

WHAT'S NEW IN INTENSIVE CARE



What's new in lung ultrasound during the COVID-19 pandemic

Giovanni Volpicelli^{1*}, Alessandro Lamorte² and Tomás Villén³

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The SARS-CoV-2 pandemic is undermining the ability of many advanced healthcare systems worldwide to provide quality care [1, 2]. COVID-19 is the disease caused by infection with SARS-CoV-2, a virus with specific tropism for the lower respiratory tract in the early disease stage [3]. Computed tomography scans of patients with COVID-19 typically show a diffuse bilateral interstitial pneumonia, with asymmetric, patchy lesions distributed mainly in the periphery of the lung [4–6]. In the context of a pandemic, rapid case identification, classification of disease severity and correct treatment allocation are crucial for increasing surge capacity. Overtriage to admission and to intensive care by clinicians working in the department of emergency medicine (ED) will overwhelm system capacity. Undertriage can lead to loss of life and cross infections. Similarly, selection of those patients most likely to respond to specific treatments and determining the response to treatment in the intensive care unit (ICU) can conserve scarce resources. Lung ultrasound (LUS) is well known for its feasibility and high accuracy when used at the bedside for diagnosing pulmonary diseases [7, 8]. As the most striking manifestation of COVID-19 disease is in the pulmonary system, LUS performed by a trained and knowledgeable clinician may aid precisely in triage, classification of disease severity and treatment allocation in both the ED and the ICU. In this paper, we describe the use of LUS in treating patients with COVID-19.

Case identification and classification of disease severity

Pending RT-PCR test results, other patients (or staff) may be unnecessarily exposed to those carrying the disease. Verifying that patients have COVID-19 therefore remains the rate-limiting step in patient triage. Alternatively, redundant implementation of precautions may lead to unnecessary resource consumption. The use of LUS in this context could revolutionize patient triage.

The LUS technique described in this paper is detailed in the supplementary material (Online Resources Supplementary file 12 LUS_TECHNIQUE.docx and Figure_1-6 and Video_1-2). The pretest probability of gaining useful information from LUS is likely to be highest when the clinician seeks to correlate clinical findings with those seen in LUS and knows what information to seek in order to do so. COVID-19 presents with not only specific LUS signs but also with typical patterns of LUS findings.

LUS signs

The signs seen in the LUS of patients with COVID-19 are similar to those extensively described in patients with other types of pneumonia [7]. These include various forms of B-lines, an irregular or fragmented pleural line, consolidations, pleural effusions and absence of lung sliding (see Online Resources Video_3-10) [9]. The LUS of patients with COVID-19 usually shows an explosion of multiform vertical artifacts and separate and coalescent B-lines. The pleural line may be irregular or fragmented as is commonly observed in ARDS. As stated above none of these signs is pathognomonic to COVID-19 pneumonia and their presence is variable.

Conversely, a typical artifact that we named “light beam” is being observed invariably in most patients with pneumonia from COVID-19. This artifact corresponds to the early appearance of “ground glass” alterations typical of the acute disease that may be detected in

*Correspondence: giovanni.volpicelli@gmail.com

¹ Department of Emergency Medicine, San Luigi Gonzaga University Hospital, Torino, Italy

Full author information is available at the end of the article

computed tomography. This broad, lucent, band-shaped, vertical artifact moves rapidly with sliding, at times creating an “on–off” effect as it appears and disappears from the screen. The bright artifact typically arises from an entirely regular pleural line interspersed within areas of normal pattern or with separated B-lines (Online Resources Video_5). At times it seems to cover the A-lines, concealing them entirely. At other times A-lines may still be visualized in the background as it is observed. The light beam is observed also in other conditions with ground glass alterations. Nevertheless, the importance of this sign is given by the contingency of the terrible pandemic of COVID-19 that we are experiencing in our EDs. A multicenter study in progress is investigating the accuracy of this sign. To date, a pilot analysis of a mono-center series of 100 patients suspected for COVID-19

revealed the presence of multiple light beams in 48 of the 49 patients with confirmed disease and pneumonia. The same sign was never observed in 12 patients with alternative pulmonary diagnoses and negative swab test (unpublished data).

