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Possible role of Chest Ultrasound for Follow up of COVID-19 Patients

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Abstract: Background: The purpose of this review paper is to discuss the diagnostic and therapeutic value of lung ultrasonography in the context of coronavirus Disease 2019 (COVID-19). Ultrasound of the lungs is a straightforward diagnostic technique that helps find patients with symptoms that could be COVID-19 early on, which in turn helps with admission decisions and treatment planning. Not only may it be done in a variety of hospital wards, emergency rooms, primary care offices, and critical care units, but it can also be done in outpatient settings with the help of portable devices. In addition to clinical and laboratory evaluation, the article explains the usual findings on a COVID-19 lung ultrasonography, which include an interstitial pattern, pleural abnormalities, and consolidations. We outline the benefits and drawbacks of using lung ultrasonography in COVID-19, as well as the necessary equipment and training for this procedure. By searching the literature for the terms "COVID-19," "lung ultrasound," and "imaging," we were able to deduce the various regions' uses of this imaging technique. Children and pregnant women can benefit greatly from lung ultrasonography since it is a noninvasive, quick, and repeatable treatment that can be done at the point of care with minimal sterilization. since it uses non-ionizing radiation, it is possible to do multiple scans on the same patient. However, in the present pandemic environment, the patient and ultrasound operator cannot be physically close, which highlights the necessity for specific procedures to avoid and control infections. A big obstacle to the use of lung ultrasonography is the availability of competent personnel who are properly trained to do the procedure. In low- and middle-income countries, in particular, local practitioners can be better equipped to employ lung ultrasonography for COVID-19 management through training, advocacy, and increased awareness.

Keywords: *Chest Ultrasound, COVID-19*

Introduction

The new coronavirus disease 2019 (COVID-19) pandemic has killed over 6.5 million people and infected over 600 million as of mid-September 2022. There has to be a quick, point-of-care diagnosis in every resource environment since an early COVID-19 diagnosis would enable early isolation and management.

As part of the diagnostic process that also involves laboratory and clinical examination, chest imaging is advised for symptomatic patients who are suspected of having COVID-19. The World Health Organization (WHO) established a sizable international expert committee to help with the creation of COVID-19 chest imaging guidelines at the outset of the pandemic in response to requests from member states [1]. While developing these guidelines, it became clear that chest radiography and chest computed tomography (CT) have a longer history of usage, better established methods, and more conclusive results in the therapy of COVID-19 than lung ultrasound. After the guidelines were published, the World Health Organization (WHO) assembled a panel of experts from different countries to discuss the use of lung ultrasonography during the COVID-19 pandemic. The panel was carefully selected to ensure geographic balance and representation from resource-setting organizations. [1].

The examination of acute or critically ill patients with a variety of respiratory diseases has seen a dramatic surge in the usage of lung ultrasonography in the past few decades. Lung ultrasonography has recently gained favor as a straightforward method that can aid in the early diagnosis of COVID-19-related symptoms, bolster the admission decision, and guide treatment planning. This function has been demonstrated in a range of clinical contexts, such as general practitioners' offices, walk-in clinics, hospital wards, and intensive care units (ICUs) [2, 3]. Health officials may be able to better allocate resources if they investigated the feasibility of doing lung ultrasounds using portable equipment in outpatient settings (such as assisted living facilities, retirement apartments, and home care).

In COVID-19, lung ultrasonography is one of several imaging modalities that are being utilized. The ionizing radiation exposure and the increased risk of virus propagation resulting from the patient's transfer to the imaging department must be considered when using chest CT for diagnostic reasons, despite the fact that it has demonstrated a high sensitivity and specificity in detecting COVID-19 [1, 4-7]. Although chest radiography is less resource intensive than chest CT, it may be done at the point of care using mobile equipment, has similar specificity, but poorer sensitivity. Nevertheless, it does expose patients and workers to ionizing radiation, although at lower doses compared to chest CT.

Lung ultrasound is a valuable tool for diagnosing and managing COVID-19 in patients. This review paper covers the typical findings of a lung ultrasound, how it is used in different regions and countries, the necessary equipment, capacity building initiatives, and training requirements, as well as the benefits and drawbacks of this diagnostic tool.

The alveoli are quickly damaged in cases of COVID-19 pneumonia, and the damage is usually bilateral and mostly located on the periphery [4, 8]. Most commonly seen in COVID-19 pneumonia on ultrasonography of the lungs are consolidations, interstitial patterns, and pleural abnormalities; these findings tend to be bilateral, patchy, and have clearly defined sparing zones [9–11]. Lung ultrasonography appears to be an ideal diagnostic tool for COVID-19 because pulmonary alterations frequently exhibit subpleural localization and abnormalities along the pleural line are detected by this modality. Figure 1 shows the typical findings of a lung ultrasonography in patients with COVID-19 pneumonia. [12].

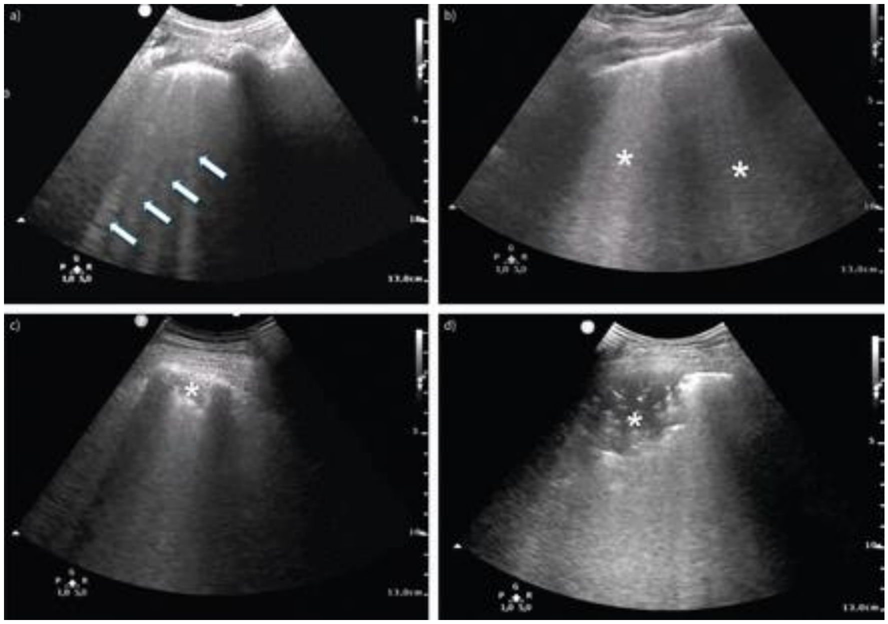


Figure 1: Typical lung ultrasound findings in patients with coronavirus disease 2019 (COVID-19) pneumonia. a) Interstitial involvement with separated B-lines (arrows) and irregular pleural line; b) confluent B-lines (asterisks); c, d) consolidations (asterisks); d) air bronchograms.

Interstitial involvement

The hallmark of interstitial syndrome on ultrasound is the presence of vertical hyperechoic artifacts, or "B-lines," that travel in unison with the patient's respiration and often begin at the pleural line and eventually reach the screen's edge [13]. In addition to a decreased aerated/non-aerated space ratio and interstitial involvement from oedema or increased collagen/fibrotic deposition, B-lines are not exclusive to COVID-19 and can be seen in a wide variety of pulmonary diseases. The distribution of B-lines, in conjunction with clinical presentation, can be used to distinguish COVID-19 pneumonia from other diseases. The most common observation in this case is bilateral, typically asymmetrical B-lines that do not have a cranial-caudal distribution gradient [10]. An abnormal pleura and interstitial lung ultrasonography pattern was observed in 92% of COVID-19 patients brought to the emergency department, with 86% of those patients exhibiting bilateral abnormalities [11].

There is minimal interstitial involvement when there are few dispersed B-lines, but the clinical picture is worse when there are more converging B-lines. Convergent hyperechoic aberrations and the indistinguishability of B-lines in severe interstitial illness are the causes of the "white lung" appearance [14, 15].

