

## Is There a Role for Lung Ultrasound During the COVID-19 Pandemic?

Lung ultrasound (LUS) has evolved considerably over the last years with respect to its theoretical and operative aspects. Consequently, its clinical application has come to be sufficiently known and widespread.

One of the characteristic aspects of LUS is the ability to define the alterations affecting the ratio between tissue and air in the superficial lung.<sup>1</sup> Normally, the lung surface mainly consists of air. Incident ultrasound (US) waves are thus generally completely back-reflected by the visceral pleural plane, especially when healthy. In this context, the scattering of US waves produces artifactual images characterized by horizontal reverberations of the pleural line (A-lines) and mirror effects.

When the ratio between air, tissue, fluid, or other biological components is reduced, the lung no longer presents itself as an almost complete specular reflector. Hence, various types of localized vertical artifacts appear on the US images in relation to the alterations of the subpleural tissue.<sup>2,3</sup>

These artifacts have generally been called B-lines,<sup>4</sup> but recently it has become clear that B-lines are very heterogeneous in their appearance. Moreover, their heterogeneity may be exploited as a means to characterize the alterations of the lung surface.<sup>5</sup>

Another well-known phenomenon linked to the increase in subpleural lung density (in the absence of consolidated tissue) is the coalescence of many vertical artifacts in more extended echogenic patterns, in which the individual artifacts are still recognizable or fused in a single homogeneous subpleural echogenic area (white lung). When the subpleural density goes toward the value of 1 g/mL (about that of the solid tissue), then consolidations appear.

Therefore, the clinician, through the visual inspection of LUS images, can detect, at the subpleural level, nonconsolidative increases in the ratio between full (tissue) and empty (air) and assess them in a range between normal and consolidative. Topographic images of the lesions can also be acquired. Finally, the extent of these lesions on the lung surface, as well as their evolution or regression over time, can also be evaluated.

The study of these patterns shows very high sensitivity in cases of interstitial and alveolar-interstitial lung

diseases, which have a peripheral distribution. Numerous studies on acute respiratory distress syndrome (ARDS)<sup>6</sup> confirm this. Other studies related to the 2009 pandemic influenza A (H1N1) epidemic<sup>7</sup> confirm these hypotheses even in a virally infectious setting.

The recent pneumonia outbreak spreading from Wuhan, China, in December 2019 is caused by the 2019 novel coronavirus infection, defined as new coronavirus disease (COVID-19).<sup>8</sup> This epidemic currently involves many areas of the world, with particular incidence in Italy, representing a serious challenge to public health and the efficiency of the health care structures.

The histopathologic appearance of initial COVID-19 pneumonia is characterized by alveolar damage, which includes alveolar edema, while the inflammatory component is patchy and mild. Reparative processes with pneumocyte hyperplasia and interstitial thickening can occur. The advanced phases show gravitational consolidations similar to those of ARDS. There are hemorrhagic necrosis, alveolar congestion, edema, flaking, and fibrosis.<sup>9</sup>

An analysis of the available computed tomographic (CT) data from patients with COVID-19 pneumonia<sup>10</sup> shows largely bilateral lesions that are patchy and also confluent, appearing as ground glass or with a mixed consolidative and ground glass pattern. Ten percent of lesions with a crazy-paving appearance are reported. The lesions often have a wedge-like appearance with a pleural base. Major consolidations may show air bronchograms. Pleural effusion is absent. Patchy or confluent lesions tend to be distributed along the pleura. The lobe most frequently affected is the lower right lobe, followed by the upper and lower left lobes. The posterior lung is involved in 67% of cases.<sup>11</sup>

Given that LUS can identify changes in the physical state of superficial lung tissue, which correlate with histopathologic findings and can be identified on CT but remain hidden in a large percentage of chest radiographs, the role of LUS can be relevant in the context of the COVID-19 epidemic. It should also not be underestimated that, in experimental models of ARDS, LUS has proved capable of detecting lung lesions before the development of hypoxemia.

The current clinical evidence (although not yet represented in the literature), the theoretical bases of LUS in the aerated lung, and LUS findings of similar aspects in other diseases (ARDS and flu virus

pneumonia) strongly suggest the potential diagnostic accuracy of LUS, which may be useful in the following situations:

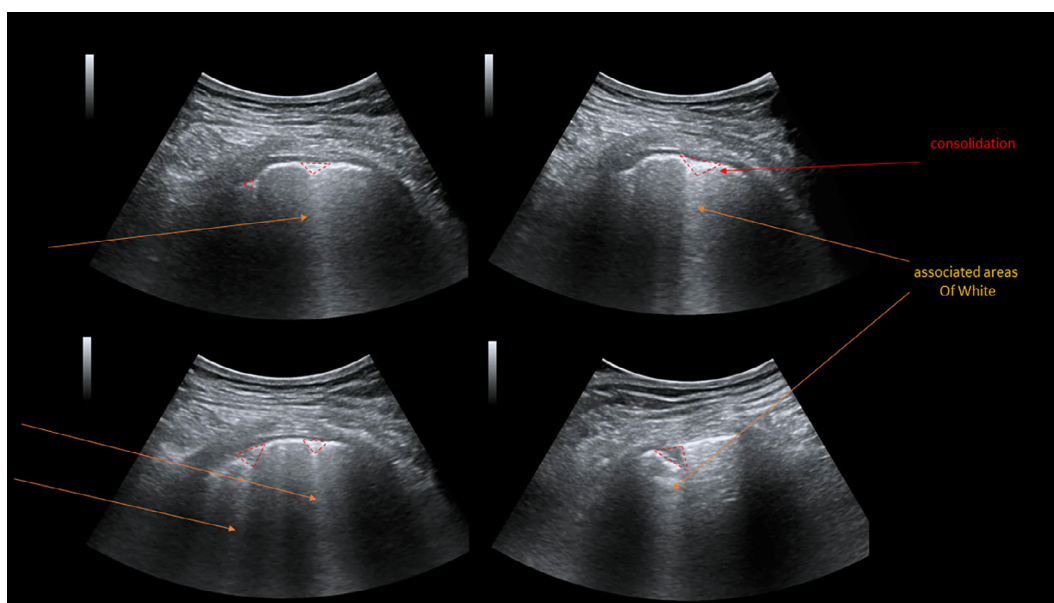
- Triage (pneumonia/non-pneumonia) of symptomatic patients at home as well as in the prehospital phase.
- Diagnostic suspicion and awareness in the emergency department setting.
- Prognostic stratification and monitoring of patients with pneumonia on the basis of the extension of specific patterns and their evolution toward the consolidation phase in the emergency department setting.
- Treatment of intensive care unit patients with regard to ventilation and weaning.
- Monitoring the effect of therapeutic measures (antiviral or others).
- Reducing the number of health care professionals exposed during patient stratification (a single clinician would be necessary to perform an objective medical examination and imaging investigation directly at the patient's bed).

From the current clinical evidence, we consider the LUS patterns of patients with COVID-19 pneumonia

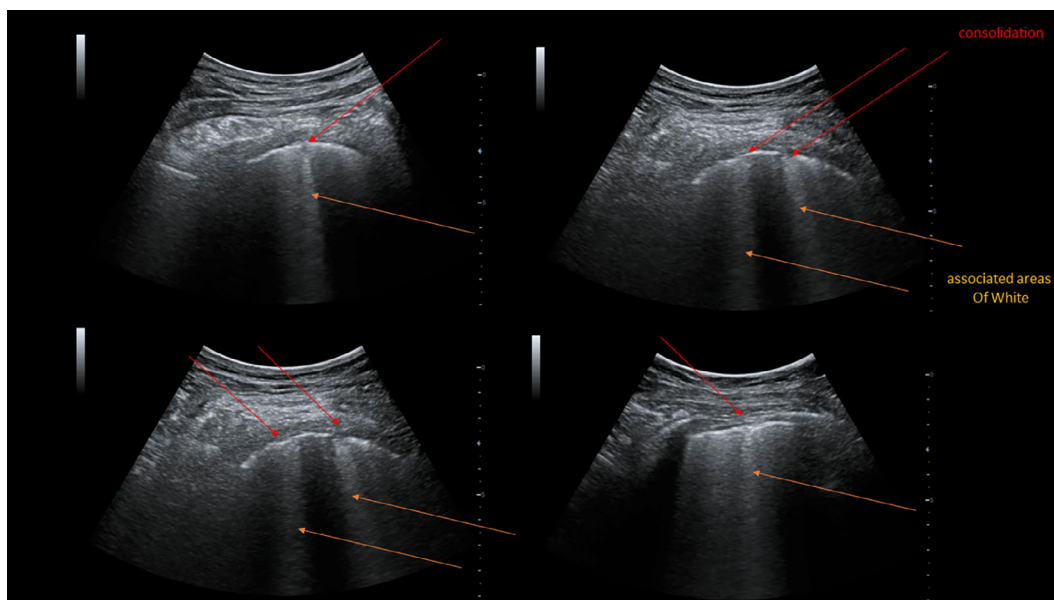
quite characteristic. The first pulmonary manifestations are represented by a patchy distribution of interstitial artifactual signs (single and/or confluent vertical artifacts and small white lung regions). Subsequently, these patterns extend to multiple areas of the lung surface. The further evolution is represented by the appearance, still patchy, of small subpleural consolidations with associated areas of white lung. The evolution in consolidations, especially in a gravitational position, with or without air bronchograms, and their increasing extension along the lung surface indicate the evolution toward the phase of respiratory insufficiency that requires invasive ventilatory support.