LUS Patterns

The LUS findings of patients with COVID-19 are unique in both combination and distribution. Therefore, patients presenting to the ED may be classified into four broad categories based on the presence of specific patterns of LUS findings (see Table 1). Patients presenting with the pattern described in category A have little or no pulmonary involvement and are therefore unlikely to have COVID-19 disease (i.e., asymptomatic *SARS-CoV-2* carriers or patients with no lung disease). In patients

Table 1 Categories of probability of the disease based on patterns of LUS findings

Category	LUS findings
A-Low probability of COVID-19 disease (normal lungs)	Regular sliding
	A-lines observed over the whole chest
	Absence of significant B-lines (i.e., isolated or limited to the bases of the lungs)
B-Pathological findings on LUS but diagnosis other than COVID-19 most likely	Large lobar consolidation with dynamic air bronchograms
	Large tissue-like consolidation without bronchograms (obstructive atelectasis)
	Large pleural effusion and consolidation with signs of peripheral respiratory re-aeration (compressive atelectasis)
	Complex effusion (septated, echoic) and consolidation without signs of re-aeration
	Diffuse homogeneous interstitial syndrome with separated B-lines with or without an irregular pleural line
	<i>Patterns suggestive of specific diagnoses:</i>
	Cardiogenic pulmonary edema: diffuse B-lines with symmetric distribution and a tight correlation between the severity of B-lines and the severity of respiratory failure (anterior areas involved in the most severe conditions); in this case distribution of B-lines is uniform and gravity related; extending the sonographic examination to the heart will support the alternative diagnosis
Pulmonary fibrosis and interstitial pneumonia from alternative common viruses: the B-lines pattern has greater spread and there are no or limited “spared areas” (alternating normal A-lines pattern)	
C-Intermediate probability of COVID-19 disease	Chronic fibrosis: diffuse B-lines with clinical severity mismatch and with diffuse irregularity of the pleural line
	Small, very irregular consolidations at the two bases without effusion or with very limited anechoic effusion
	Focal unilateral interstitial syndrome (multiple separated and/or coalescent B-lines) with or without irregular pleural line
D-High probability of COVID-19 disease	Bilateral focal areas of interstitial syndrome with well-separated B-lines with or without small consolidations
	Bilateral, patchy distribution of multiple cluster areas with the light beam sign, alternating with areas with multiple separated and coalescent B-lines and well-demarcated separation from large “spared” areas
	The pleural line can be regular, irregular and fragmented
	Sliding is usually preserved in all but severe cases
	Multiple small consolidations limited to the periphery of the lungs
	A light beam may be visualized below small peripheral consolidations and zones with irregular pleural line

presenting with any of the LUS patterns described in category B (Online Resources Video_11-14) alternative diagnoses should be sought. These patients are most likely to have a condition other than COVID-19 causing their pulmonary disease. Patients presenting with the pattern of LUS findings described in category C (Online Resource Video_15) may have COVID-19 disease, whereas those presenting with the patterns of LUS findings described in category D (Online Resources Video_16-21 and Figure_7-8) probably have COVID-19 disease.

The presence of large consolidations with air bronchograms mainly in the bases of the lungs should always raise suspicion of bacterial cross-infection. As noted above, LUS findings are always most informative when they are interpreted in light of the clinical context; some asymptomatic or mildly symptomatic patients may have surprisingly impressive high probability LUS findings. Conversely, in our experience, patients with COVID-19 disease who suffer from severe respiratory failure are not likely to have no or mild LUS alterations.

Treatment allocation

There are several ways LUS may be used to determine allocation of treatment resources to those patients most likely to respond. These include early quantification of the severity of lung involvement, periodic assessment for the appearance of findings suggestive of atelectasis or pneumonia and monitoring the effects of changes in mechanical ventilation and recruitment maneuvers on lung aeration.

The use of LUS to quantify and monitor changes in aeration has been described in critically ill patients with ARDS [10, 11]. It is our impression that, contrary to what has been described in ARDS, interstitial patterns and consolidations contribute almost equally to lack of aeration in patients with COVID-19 [12]. Rather, the severity of respiratory impairment seems to be related to the overall proportion of lung tissue showing ground-glass alterations [6]. Early quantification of the severity of lung involvement in patients with COVID-19 may be

obtained by estimating the overall amount of lung areas detected as being pathological with ultrasound. Documenting the ultrasound images obtained enables later assessment of lesion size and more precise calculation of the proportion of diseased lung. The diseased lung is identified by the presence of any pathological finding (e.g., separated and coalescent B-lines, light beams, consolidations) and the areas of diseased lung are measured. For each video clip, the proportion of involved lung is estimated (0–30-50-70-100%) and the overall proportion is then calculated. This method of semi-quantification may be used to estimate the extent of lung involvement which could serve to identify at least some of the patients more likely to require invasive ventilation.