With COVID-19, a specific artefact known as "light beam" has been documented. A big, bright band-shaped B-line, emerging from a segment of the normal pleural line within the framework of the usual A-line pattern, often emerges and vanishes as the patient breathes in and out. Possible correspondence between this artefact and ground-glass opacities detected on CT in the early stages of active illness [16].

Alterations of the pleural line

Lung ultrasonography often finds changes to the pleural line in COVID-19 patients [10, 11]. As seen in acute respiratory distress syndrome (ARDS) and interstitial lung disease/pulmonary fibrosis, the pleural line might seem thicker, uneven, or fractured in affected areas. In conjunction with pleural changes, one can notice a decrease or complete absence of the typical pleural sliding. Alterations to the pleural lines and small, subcentimetric consolidations inside the pleura are both possible.

Consolidations

When the pleural line is disrupted and the air content in the lung tissue goes below 10% of normal aeration, solid lesions form. Patients with COVID-19 pneumonia typically have numerous consolidations, which tend to form in the lower posterior regions more commonly. Air bronchograms may or may not be seen [17, 18]. Lobar hepatisation, which is more common in cases of bacterial pneumonia, is rare.

Additional findings

Elastography and contrast-enhanced ultrasonography (CEUS) are two cutting-edge uses of ultrasound that have the ability to improve the diagnostic yield of ultrasound in the lungs.

To identify changes in capillary perfusion, contrast-enhanced ultrasonography (CEUS) makes use of sulfur-hexafluoride microbubbles. In COVID-19 patients, CEUS may reveal low-perfusion regions and numerous infarction locations in the periphery [19, 20].

By studying how waves travel through different types of tissues, ultrasound elastography may quantify how pliable a material is [21]. Using ultrasonic elastography, researchers in an animal model were able to demonstrate a decrease in lung surface wave speed associated with interstitial lung oedema [22].

A clearer picture of how these cutting-edge tools fit into the clinical assessment of COVID-19 pneumonia requires additional data collection.

Differential diagnosis and complications

Patients infected with COVID-19 may present with a variety of symptoms and consequences. Laboratory results, the disease's prevalence during the pandemic phases, and the patient's past medical history (including comorbidities like cardiovascular disease, lung interstitial disease, or fibrosis) must be considered and understood in conjunction with the results of the lung ultrasound in order to appropriately account for these situations [23].

Respiratory viral infections

Lung ultrasonography results are comparable in different viral pneumonias, making differential diagnosis with other viral lung infections challenging. These findings include patches of white lung, pleuropulmonary line abnormalities, solitary or confluent B lines, and small subpleural consolidations (<0.5 cm) [24, 25].

Asthma caused by bacteria

In this case, bacterial pneumonia is likely due to the existence of an isolated big lobar consolidation together with air bronchograms. Compared to traditional radiology tests, lung ultrasound during the 2009 H1N1 pandemic was able to differentiate between bacterial and viral pneumonia or coexistence of the two infections with an agreement between observers of 0.82 [26]. The reliability of lung ultrasonography for pneumonia diagnosis has been the subject of a great deal of research. Lung ultrasonography has a sensitivity and specificity of above 90% for diagnosing pneumonia, according to two meta-analyses [27, 28].

Myocardial infarction and embolism of the lungs

Excessive inflammation, diffuse intravascular coagulation, hypoxia, and immobilization are the main causes of venous and arterial thromboembolism in COVID-19 [29]. Patients with COVID-19 have an increased risk of pulmonary embolism, with reported rates ranging from 1.6% to 36% in non-ICU wards [30, 31] and from 14% to 25% in ICUs [29, 30]. Even when a patient's lungs appear normal on ultrasound, pulmonary embolism may be present if they are experiencing severe dyspnea or other symptoms of respiratory failure [32, 33]. Lung ultrasonography presents unique challenges when diagnosing pulmonary embolism in COVID-19 patients: Multiple COVID-19 inflammatory abnormalities might be difficult to differentiate from triangular or rounded pleural-based lesions, which are typically signs of pulmonary embolism [34]. Pulmonary infarcts and COVID-

19 inflammatory lesions can be differentiated with the use of CEUS [35]. Patients suspected of having pulmonary thromboembolism should always be investigated for CT pulmonary angiography as the imaging exam of choice[36, 37] due to the seriousness of the condition and the possibility of a targeted therapy.

Cardiac arrest

Rarely seen in COVID-19 pneumonia, diffuse and symmetrical B-lines distributed according to gravity are more typical of cardiogenic pulmonary edema. Compared to chest radiography and natriuretic peptides, lung ultrasonography combined with clinical evaluation greatly improved the accuracy of distinguishing acute decompensated heart failure from noncardiac causes of acute dyspnea [38]. Additionally, lung ultrasonography may aid in the diagnosis of heart failure when utilized in conjunction with a more comprehensive bedside ultrasound examination that also includes the heart, deep veins of the extremities, and inferior vena cava [39].

Lumbar puncture

Pleural effusion is a rare complication of COVID-19 and is typically caused by some underlying health issue [11, 18]. In comparison to chest radiography, ultrasound has far higher diagnostic accuracy when it comes to detecting, quantifying, and monitoring pleural effusion [40, 41]. Thoracentesis and pleural drainage are two examples of image-guided operations that can benefit from lung ultrasonography.

Chest infection

Pneumothorax that develops on its own is unusual in COVID-19 patients who are not in critical care [42]. It has a significant mortality rate and is more common in patients with early severe COVID-19 [43]. The exact cause is unclear, however it is likely associated with patients' ability to do harm to their own lungs. When a patient has a pneumothorax, an ultrasonography of the chest will show certain characteristics. These include the absence of B-lines, a lack of lung sliding, and the identification of a lung point. This point is the junction between the margin of the pneumothorax and the normal visceral/parietal pleura coupling; it is a size-determining tool that is specific to pneumothorax [44]. When compared to chest radiography, lung ultrasound performs much better in detecting pneumothorax [45]. More so than chest radiography, which has a sensitivity of 39% to 52% and a specificity of >98%, lung ultrasonography is useful for monitoring pneumothorax, particularly in severely sick patients, with reported sensitivity ranging from 78% to 90% [45-48].

Underlying emphysema

Patients with severe illness [49], pneumothorax or pneumomediastinum [50], typically as a result of invasive mechanical ventilation and barotrauma, may develop subcutaneous emphysema, but it is uncommon in COVID-19 patients. Many reverberation artifacts are evident during lung ultrasound scans because of subcutaneous gas bubbles, which makes it difficult to see deeper structures like the ribs and the lung.

Using lung ultrasonography for triage purposes

For patients with suspected or confirmed COVID-19, chest imaging should be done in addition to clinical and laboratory examination. This will help with decisions like whether to admit them to the hospital or discharge them home, and whether to admit them to the main ward or the intensive care unit [1].

Pulmonary ultrasonography results in outpatients with probable COVID-19 pneumonia are associated with illness severity and the necessity of hospitalization referral [51]. When it comes to diagnosing COVID-19 pneumonia in emergency departments, lung ultrasonography has a sensitivity of over 90% and a specificity of 20-65% [11, 52]. Thus, it appears that a negative lung ultrasound in patients with symptoms is a valid result, and further invasive, expensive, and time-consuming testing is unnecessary. Also, adult emergency department patients exhibiting signs of lower respiratory tract infection can be accurately classified as either needing ward admission or safe outpatient management using early lung ultrasonography [53]. In a similar vein, early ED lung ultrasonography has successfully distinguished between patients who have survived and those who have not. In addition, there was a correlation between the level of lung aeration loss and the clinical result [54].