Figures 1 and 2 show the US characteristics of the interstitial syndrome present in intermediate COVID-19 pneumonia. Early viral pneumonia shows few, usually bilateral, pulmonary lung areas characterized by single or bundled, pneumogenic-type vertical artifacts, or small areas of white lung. Advanced COVID-19 pneumonia shows evident consolidations, especially in the posterobasal regions, and widespread patchy artifactual changes. This pattern is similar to that of ARDS. In this context, the development of algorithms able to aid the clinician with a real-time detection and localization system is of great interest.<sup>12</sup>

**Figure 1.** Top, Two images from a patient confirmed with COVID-19 pneumonia. Typical vertical pneumogenic large artifacts originate from the pleural line or from small, blurred subpleural consolidations. Their origin is not point-like. Bottom, The pleural line is interrupted by more visible yet small consolidations. Large vertical artifacts are seen arising from the consolidations, and they are superimposed on areas of white lung (convex transducer, intercostal scans).



**Figure 2.** Similar findings from a second patient confirmed with COVID-19 pneumonia.



Studies aimed at clarifying the diagnostic and prognostic role of LUS in COVID-19 are urgently needed. The well-known advantages of LUS in terms of portability, bedside evaluations, safety, and the possibility of repeating the examination during follow-up cannot be overlooked and should be exploited and implemented. Moreover, the possibility of performing a LUS examination at the bedside minimizes the need for transferring the patient, with a potential risk of further infection spreading among health care personnel. Comparison with chest radiography and/or a lung CT scan might help in designing a proper diagnostic workup according to the general and local technological and human resources.

A suggested acquisition protocol is described below:

- Use convex or linear transducers. The latter are preferable to study the detail of the pleural and subpleural alterations.
- Use a single-focal point modality (no multifocusing), and set the focal point on the pleural line.
- Preferably, scans need to be intercostal (not orthogonal to the ribs) to cover the widest surface possible with a single scan.
- Evaluate the presence of the artifactual patterns in multiple areas and bilaterally to study the extent of the lung surface affected. Ideally, 16 areas in total

should be evaluated: anterior midclavicular (apical, medial, and basal), right and left; posterior paraspinal (apical, medial, and basal), right and left; and lateral axillary (apical and basal), medial right and left.

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doi:10.1002/jum.15284

## References

1. Soldati G, Smargiassi A, Inchingolo R, et al. Lung ultrasonography may provide an indirect estimation of lung porosity and airspace geometry. *Respiration* 2014; 88:458–468.
2. Demi M, Prediletto R, Soldati G, Demi L. Physical mechanisms providing clinical information from ultrasound lung images: hypotheses and early confirmations. *IEEE Trans Ultrason Ferroelectr Freq Control* 2020; 67:612–623.
3. Soldati G, Demi M, Smargiassi A, Inchingolo R, Demi L. The role of ultrasound lung artifacts in the diagnosis of respiratory diseases. *Expert Rev Respir Med* 2019; 13:163–172.
4. Lichtenstein D, Mézière G, Biderman P, Gepner A, Barré O. The comet-tail artifact: an ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997; 156:1640–1646.
5. Soldati G, Smargiassi A, Demi L, Inchingolo R. Artifactual lung ultrasonography: it is a matter of traps, order, and disorder. *Appl Sci* 2020; 10:1570.
6. Bass CM, Sajed DR, Adedipe AA, West TE. Pulmonary ultrasound and pulse oximetry versus chest radiography and arterial blood gas analysis for the diagnosis of acute respiratory distress syndrome: a pilot study. *Crit Care* 2015; 19:282.
7. Testa A, Soldati G, Copetti R, Giannuzzi R, Portale G, Gentiloni SN. Early recognition of the 2009 pandemic influenza A (H1N1) pneumonia by chest ultrasound. *Crit Care* 2012; 16:R30.
8. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med* 2020; 382: 727–733.
9. Tian S, Hu W, Niu L, Liu H, Xu H, Xiao SY. Pulmonary pathology of early phase 2019 novel coronavirus (COVID-19) pneumonia in two patients with lung cancer [published online ahead of print February 28, 2020]. *J Thorac Oncol*. <https://doi.org/10.1016/j.jtho.2020.02.010>.
10. Bernheim A, Mei X, Huang M, et al. Chest CT findings in coronavirus disease-19 (COVID-19): relationship to duration of infection [published online ahead of print February 20, 2020]. *Radiology*. <https://doi.org/10.1148/radiol.2020200463>.
11. Yoon SH, Lee KH, Kim JY, et al. Chest radiographic and CT findings of the 2019 novel coronavirus disease (COVID-19): analysis of nine patients treated in Korea. *Korean J Radiol* 2020; 21: 494–500.
12. van Sloun RJ, Demi L. Localizing B-lines in lung ultrasonography by weakly-supervised deep learning: in-vivo results. *IEEE J Biomed Health Inform* 2020; 24:957–964.