual probe (GE Healthcare, Chicago, IL). Portability of these devices allows enhanced vigilance, saves time in equipment sterilization, and offers integrated teleguidance to allow a trained practitioner to collaborate with a novice or a junior colleague at the bedside.

Although the power of current studies on ultrasound use in COVID-19 is low, the results are promising and advocated by multiple expert groups across different countries.[4,12,13] This delineates the need to gather high-quality clinical evidence by designing large-scale studies implementing ultrasound as a real-time diagnostic and navigation tool for management. Herein, the authors offer additional evidence of the value of point-of-care ultrasound in a challenging clinical environment and propose a pragmatic method for provider training and incorporation of ultrasound into clinical management. Future study can further illustrate the effectiveness of these techniques.

Conflict of Interest: Authors report no conflicts of interest.

Video 1. Lung ultrasound window shows diffuse and coalesced B-lines; small consolidations; and irregular, thickened pleural line in case 1, depicting progression of pulmonary edema.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1053/j.jvca.2020.07.005.

References

1 Mayo PH, Copetti R, Feller-Kopman D, et al. Thoracic ultrasonography: A narrative review. Intensive Care Med 2019;45:1200–11.

2 Pagano A, Numis FG, Visone G, et al. Lung ultrasound for diagnosis of pneumonia in emergency department. Intern Emerg Med 2015;10:851–4.

3 Fried JA, Ramasubbu K, Bhatt R, et al. The variety of cardiovascular presentations of COVID-19. Circulation 2020;141:1930–6.

4 Smith MJ, Hayward SA, Innes SM, et al. Point−of−care lung ultrasound in patients with COVID−19−a narrative review. Anaesthesia 2020;75:1096–104.

5 Lichtenstein DA, Mezière G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. Crit Care Med 2005;33:1231–8.

6 Lichtenstein D, Mezière G, Biderman P, et al. The "lung point": An ultrasound sign specific to pneumothorax. Intensive Care Med 2000;26:1434–40.

7 Driggin E, Madhavan MV, Bikdeli B, et al. Cardiovascular considerations for patients, health care workers, and health systems during the COVID-19 pandemic. J Am Coll Cardiol 2020;75:2352–71.

8 Mohamed MF, Al-Shokri S, Yousaf Z, et al. Frequency of abnormalities detected by point-of-care lung ultrasound in symptomatic COVID-19 patients: Systematic review and meta-analysis [e-pub ahead of print]. Am J Trop Med Hyg 2020. https://doi.org/10.4269/ajtmh.20-0371; Accessed May 15, 2020.

9 Huang Y, Wang S, Liu Y, et al. A preliminary study on the ultrasonic manifestations of peripulmonary lesions of non-critical novel coronavirus pneumonia (COVID-19) [e-pub ahead of print]. SSRN 2020. https://doi.org/10.21203/rs.2.24369/v1; Accessed May 15, 2020.

10 Jin Y, Cai L, Cheng Z, et al. A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). Military Med Res 2020;7:4.

11 Intensive Care Society. Focused ultrasound for intensive care. Available at: https://www.ics.ac.uk/ICS/FUSIC/ICS/FUSIC/FUSIC_Accreditation.aspx?hkey=c88fa5cd-5c3f-4c2-b007-53e01a523ce8; Accessed May 15, 2020.

12 Wang E, Mei W, Shang Y, et al. Chinese Association of Anesthesiologists expert consensus on the use of perioperative ultrasound in coronavirus disease 2019 patients. J Cardiothorac Vasc Anesth 2020;34:1727–32.

13 Convissar D, Gibson LE, Berra L, et al. Application of lung ultrasound during the coronavirus disease 2019 pandemic: A narrative review. Anesth Analg 2020:345–50.