The prevalence of pleural thickening, subpleural consolidations, and total lung ultrasound score increased with worsening disease in a prospective investigation of 120 adult patients with COVID-19. The results of the ultrasound were predictive of clinical deterioration and were associated with mortality [55]. Refractory hypoxaemia was associated with an increased total lung ultrasound score, pleural effusions, consolidations of the lungs, and areas with multiple coalescent B-lines in intensive care unit patients [56]. In hospitalized patients, the onset of respiratory failure was predicted by the lung ultrasonography severity score [18]. According to a recent systematic review, there is a correlation between pleural abnormalities, the presence of three or more B-lines on lung ultrasound, and an increased risk of unfavourable outcomes such as death, need for mechanical ventilation, or admission to the intensive care unit [57]. These findings are in line with this review.

Research demonstrating the usefulness of lung ultrasound—which shields pregnant patients from ionizing radiation—in a study involving COVID-19 pregnant women established the utility of this imaging modality. This study discovered that the quantification using lung ultrasound score has a strong correlation with the patient's symptoms and the illness development, allowing for the prediction of when clinical symptoms would get worse or better [58].

Diagnostic accuracy of lung ultrasound and comparison with other chest imaging modalities

Ultrasound of the lungs has not been shown to be an effective diagnostic tool for COVID-19 pneumonia. It has been shown in multiple trials that point-of-care lung ultrasonography is an incredibly sensitive diagnostic, especially when used in high prevalence areas [11, 59-61]. The integration of probability patterns of lung ultrasound with clinical findings allows to rule in or rule out COVID-19 pneumonia at the bedside, according to an international multicenter study with over 1400 patients [23]. Lung ultrasound has shown a high degree of sensitivity in the diagnosis of interstitial syndrome, which is consistent with earlier findings [14, 15]. But there's a problem with the lack of specificity.

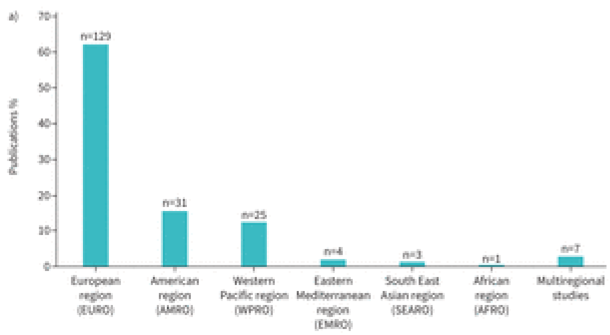
In COVID-19, there has been a dearth of research comparing the diagnostic efficacy of lung ultrasound with other imaging modalities. The diagnostic accuracy of chest CT, chest radiography, and lung ultrasound in symptomatic patients suspected of having COVID-19 was assessed in 37 studies that were systematically reviewed in April 2021. The results showed that, respectively, these tests had a pooled sensitivity of 89%, 72%, and 78%, and a specificity of 81%, 71%, and 76% [1]. The diagnostic accuracy of lung ultrasound was found to be comparable with chest CT in a multicenter prospective study. The sensitivity and specificity for lung ultrasound were 71.0%, 91.9%, and 0.81 compared to 88.4% and 82.0% for CT, respectively. This suggests that lung ultrasound can help rule out clinically relevant cases of COVID-19 pneumonia in emergency departments and diagnose COVID-19 more easily in areas with a high prevalence of the virus [59]. Lung ultrasonography also proved useful in ruling out COVID-19 symptoms in the lungs, particularly in individuals without a prior history of heart or lung disease (sensitivity and negative predictive value of 100%) [60]. Nevertheless, computed tomography (CT) performed better than lung ultrasound for COVID-19 diagnosis at hospital admission (sensitivity 90-95% and specificity 43-69% vs. 94-93% and 7-31% for lung ultrasound, respectively) [61]. To confirm these findings, additional COVID-19 prevalence investigations are needed.

It is possible that, under the hands of trained professionals, lung ultrasonography is the best imaging method for children [62]. It is important to consider the potential risks of radiation exposure to children when deciding whether or not to utilize chest radiography or chest CT for the diagnosis of COVID-19 [1]. Findings from lung ultrasounds in children are comparable to those in adults [63], with a higher frequency in moderate to severe cases [64]. Ultrasound of the lungs and computed tomography scans of the chest can reveal anomalies indicative of COVID-19 in certain infants whose chest radiographs come back normal [65, 66].

The use of lung ultrasound in COVID-19 in different regions/countries

A recent online survey by the International Society of Radiology revealed that COVID-19 imaging practices vary globally. The most commonly used imaging modalities were CT and conventional chest radiography, while intensivists and those doing bedside imaging in the intensive care unit often utilized lung ultrasound, typically with small mobile units for point-of-care ultrasound [67]. When the initial wave of the COVID-19 epidemic hit, anaesthesiologists and intensivists in Italy were already heavily using lung ultrasonography, and their usage only grew from there [68].

As of the article's creation, there was no comprehensive review of current trends in the worldwide usage of lung ultrasonography for COVID-19 therapy. Hence, we used the search terms "COVID-19," "lung ultrasound," and "imaging" to scour the PubMed and Google Scholar databases for any information we could glean about the application of this imaging technique in various parts of the world. Review articles were not considered, however case reports and series were. The requirements for the literature review were met by 200 publications published between May 2020 and November 2021.You may find information about the countries of origin and a summary of the regional distribution of these publications in Figure 2.



b)

Country	National articles (+ multinational articles)
Australia	4
Belgium	2 (+2)
Brazil	6
Canada	7 (+3)
China	19
Denmark	4
France	6 (+2)
Germany	11
Greece	1
India	1
Iran	1
Ireland	0 (+2)
Israel	3
Italy	55 (+7)
Kuwait	1
Mexico	3 (+1)
The Netherlands	0 (+2)
Pakistan	1
Peru	1
Poland	2
Russia	1
Saudi Arabia	1
Singapore	1
South Africa	1
South Korea	1
Spain	15 (+2)
Switzerland	2
Turkey	7
UK	13 (+5)
USA	14 (+5)

FIGURE 2: Geographical distribution of publications on use of lung ultrasound in coronavirus disease 2019 (COVID-19) based on the results of the literature review. a) Distribution of the publications according to the six World Health Organization regional offices for a total of 200 publications on use of lung ultrasound in COVID-19, including 187 national articles and 13 multinational papers. Data presented as “EURO” comprise papers published by one single country in Europe as well as six articles jointly published by more than one European country.

Because it does not necessitate any special setup, ultrasound is both a cheap and widely available imaging technique. It can be powered by batteries or regular electrical outlets. In addition to being sturdy, portable, and requiring little in the way of upkeep, machines are also highly mobile. Emergency and critical care settings can benefit from point-of-care ultrasonography for COVID-19 management [68], and it can also be used outside of hospitals [69]. Particularly in low- and middle-income countries (LMICs), there may be a dearth of competent personnel properly trained to do lung ultrasound and a general lack of knowledge about the numerous benefits of ultrasound technology. Local medical professionals can be better equipped to scale up the use of lung ultrasonography for COVID-19 management by training, advocacy, and raising awareness. Lung ultrasound could become more commonplace as a result of telemedicine's ability to make remote knowledge available for clinical and educational uses. In situations with limited resources, diagnostic ultrasound systems powered by artificial intelligence have the potential to reduce variability, achieve standardized picture acquisitions, enhance diagnostic accuracy, and pave the way for future clinical applications of lung ultrasound.

Equipment, capacity building and training needs

Technology needs and issues related with ultrasound equipment

Specified ultrasonic probes or equipment are not necessary for a lung ultrasonography. For transthoracic ultrasound, any commercially available portable ultrasound machine that can produce standard B-mode images will do [14, 70]. The evaluation of interstitial lung disorders can be done with a pocket-sized device that is just as effective as standard equipment [71, 72] and can drastically cut down on the time it takes to do a bedside examination [73, 74]. The evaluation of the heart, lung vascularization, and vasculature is greatly enhanced by ultrasound machines that are equipped with color Doppler, pulsed-wave Doppler, and cardiac functionality [75]. For bedside monitoring of diseases such pleural reactive inflammatory effusion or peripheral thrombus embolism in severe cases of COVID-19 infection, high-end systems including CEUS, shear-wave elastography, and image fusion could be of benefit [19, 76]. Turning off or limiting the use of advanced ultrasound modes, such as tissue harmonic imaging, compound imaging, various pre- and post-processing techniques, filters, and interpolation algorithms, can improve the visualization of B-line artefacts [77, 78].