Periodic assessment for the appearance of findings suggestive of atelectasis or pneumonia can be highly informative. Identification of interstitial patterns or consolidations typical of pneumonia in patients with COVID-19 should lead to a change in care. Modifying ventilation parameters is simple but may not suffice for recruitment. We are adopting pronation guided mainly by LUS detection of extended lesions in the dorsal areas both in patients treated with continuous positive airway pressure (CPAP) and in invasively ventilated patients.

In patients that are invasively ventilated we suggest following evidence-based suggestions for monitoring aeration changes [10, 11]. The lung is studied in oblique scans in two anterior, two lateral and two posterior areas per side. Each area is assigned a score ranging from 0 to 3 (0=normal A-lines, 1= multiple separated B-lines, 2=coalescent B-lines or light beam, 3= consolidation). The sum of all the areas represents the aeration score. The dynamic changes in aeration can then be quantified by reassigning a new score to re-aerated areas (see Table 2). New methods for automated computer-aided measurement of aeration could be considered when available, with the advantage of a more standardized quantitative approach for monitoring [13].

Table 2 Quantification of re-aeration and loss of aeration by the observation of changes of the LUS pattern in each of the 12 chest areas. The final score is the sum of the 12 areas

Re-aeration score	Loss of aeration score				
+ 1 point	+ 3 points	+ 5 points	– 5 points	– 3 points	– 1 point
B1 to Normal	B2 to Normal	C to Normal	Normal to C	Normal to B2	Normal to B1
B2 to B1	C to B1			B1 to C	B1 to B2
C to B2					B2 to C

B1: multiple separated B-lines; B2: coalescent B-lines or light beam; C: consolidation

In the setting of critically ill COVID-19 patients with severe pneumonia, the possibility of thromboembolic disease should be considered [14]. Even if there are no published studies thus far, COVID-19 patients are likely at increased risk for thromboembolism [15]. Critically ill patients should be treated accordingly and monitored by cardiac and venous ultrasound to diagnose deep venous thrombosis and cardiac signs of acute pulmonary embolism [16]. We show a case of COVID-19 with sudden deterioration and cardiac arrest due to acute pulmonary embolism with popliteal thrombosis (Online Resources Video_22-23).

Hospital flooding of patients with COVID-19 imposes a huge burden on the medical system. This burden can be somewhat mitigated with optimization of patient identification, triage and management. LUS is noninvasive and can be performed very rapidly. LUS may be used in the ED to identify likely COVID-19 patients and to identify those patients with more extensive pulmonary involvement who should probably be referred to the ICU. It may serve to differentiate between patients with acute signs of respiratory failure, patients with mild symptoms and normal respiratory function, patients with preexisting chronic cardiac or pulmonary diseases (see flow charts in Online Resources Figure_9-11). In the ICU, LUS may be used to identify areas of poor lung aeration and to monitor the effect of changes in ventilation and recruitment maneuvers on lung aeration.

Electronic supplementary material

The online version of this article (<https://doi.org/10.1007/s00134-020-06048-9>) contains supplementary material, which is available to authorized users.

Author details

¹ Department of Emergency Medicine, San Luigi Gonzaga University Hospital, Torino, Italy. ² Emergency Department and Pre-Hospital Medicine, Valle D'Aosta General Hospital, Aosta, Italy. ³ School of Medicine, Universidad Francisco de Vitoria, Madrid, Spain.

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Authors' contribution

Luna Gargani, MD, Institute of Clinical Physiology, National Research Council, Pisa, Italy. Enrico Storti, MD, Department of Anesthesia and Intensive Care Unit, Maggiore Hospital, Lodi, Italy. Dr. Gargani and Dr. Storti contributed actively to the conception of this manuscript, sharing their experience with COVID-19 patients and their expertise in lung ultrasound.

Compliance with ethical standards

Conflicts of interest

Authors declare no conflict of interest with the subject matter.

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