Considerations such as patient anatomy, size, age, and the goal of the test play a crucial role in transducer selection, which in turn affects the results of a lung ultrasound [77]. We recommend transducers with a variety of forms and frequencies, such as micro-convex and low-frequency convex probes, high-resolution linear probes, and sector (phased-array) cardiac probes [70, 77]. When it comes to imaging superficial structures and abnormalities, such as pleural irregularities, pneumothorax, subpleural consolidations, and small amounts of pleural effusion, specifically in the anterior fields, or when evaluating muscles of the chest wall, such as the diaphragm or intercostals, high-frequency and high-definition linear transducers are the way to go. Their low penetration capacity and high superficial definition make them ideal for these tasks. Deep structures, including consolidations and pleural effusions, can be seen with low-frequency phased-array and convex transducers. Thick parietal wall portions, particularly in the lateral and posterior fields, can also be visualized [77-79]. The pleural surface may be seen more clearly and the probe can penetrate deeper with micro-convex (small surface) technology [14]. When comparing low-frequency and high-frequency probes, more B-lines are visible with the former [77, 78].

Essentials of lung ultrasound education

Having competent personnel who are well-versed in the ins and outs of lung ultrasonography is of the utmost importance in light of the current COVID-19 outbreak. Anaesthesiologists and intensivists in Italy were surveyed following the first wave of the COVID-19 pandemic. The results showed that while residency programs were gradually adding lung ultrasonography training, 76.7% of the participants had not gotten certified in the field [68].

No universal agreement has been reached on the minimum education or experience required to do a lung ultrasonography [80]. Further study with verified theoretical and practical assessments for evaluation is advised by a systematic review that revealed few high-quality studies for lung ultrasound training [81]. After completing ≥10 guided scans, doctors who had no prior experience with ultrasonography were able to competently and autonomously conduct lung ultrasounds, with an accuracy rate of over 95% of the time [82]. Trainees without experience in this process could become competent after 25 guided lung ultrasonography examinations, according to another study [83]. Clinicians can gain good competency and accurate identification of lung patterns with only a brief formal training in lung ultrasonography [9, 10, 84–89].

Lung ultrasound scoring system standardization

Lung ultrasonography may seem easy at first glance due to the short learning curve and small number of ultrasonographic patterns; nonetheless, a systematic approach is required for examination to yield the most trustworthy results [13, 90]. Lung ultrasonography relies heavily on the operator, which is a well-known drawback [91, 92]. To reduce the possibility of mistakes in the diagnosis of lung disease, it has been proposed that ultrasonography abnormalities be defined and labelled clearly [13].

If we want most doctors to be able to spot lung ultrasound symptoms and keep inter-examiner variability to a minimum, we require a standardized ultrasonographic method [93]. Selecting the probe and imaging settings is the first step in the examination. The next step is to partition the chest surface so that all parts of the lungs are covered.

Artefacts from air, lung parenchyma, the chest wall, and the pleura make up the bulk of lung ultrasound findings [13, 94]. To avoid these artefacts, it is crucial to use a single-focal point modality, focus at the level of the pleural line, and set the depth to 6-7 cm from the pleural line. To keep the echoic image consistent over the entire screen, including the bottom edge, the gain should be adjusted. Make sure to avoid using any cosmetic filters or specialized modalities like harmonic imaging, contrast, or compounding, and aim for the greatest possible frame rate [95].

It has been proposed that patients with COVID-19 undergo a standardized approach to lung ultrasonography examinations [96]. The recommended examination sequence for patients who can sit for long periods of time includes 14 assessments total, with three posterior, two lateral, and two anterior assessments for each hemithorax. When a patient is unable to remain in a sitting position, a 12-zone acquisition protocol is typically used, which is less complicated. Before accurately identifying the pleura within the intercostal region, a longitudinal scan should be conducted, visualizing the so-called "bat sign" throughout. The usefulness of a score based on extension of artifacts per scan may be limited because the length of the visualised pleura varies greatly among individuals and even within the same patient across different intercostal gaps [97]. Therefore, when doing a lung ultrasound with the express purpose of quantifying lung aeration, a transversal scan is the way to go because it provides a much larger window and a more consistent pleural length.

Various lung ultrasonography grading systems have evolved from attempts to quantify aeration loss. The gold standard uses an ultrasonographic pattern to demarcate the four stages of aeration loss [98–101]. This regional lung ultrasound score is highly linked with quantitative computed tomography-assessed tissue density, and it has demonstrated good diagnostic accuracy in ARDS patients compared to chest CT [102, 103]. Lung ultrasonography typically employs a 12-zone technique, where each region of the lungs is evaluated for aeration loss and given a score between 0 and 3. The only areas that cannot be examined using lung ultrasonography are the dorsal segments of the upper lobes of the lungs, which are situated behind the scapula [104]. The worst ultrasound pattern seen in each area is used to allocate points. The total of all the regions is then used to determine a score for the lungs, which can be anywhere from 0 to 36; a lower number indicates less aeration. It is possible to track this score over time and use it to evaluate the efficacy of the treatments since it provides a comprehensive view of lung aeration. Standardized reporting of the examination and the acquisition of representative images (possibly saved as video clips) are also necessary for serial comparisons and monitoring. Each scan can be assigned a percentage of the existence of pathological symptoms (0-30-50-70-100%), which helps to better quantify the extent of the disease. Pathological findings such as separated and coalescent B-lines, light beams, and consolidations define a diseased area. To obtain a percentage of the whole examination, add the percentages of diseased lung in each area and divide by the total number of scans. By using this method, the percentage of diseased lung may be more accurately calculated and the extent of lesions can be monitored over time [105].

Infection prevention and control measures when performing lung ultrasound

Regarding infection prevention and control (IPC), there are unique difficulties in doing lung ultrasounds on patients who have confirmed or suspected COVID-19. Unlike chest radiography and CT, this treatment requires close physical contact with the patient throughout. When doing a lung ultrasound, the sonographer and patient may be as close as 30–50 cm apart, and the patient may be instructed to breathe deeply in and out while holding their breath. Depending on the patient and the specialist's expertise, a lung ultrasound evaluation for COVID-19 patients can take anywhere from five to ten minutes [106]. To avoid the transmission of COVID-19 and guarantee the safety of patients and healthcare workers, it is essential that IPC precautions be effectively implemented during lung ultrasonography procedures [107]. Competence in IPC, including PPE use, equipment cleaning protocols, and accessory and equipment administration and maintenance, should be a goal of training. All individuals involved in the practice of ultrasound, including both practitioners and patients, should adhere to standard procedures for personal protection equipment and hand cleanliness [107, 108]. Cleaning and disinfecting probes used on essential aseptic fields or contaminated through contact with blood, mucosal membranes, or bodily fluids during usage must continue to be normal clinical practices for ultrasound practitioners [107-109]. Use a low- or intermediate-level instrument-grade disinfectant to wipe out any exposed parts of the ultrasound machine or probe. The usage of handheld touch screens and individual sachets of gel is also strongly advised [110].

In the context of the COVID-19 pandemic, lung ultrasound has many potential uses, such as determining which patients should be admitted to the hospital, which patients should be sent to the intensive care unit for more severe lung involvement, and which patients can have their COVID-19 pneumonia symptoms tracked. Patients with thoracic problems (such as pneumothorax, heart failure, pleural effusion, or progressive pulmonary involvement) who need to be transferred to a higher level of medical care can be identified and therapeutic management can be informed by point-of-care ultrasound. More sophisticated uses of ultrasound in the lung, like computed tomography (CEUS) and elastography, can reveal details about the perfusion of the periphery of the lung, the extent of infarction, and the amount of interstitial edema in the lungs.

Lab results, the disease's prevalence during the pandemic phases, the patient's medical history (including comorbidities like cardiovascular disease, lung interstitial disease, or fibrosis), and the results of a lung ultrasound are all necessary for evaluating and interpreting the results of a COVID-19 pneumonia diagnosis.

Performing a lung ultrasound at the bedside, without moving unstable patients, is a noninvasive, quick, and repeatable procedure that requires simple sterilisation. The patient is typically monitored clinically by a physician, who can then interpret the imaging features of the lung ultrasound in addition to other important clinical and laboratory findings. An important consideration for allocating resources wisely is the feasibility of doing lung ultrasonography in outpatient settings. Because it does not expose patients to ionizing radiation, lung ultrasonography is a safe imaging modality for diagnosing and monitoring COVID-19 in pregnant women and children. It can also be performed on the same patient multiple times.

Due to a lack of standardized training programs and the necessity for qualified personnel, lung ultrasonography has not been widely used. When deciding to launch a lung ultrasound service, it is important to take into account the patient's and operator's physical proximity, as well as the necessity to take specific measures to prevent and control infections, particularly in light of the present pandemic situation. In the end, it's well-known that lung ultrasound can reliably diagnose respiratory failure and is at least as sensitive and specific as traditional chest radiography. However, compared to lung CT scans, inter-rater agreement is lower for ultrasound, and the sensitivity and specificity aren't as good.

Healthcare providers, especially those working in low- and middle-income countries (LMICs), can benefit from organized, standardized training in the various lung ultrasonography applications in the context of the COVID-

19 pandemic. There needs to be a worldwide effort to address the growing concern of multi-organ symptoms following a COVID-19 acute infection. These symptoms can range from coughing and shortness of breath to exhaustion, headaches, palpitations, chest and joint pain, physical limitations, depression, and insomnia. For diagnostic evaluation of lung involvement in those individuals and for monitoring of short- and long-term pulmonary alterations, lung ultrasound—which is portable, inexpensive, and relatively easy of access—may be the appropriate imaging method. Artificial intelligence (AI) has the ability to enhance computer-assisted processing of lung ultrasound pictures, which could be particularly useful in areas with limited human resources. The potential use of lung ultrasonography in the treatment of COVID-19 may be illuminated by more studies that investigate those questions.

References

1. ↵World Health Organization. Use of Chest Imaging in COVID-19. 2020. www.who.int/publications/i/item/use-of-chest-imaging-in-covid-19 Date last updated: 11 June 2020. Date last accessed: 1 February 2022.Google Scholar
2. ↵Shokoohi H, Duggan NM, García-de-Casasola Sánchez G, et al. Lung ultrasound monitoring in patients with COVID-19 on home isolation. Am J Emerg Med 2020; 38: 2759.e5–2759.e8. doi:10.1016/j.ajem.2020.05.079Google Scholar
3. ↵Shaw JA, Louw EH, Koegelenberg CFN. Lung ultrasound in COVID-19: not novel, but necessary. Respiration 2020; 99: 545–547. doi: 10.1159/000509763PubMedGoogle Scholar
4. ↵Chung M, Bernheim A, Mei X, et al. CT imaging features of 2019 novel coronavirus (2019-nCoV). Radiology 2020; 295: 202–207. doi: 10.1148/radiol.2020200230CrossRefPubMedGoogle Scholar
5. Ai T, Yang Z, Hou H, et al. Correlation of chest CT and RT-PCR testing for coronavirus disease 2019 (COVID-19) in China: a report of 1014 cases. Radiology 2020; 296: E32–E40. doi: 10.1148/radiol.2020200642CrossRefPubMedGoogle Scholar
6. Li J, Lin Z, Xiong N. Effective chest CT-based diagnosis for coronavirus disease (COVID-19). AJR Am J Roentgenol 2020; 215: W37–W38. doi: 10.2214/AJR.20.23548Google Scholar
7. ↵Borakati A, Perera A, Johnson J, et al. Diagnostic accuracy of X-ray versus CT in COVID-19: a propensity-matched database study. BMJ Open 2020; 10: e042946. doi:10.1136/bmjopen-2020-042946Abstract/FREE Full TextGoogle Scholar
8. ↵Shi H, Han X, Jiang N, et al. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: a descriptive study. Lancet Infect Dis 2020; 20: 425–434. doi:10.1016/S1473-3099(20)30086-4CrossRefPubMedGoogle Scholar
9. ↵Peng QY, Wang XT, Zhang LN, et al. Findings of lung ultrasonography of novel corona virus pneumonia during the 2019–2020 epidemic. Intensive Care Med 2020; 46: 849–850. doi:10.1007/s00134-020-05996-6PubMedGoogle Scholar
10. ↵Mohamed MFH, 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. Am J Trop Med Hyg 2020; 103: 815–821. doi:19.4269/ajtmh.20-0371CrossRefPubMedGoogle Scholar

11. ↵Sorlini C, Femia M, Nattino G, et al. The role of lung ultrasound as a frontline diagnostic tool in the era of COVID-19 outbreak. Intern Emerg Med 2021; 16: 749–756. doi:10.1007/s11739-020-02524-8PubMedGoogle Scholar
12. ↵Cho YJ, Song KH, Lee Y, et al. Lung ultrasound for early diagnosis and severity assessment of pneumonia in patients with coronavirus disease 2019. Korean J Intern Med 2020; 35: 771–781. doi:10.3904/kjim.2020.180Google Scholar
13. ↵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. doi:10.1007/s00134-012-2513-4CrossRefPubMedGoogle Scholar
14. ↵Lichtenstein D, Mézière G, Biderman P, et al. The comet-tail artefact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 1997; 156: 1640–1646. doi:10.1164/ajrccm.156.5.96-07096CrossRefPubMedGoogle Scholar
15. ↵Laursen CB, Clive A, Hallifax R, et al. European Respiratory Society statement on thoracic ultrasound. Eur Respir J 2021; 57: 2001519. doi:10.1183/13993003.01519-2020Abstract/FREE Full TextGoogle Scholar
16. ↵Millington SJ, Koenig S, Mayo P, et al. Lung ultrasound for patients with coronavirus disease 2019 pulmonary disease. Chest 2021; 159: 205–211. doi:10.1016/j.chest.2020.08.2054PubMedGoogle Scholar
17. ↵Xing C, Li Q, Du H, et al. Lung ultrasound findings in patients with COVID-19 pneumonia. Crit Care 2020; 24: 174. doi:10.1186s13054-020-02876-9PubMedGoogle Scholar
18. ↵Casella F, Barchiesi M, Leidi F, et al. Lung ultrasonography: a prognostic tool in non-ICU hospitalized patients with COVID-19 pneumonia. Eur J Intern Med 2021; 85: 34–40. doi:10.1016/j.ejim.2020.12.012Google Scholar
19. ↵Jung EM, Stroszczynski C, Jung F. Contrast enhanced ultrasound (CEUS) to assess pleural pulmonal changes in severe COVID-19 infection: first results. Clin Hemorheol Microcirc 2020; 75: 19–26. doi: 10.3233/CH-209005Google Scholar
20. ↵Yusuf GT, Wong A, Rao D, et al. The use of contrast-enhanced ultrasound in COVID-19 lung imaging. J Ultrasound 2022; 25: 319–323. doi: 10.1007/s40477-020-00517-zGoogle Scholar
21. ↵Zhou B, Yang X, Zhang X, et al. Ultrasound elastography for lung disease assessment. IEEE Trans Ultrason Ferroelectr Freq Control 2020; 67: 2249–2257. doi:10.1109/TUFFC.2020.3026536Google Scholar
22. ↵Zhang X, Zhou B, Osborn T, et al. Lung ultrasound surface wave elastography for assessing interstitial lung disease. IEEE Trans Biomed Eng 2019; 66: 1346–1352. doi: 10.1109/TBME.2018.2872907Google Scholar
23. ↵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. doi: 10.1007/s00134-021-06373-7PubMedGoogle Scholar
24. ↵Rossetti E, Bianchi R, Di Nardo M. Lung ultrasound assessment of influenza A(H1N1)-associated ARDS in a child with acute lymphoblastic leukemia outbreak undergoing extracorporeal membrane oxygenation. Paediatr Anaesth 2015; 25: 1301–1302. doi:10.1111/pan.12795Google Scholar
25. ↵Yousef N, De Luca D. The role of lung ultrasound in viral lower respiratory tract infections. Am J Perinatol 2018; 35: 527–529. doi:10.1055/s-0038-1637758PubMedGoogle Scholar
26. ↵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: 16. doi:10.1186/2036-7902-4-16PubMedGoogle Scholar

27. ↵Ye X, Xiao H, Chen B, et al. Accuracy of lung ultrasonography versus chest radiography for the diagnosis of adult community-acquired pneumonia: review of the literature and meta-analysis. PLoS One 2015; 10: e0130066. doi: 10.1371/journal.pone.0130066CrossRefPubMedGoogle Scholar
28. ↵Orso D, Guglielmo N, Copetti R. Lung ultrasound in diagnosing pneumonia in the emergency department: a systematic review and meta-analysis. Eur J Emerg Med 2018; 25: 312–321. doi:10.1097/MEJ.0000000000000517PubMedGoogle Scholar
29. ↵Klok FA, Kruip MJHA, van der Meer NJM, et al. Incidence of thrombotic complications in critically ill ICU patients with COVID-19. Thromb Res 2020; 191: 145–147. doi: 10.1016/j.thromres.2020.04.013CrossRefPubMedGoogle Scholar
30. ↵Lodigiani C, Iapichino G, Carenzo L, et al. Venous and arterial thromboembolic complications in COVID-19 patients admitted to an academic hospital in Milan, Italy. Thromb Res 2020; 191: 9–14. doi: 10.1016/j.thromres.2020.04.024CrossRefPubMedGoogle Scholar
31. ↵Middeldorp S, Coppens M, van Haaps TF, et al. Incidence of venous thromboembolism in hospitalized patients with COVID-19. J Thromb Haemost 2020; 18: 1995–2002. doi:10.1111/jth.14888CrossRefPubMedGoogle Scholar
32. ↵Boonyawat K, Chantrathammachart P, Numthavaj P. Incidence of thromboembolism in patients with COVID-19: a systematic review and meta-analysis. Thromb J 2020; 18: 34. doi:10.1186/s12959-020-00248-5Google Scholar
33. ↵Suh YJ, Hong H, Ohana M. Pulmonary embolism and deep vein thrombosis in COVID-19: a systematic review and meta-analysis. Radiology 2021; 298: E70–E80. doi:10.1148/radiol.2020203557CrossRefPubMedGoogle Scholar
34. ↵Mathis G, Blank W, Reissig A, et al. Thoracic ultrasound for diagnosing pulmonary embolism: a prospective multicenter study of 352 patients. Chest 2005; 128: 1531–1538. doi:10.1378/chest.128.3.1531CrossRefPubMedGoogle Scholar
35. ↵Bartelt S, Trenker C, Görg C, et al. Contrast-enhanced ultrasound of embolic consolidations in patients with pulmonary embolism: a pilot study. J Clin Ultrasound 2016; 44: 129–135. doi:10.1002/jcu.22313Google Scholar
36. ↵Revel MP, Parkar AP, Prosch H, et al. COVID-19 patients and the radiology department – advice from the European Society of Radiology (ESR) and the European Society of Thoracic Imaging (ESTI). Eur Radiol 2020; 30: 4903–4909. doi: 10.1007/s00330-020-06865-yPubMedGoogle Scholar
37. ↵Rubin GD, Ryerson CJ, Haramati LB, et al. The role of chest imaging in patient management during the COVID-19 pandemic: a multinational consensus statement from the Fleischner Society. Chest 2020; 158: 106–116. doi: 10.1016/j.chest.2020.04.003CrossRefPubMedGoogle Scholar
38. ↵Pivetta E, Goffi A, Lupia E, et al. Lung ultrasound-implemented diagnosis of acute decompensated heart failure in the ED: a SIMEU multicenter study. Chest 2015; 148: 202–210. doi:10.1378/chest.14-2608CrossRefPubMedGoogle Scholar
39. ↵Nazerian P, Vanni S, Volpicelli G, et al. Accuracy of point-of-care multiorgan ultrasonography for the diagnosis of pulmonary embolism. Chest 2014; 145: 950–957. doi:10.1378/chest.13-1087CrossRefPubMedGoogle Scholar
40. ↵Vollmer I, Gayete A. Chest ultrasonography. Arch Bronconeumol 2010; 46: 27–34. doi:10.1016/j.arbres.2008.12.004CrossRefPubMedGoogle Scholar
41. ↵Kocijancic I, Vidmar K, Ivanovi-Herceg Z. Chest sonography versus lateral decubitus radiography in the diagnosis of small pleural effusions. J Clin Ultrasound 2003; 31: 69–74. doi:10.1002/jcu.10141CrossRefPubMedGoogle Scholar

42. ↵Miró O, Llorens P, Jiménez S, et al. Frequency, risk factors, clinical characteristics and outcomes of spontaneous pneumothorax in patients with coronavirus disease 2019: a case-control, emergency medicine-based multicenter study. Chest. 2021; 159: 1241–1255. doi:10.1016/j.chest.2020.11.013PubMedGoogle Scholar
43. ↵Wang XH, Duan J, Han X, et al. High incidence and mortality of pneumothorax in critically ill patients with COVID-19. Heart Lung 2021; 50: 37–43. doi: 10.1016/j.hrtlng.2020.10.002PubMedGoogle Scholar
44. ↵Laursen CB, Sloth E, Lassen AT, et al. Point-of-care ultrasonography in patients admitted with respiratory symptoms: a single-blind, randomised controlled trial. Lancet Respir Med 2014; 2: 638–646. doi:10.1016/S2213-2600(14)70135-3PubMedGoogle Scholar
45. ↵Alrajhi K, Woo MY, Vaillancourt C. Test characteristics of ultrasonography for the detection of pneumothorax: a systematic review and meta-analysis. Chest 2012; 141: 703–708. doi:10.1378/chest.11-0131CrossRefPubMedGoogle Scholar
46. Alrajab S, Youssef AM, Akkus NI, et al. Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. Crit Care 2013; 17: R208. doi:10.1186/cc13016CrossRefPubMedGoogle Scholar
47. Ding W, Shen Y, Yang J, et al. Diagnosis of pneumothorax by radiography and ultrasonography: a meta-analysis. Chest 2011; 140: 859–866. doi:10.1378/chest.10-2946CrossRefPubMedGoogle Scholar
48. ↵Vetrugno L, Mojoli F, Cortegiani A, et al. Italian Society of Anesthesia, Analgesia, Resuscitation, and Intensive Care expert consensus statement on the use of lung ultrasound in critically ill patients with coronavirus disease 2019 (ITACO). J Anesth Analg Crit Care 2021; 1: 16. doi:10.1186/s44158-021-00015-6Google Scholar
49. ↵Xiang C, Huang L, Xia L. Mobile chest X-ray manifestations of 54 deceased patients with coronavirus disease 2019: retrospective study. Medicine 2020; 99: e23167. doi:10.1097/MD.0000000000023167Google Scholar
50. ↵Manna S, Maron SZ, Cedillo MA, et al. Spontaneous subcutaneous emphysema and pneumomediastinum in non-intubated patients with COVID-19. Clin Imaging 2020; 67: 207–213. doi:10.1016/j.clinimag.2020.08.013PubMedGoogle Scholar
51. ↵Calvo-Cebrián A, Alonso-Roca R, Rodriguez-Contreras FJ, et al. Usefulness of lung ultrasound examinations performed by primary care physicians in patients with suspected COVID-19. J Ultrasound Med 2021; 40: 741–750. doi:10.1002/jum.15444CrossRefPubMedGoogle Scholar
52. ↵Narinx N, Smismans A, Symons R, et al. Feasibility of using point-of-care lung ultrasound for early triage of COVID-19 patients in the emergency room. Emerg Radiol 2020; 27: 663–670. doi: 10.1007/s10140-020-01849-3Google Scholar
53. ↵Brahier T, Meuwly JY, Pantet O, et al. Lung ultrasonography for risk stratification in patients with COVID-19: a prospective observational cohort study. Clin Infect Dis 2021; 73: e4189–e4196. doi: 10.1093/cid/ciaa1408Google Scholar
54. ↵Bonadia N, Carnicelli A, Piano A, et al. Lung ultrasound findings are associated with mortality and need for intensive care admission in COVID-19 patients evaluated in the emergency department. Ultrasound Med Biol 2020; 46: 2927–2937. doi: 10.1016/j.ultrasmedbio.2020.07.005PubMedGoogle Scholar
55. ↵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. doi: 10.1007/s00134-020-06212-1PubMedGoogle Scholar

56. ↵Zhao L, Yu K, Zhao Q, et al. Lung ultrasound score in evaluating the severity of coronavirus disease 2019 (COVID-19) pneumonia. Ultrasound Med Biol 2020; 46: 2938–2944. doi: 10.1016/j.ultrasmedbio.2020.07.024Google Scholar
57. ↵Gil-Rodríguez J, Pérez de Rojas J, Aranda-Laserna P, et al. Ultrasound findings of lung ultrasonography in COVID-19: a systematic review. Eur J Radiol 2022; 148: 110156. doi: 10.1016/j.ejrad.2022.110156Google Scholar
58. ↵Vetrugno L, Sala A, Orso D, et al. Lung ultrasound signs and their correlation with clinical symptoms in COVID-19 pregnant women: the 'PINK-CO' observational study. Front Med 2022; 8: 768261. doi: 10.3389/fmed.2021.768261Google Scholar
59. ↵Lieveld AWE, Kok B, Schuit FH, et al. Diagnosing COVID-19 pneumonia in a pandemic setting: Lung Ultrasound versus CT (LUVCT) – a multicentre, prospective, observational study. ERJ Open Res 2020; 6: 00539-2020. doi: 10.1183/23120541.00539-2020Abstract/FREE Full TextGoogle Scholar
60. ↵Haak SL, Renken IJ, Jager LC, et al. Diagnostic accuracy of point-of-care lung ultrasound in COVID-19. Emerg Med J 2021; 38: 94–99. doi: 10.1136/emermed-2020-210125Abstract/FREE Full TextGoogle Scholar
61. ↵Colombi D, Petrini M, Maffi G, et al. Comparison of admission chest computed tomography and lung ultrasound performance for diagnosis of COVID-19 pneumonia in populations with different disease prevalence. Eur J Radiol 2020; 133: 109344. doi:10.1016/j.ejrad.2020.109344CrossRefPubMedGoogle Scholar
62. ↵de Rose C, Inchingolo R, Smargiassi A, et al. How to perform pediatric lung ultrasound examinations in the time of COVID-19. J Ultrasound Med 2020; 39: 2081–2082. doi:10.1002/jum.15306Google Scholar
63. ↵Musolino A, Supino M, Buonsenso D, et al. Lung ultrasound in children with COVID-19: preliminary findings. Ultrasound Med Biol 2020; 46: 2094–2098. doi:10.1016/j.ultrasmedbio.2020.04.026Google Scholar
64. ↵Guitart C, Suárez R, Girona M, et al. Lung ultrasound findings in pediatric patients with COVID-19. Eur J Pediatr 2021; 180: 1117–1123. doi: 10.1007/s00431-020-03839-6Google Scholar
65. ↵Hizal M, Aykac K, Yayla BCC, et al. Diagnostic value of lung ultrasonography in children with COVID-19. Pediatric Pulmonol 2021; 56: 1018–1025. doi: 10.1002/ppul.25127Google Scholar
66. ↵Giorno EPC, de Paulis M, Sameshima YT, et al. Point-of-care lung ultrasound imaging in pediatric COVID-19. Ultrasound J 2020; 12: 50. doi:10.1186/s13089-020-00198-zGoogle Scholar
67. ↵Blažić I, Brkljačić B, Frija G. The use of imaging in COVID-19 – results of a global survey by the International Society of Radiology. Eur Radiol 2021; 31: 1185–1193. doi: 10.1007/s00330-020-07252-3Google Scholar
68. ↵Vetrugno L, Mojoli F, Boero E, et al. Level of diffusion and training of lung ultrasound during the COVID-19 pandemic – a national online Italian survey (ITALUS) from the lung ultrasound working group of the Italian Society of Anesthesia, Analgesia, Resuscitation, and Intensive Care (SIAARTI). Ultraschall Med 2022; 43: 464–472. doi: 10.1055/a-1634-4710Google Scholar
69. ↵Tran TT, Hlaing M, Krause M. Point-of-care ultrasound: applications in low- and middle-income countries. Curr Anesthesiol Rep 2021; 11: 69–75. doi:10.1007/s40140-020-00429-yGoogle Scholar
70. ↵World Health Organization. Technical specifications for imaging equipment. In: Priority Medical Devices List for the COVID-19 Response and Associated Technical Specifications: Interim Guidance. pp. 139–161. 2020. www.who.int/publications/i/item/WHO-2019-nCoV-MedDev-TS-O2T.V2 Date last updated: 19 November 2020. Date last accessed: 1 February 2022.Google Scholar

71. ↵Cogliati C, Antivalle M, Torzillo D, et al. Standard and pocket-size lung ultrasound devices can detect interstitial lung disease in rheumatoid arthritis patients. Rheumatology 2014; 53: 1497–1503. doi:10.1093/rheumatology/keu033CrossRefPubMedGoogle Scholar
72. ↵Güney T, Gürsel G, Özdemir U, et al. Are pocket sized ultrasound devices sufficient in the evaluation of lung ultrasound patterns and aeration scoring in pulmonary ICU patients? J Clin Monit Comput 2021; 35: 1491–1499. doi:10.1007/s10877-020-00617-5Google Scholar
73. ↵Qian F, Zhou X, Zhou J, et al. A valuable and affordable handheld ultrasound in combating COVID-19. Crit Care 2020; 24: 334. doi:10.1186/s13054-020-03064-5Google Scholar
74. ↵European Society of Radiology (ESR). ESR statement on portable ultrasound devices. Insights Imaging 2019; 10: 89. doi:10.1186/s13244-019-0775-xGoogle Scholar
75. ↵Huang Y, Wang S, Liu Y, et al. A preliminary study on the ultrasonic manifestations of peri-pulmonary lesions of non-critical novel coronavirus pneumonia (COVID-19). Research Square 2020; preprint [https://doi.org/10.21203/rs.2.24369/v1]. doi:10.21203/rs.2.24369/v1Google Scholar
76. ↵Tee A, Wong A, Yusuf GT, et al. Contrast-enhanced ultrasound (CEUS) of the lung reveals multiple areas of microthrombi in a COVID-19 patient. Intensive Care Med 2020; 46: 1660–1662. doi: 10.1007/s00134-020-06085-4Google Scholar
77. ↵Dietrich CF, Mathis G, Blaivas M, et al. Lung B-line artefacts and their use. J Thorac Dis 2016; 8: 1356–1365. doi:10.21037/jtd.2016.04.55CrossRefPubMedGoogle Scholar
78. ↵Sperandeo M, Varriale A, Sperandeo G, et al. Assessment of ultrasound acoustic artefacts in patients with acute dyspnea: a multicenter study. Acta Radiol 2012; 53: 885–892. doi:10.1258/ar.2012.120340CrossRefPubMedGoogle Scholar
79. ↵Bouhemad B, Mongodi S, Via G, et al. Ultrasound for 'lung monitoring' of ventilated patients. Anesthesiology 2015; 122: 437–447. doi: 10.1097/ALN.0000000000000558CrossRefPubMedGoogle Scholar
80. ↵Strøm JJ, Haugen PS, Hansen MP, et al. Accuracy of lung ultrasonography in the hands of non-imaging specialists to diagnose and assess the severity of community-acquired pneumonia in adults: a systematic review. BMJ Open 2020; 10: e036067. doi:10.1136/bmjopen-2019-036067Abstract/FREE Full TextGoogle Scholar
81. ↵Pietersen PI, Madsen KR, Graumann O, et al. Lung ultrasound training: a systematic review of published literature in clinical lung ultrasound training. Crit Ultrasound J 2018; 10: 23. doi:10.1186/s13089-018-0103-6CrossRefPubMedGoogle Scholar
82. ↵See KC, Ong V, Wong SH, et al. Lung ultrasound training: curriculum implementation and learning trajectory among respiratory therapists. Intensive Care Med 2016; 42: 63–71. doi:10.1007/s00134-015-4102-9PubMedGoogle Scholar
83. ↵Rouby JJ, Arbelot C, Gao Y, et al. Training for lung ultrasound score measurement in critically ill patients. Am J Respir Crit Care Med 2018; 198: 398–401. doi: 10.1164/rccm.2018020227LECrossRefPubMedGoogle Scholar
84. ↵Mazmanyan P, Kerobyan V, Shankar-Aguilera S, et al. Introduction of point-of-care neonatal lung ultrasound in a developing country. Eur J Pediatr 2020; 179: 1131–1137. doi:10.1007/s00431-020-03603-wGoogle Scholar
85. Benchoufi M, Bokobza J, Chauvin A, et al. Lung injury in patients with or suspected COVID-19: a comparison between lung ultrasound and chest CT-scanner severity assessments, an observational study. MedRxiv 2020; preprint [https://doi.org/10.1101/2020.04.24.20069633]. doi: 10.1101/2020.04.24.20069633Google Scholar

86. Dargent A, Chatelain E, Kreitmann L, et al. Lung ultrasound score to monitor COVID-19 pneumonia progression in patients with ARDS. PLoS One 2020; 15: e0236312. doi: 10.1371/journal.pone.0236312Google Scholar
87. Smith MJ, Hayward SA, Innes SM, et al. Point-of-care lung ultrasound in patients with COVID-19 – a narrative review. Anaesthesia 2020; 75: 1096–1104. doi: 10.1111/anae.15082PubMedGoogle Scholar
88. Buonsenso D, Moro F, Inchingolo R, et al. Effectiveness of rapid lung ultrasound training program for gynecologists and obstetricians managing pregnant women with suspected COVID-19. Ultrasound Obstet Gynecol 2020; 56: 110–111. doi:10.1002/uog.22066Google Scholar
89. ↵Denault AY, Delisle S, Canty D, et al. A proposed lung ultrasound and phenotypic algorithm for the care of COVID-19 patients with acute respiratory failure. Can J Anaesth 2020; 67: 1393–1404. doi:10.1007/s12630-020-01704-6PubMedGoogle Scholar
90. ↵Boero E, Schreiber A, Rovida S, et al. The role of lung ultrasonography in COVID-19 disease management. J Am Coll Emerg Physicians Open 2020; 1: 1357–1363. doi: 10.1002/emp2.12194Google Scholar
91. ↵Sperandeo M, Trovato GM, Catalano D. Quantifying B-lines on lung sonography: insufficient evidence as an objective, constructive, and educational tool. J Ultrasound Med 2014; 33: 362–365. doi: 10.7863/ultra.33.2.362FREE Full TextGoogle Scholar
92. ↵Gullett J, Donnelly JP, Sinert R, et al. Interobserver agreement in the evaluation of B-lines using bedside ultrasound. J Crit Care 2015; 30: 1395–1399. doi: 10.1016/j.jcrc.2015.08.021CrossRefPubMedGoogle Scholar
93. ↵Smargiassi A, Soldati G, Borghetti A, et al. Lung ultrasonography for early management of patients with respiratory symptoms during COVID-19 pandemic. J Ultrasound 2020; 23: 449–456. doi: 10.1007/s40477-020-00501-7Google Scholar
94. ↵Lichtenstein DA. Ultrasound in the management of thoracic disease. Crit Care Med 2007; 35: Suppl. 5, S250–S261. doi: 10.1097/01.CCM.0000260674.60761.85CrossRefPubMedGoogle Scholar
95. ↵Via G, Storti E, Gulati G, et al. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. Minerva Anestesiol 2012; 78: 1282–1296.PubMedGoogle Scholar
96. ↵Soldati G, Smargiassi A, Inchingolo R, et al. Proposal for international standardization of the use of lung ultrasound for patients with COVID-19: a simple, quantitative, reproducible method. J Ultrasound Med 2020; 39: 1413–1419. doi: 10.1002/jum.15285PubMedGoogle Scholar
97. ↵Mongodi S, Bouhemad B, Orlando A, et al. Modified lung ultrasound score for assessing and monitoring pulmonary aeration. Ultraschall Med 2017; 38: 530–537. doi: 10.1055/s-0042-120260Google Scholar
98. ↵Soummer A, Perbet S, Brisson H, et al. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. Crit Care Med 2012; 40: 2064–2072. doi: 10.1097/CCM.0b013e31824e68aeCrossRefPubMedGoogle Scholar
99. Bouhemad B, Liu ZH, Arbelot C, et al. Ultrasound assessment of antibiotic-induced pulmonary reaeration in ventilator-associated pneumonia. Crit Care Med 2010; 38: 84–92. doi: 10.1097/CCM.0b013e3181b08cdbCrossRefPubMedGoogle Scholar
100. Bouhemad B, Brisson H, Le-Guen M, et al. Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. Am J Respir Crit Care Med 2011; 183: 341–347. doi: 10.1164/rccm.201003-0369OCCrossRefPubMedGoogle Scholar

101. ↵Wang XT, Ding X, Zhang HM, et al. 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. doi: 10.1186/s13054-016-1558-0PubMedGoogle Scholar
102. ↵Chiumello D, Umbrello M, Sferrazza Papa GF, et al. Global and regional diagnostic accuracy of lung ultrasound compared to CT in patients with acute respiratory distress syndrome. Crit Care Med 2019; 47: 1599–1606. doi: 10.1097/CCM.0000000000003971Google Scholar
103. ↵Chiumello D, Mongodi S, Algieri I, et al. Assessment of lung aeration and recruitment by CT scan and ultrasound in acute respiratory distress syndrome patients. Crit Care Med 2018; 46: 1761–1768. doi: 10.1097/CCM.0000000000003340CrossRefPubMedGoogle Scholar
104. ↵Bouhemad B, Zhang M, Lu Q, et al. Clinical review: bedside lung ultrasound in critical care practice. Crit Care 2007; 11: 205. doi: 10.1186/cc5668CrossRefPubMedGoogle Scholar
105. ↵Volpicelli G, Lamorte A, Villén T. What's new in lung ultrasound during the COVID-19 pandemic. Intensive Care Med 2020; 46: 1445–1448. doi: 10.1007/s00134-020-06048-9PubMedGoogle Scholar
106. ↵Meroi F, Orso D, Vetrugno L, et al. Lung ultrasound score in critically ill COVID-19 patients: a waste of time or a time-saving tool? Acad Radiol 2021; 28: 1323–1324. doi: 10.1016/j.acra.2021.06.008Google Scholar
107. ↵Akl EA, Blažić I, Yaacoub S, et al. Use of chest imaging in the diagnosis and management of COVID-19: a WHO rapid advice guide. Radiology 2021; 298: E63–E69. doi:10.1148/radiol.2020203173CrossRefGoogle Scholar
108. ↵Basseal JM, Westerway SC, McAuley T. COVID-19: infection prevention and control guidance for all ultrasound practitioners. Australas J Ultrasound Med 2020; 23: 90–95. doi:10.1002/ajum.12210Google Scholar
109. ↵World Federation for Ultrasound in Medicine and Biology Safety Committee. World Federation for Ultrasound in Medicine and Biology position statement: how to perform a safe ultrasound examination and clean equipment in the context of COVID-19. Ultrasound Med Biol 2020; 46: 1821–1826. doi:10.1016/j.ultrasmedbio.2020.03.033Google Scholar