European Heart Journal - Cardiovascular Imaging (2020) **00**, 1–8
doi:10.1093/ehjci/jeaa163

REVIEW

Why, when, and how to use lung ultrasound during the COVID-19 pandemic: enthusiasm and caution

Luna Gargani[1†], Hatem Soliman-Aboumarie[2*†], Giovanni Volpicelli[3], Francesco Corradi[4,5], Maria Concetta Pastore[6], and Matteo Cameli[6]

Received 8 May 2020; editorial decision 9 May 2020; accepted 14 May 2020

[1]Institute of Clinical Physiology, National Research Council, Pisa, Italy; [2]Department of Anaesthesia and Critical Care', Harefield Hospital, Royal Brompton and Harefield NHS Foundation Trust, London, UK; [3]Emergency Medicine, San Luigi Gonzaga University Hospital, Turin, Italy; [4]Department of Surgical, Medical and Molecular Pathology and Critical Care Medicine, University of Pisa, Italy; [5]Anaesthesia and Intensive Care Unit, E.O. Ospedali Galliera, Via Mura delle Cappuccine 14, Genova, Italy; and [6]Department of Medical Biotechnologies, Division of Cardiology, University of Siena, Siena, Italy

Introduction

The coronavirus disease-2019 (COVID-19) pandemic is one of the major current global health issues, due to its high rate of infection and increasing mortality. SARS-CoV-2 is a novel coronavirus that spreads easily from symptomatic and asymptomatic patients through close contact and respiratory droplets, causing a severe acute respiratory infection in a certain percentage of cases.[1] It is a challenge for clinicians to provide early diagnosis to isolate patients and prevent the most severe forms of acute distress respiratory syndrome (ARDS) or COVID-19 ARDS (CARDS), which represent a serious burden even for the most advanced medical systems.[2,3]

Diagnosis of COVID-19 is based on the real-time reverse transcription–PCR (rRT–PCR) analysis of respiratory tract specimens. However, rRT–PCR has a low sensitivity, translating in a subgroup of patients admitted to the hospital with the typical clinical aspects of the diseases but with false negative specimens. Chest computed tomography (CT) has a high sensitivity for the diagnosis of COVID-19 pneumonia, so it is considered the reference imaging method.[4,5] Chest CT analysis of patients with COVID-19 pneumonia typically shows bilateral and peripheral ground-glass opacities, crazy paving, and consolidations in a patchy distribution, that worsen with the progression of the disease.[6] Nevertheless, the feasibility of CT can be limited by its availability, the need to mobilize the patient, and the long-term risks related to ionizing radiation.[7] Bedside real-time lung ultrasound (LUS) for the assessment of COVID-19 pneumonia could support and integrate lung imaging with several advantages.[8–10] In fact, beyond its consolidated importance as a diagnostic and prognostic tool in heart failure and critically ill patients,[11–13] LUS can detect some typical characteristics of COVID-19 pneumonia.[8–10,14] The present review describes the role of LUS for the evaluation of COVID-19 pulmonary involvement and its applications for triaging, monitoring, and prognostic management of these patients.

Why to use lung ultrasound in COVID-19 patients?

LUS is showing a growing value in everyday clinical practice, especially in the emergency and intensive care settings. This imaging modality is portable, quick, repeatable, easy to learn, as compared with other ultrasonographic techniques, and with high inter-rater and intra-rater reproducibility.[15,16] It can reduce a patient's exposure to ionizing radiation and contribute to the safety of the healthcare providers by minimizing the need for moving the patient, therefore reducing the incidence of cross-contamination and the number of healthcare professionals exposed to the patient. Moreover, the growing use of small and portable handheld devices is running in parallel with the wider integration of point-of-care ultrasound in daily practice as an extension to bedside clinical examination.[17,18] The high sensitivity of LUS for the detection of pulmonary involvement allows it to be a reliable monitoring tool for the regular assessment of patients with COVID-19.

When and where to use lung ultrasound in COVID-19 patients

LUS can be performed at all steps in the evaluation of COVID-19 patients. *Table 1* summarizes the main aspects of the use of LUS in different COVID-19 clinical scenarios.

*Corresponding author. Tel: +44 7873451401, Email: hatem.soliman@gmail.com
†The authors contribute equally to this work.

Table 1 Clinical scenarios where LUS can support the management of COVID-19 patients

Location	Main aim	Advantages	Potential pitfalls
Home	Diagnosis	Portable Quick and bedside	'Grey' cases Potential increase of false positives
Emergency Department	Diagnosis	Quick and bedside More sensitive than chest X-ray Differential diagnosis with other conditions causing acute dyspnoea	Overlapping patterns in patients with comorbidities
Internal medicine	Risk stratification Monitoring subclinical pulmonary worsening Monitoring treatment response	Quick and bedside Dynamic May anticipate clinical deterioration	Daily monitoring not supported by data yet
Intensive care unit	Risk stratification Monitoring/titration of mechanical ventilation	Quick and bedside Dynamic	Excessive number of exams

Emergency Department

In the Emergency Department (ED), LUS can be employed for an early detection of pulmonary involvement in symptomatic patients suspected for COVID-19, with still pending rRT–PCR, as soon as they arrive. A typical LUS pattern, even in the absence of rRT–PCR results, should prompt isolation and treatment of the pulmonary involvement. Even with negative rRT–PCR, a typical LUS examination should lead to managing the patient as having a high probability for COVID-19, and to repeating the swab. In this scenario, LUS is more sensitive than chest X-ray, whereas CT scan should be reserved for confirmation in doubtful cases and for a better definition of the pulmonary involvement, when needed.

Internal medicine ward

In patients who have a diagnosis of COVID-19, LUS is useful to detect pulmonary involvement and to grade it. There are no validated scoring systems to clearly differentiate a mild from a moderate or severe degree but, as a general rule, a few separated B-lines in a limited number of chest areas would indicate a mild degree, whereas coalescent and compacted B-lines, with peripheral consolidations diffuse all over the chest, indicate a more severe involvement. In these patients, LUS can also help in monitoring treatment effects; in patients with an initial mild LUS pattern and clinical picture, a daily LUS monitoring can anticipate the clinical deterioration, which is not so uncommon in these patients, often at 7–14 days from symptom onset.

Intensive care unit

In patients in the intensive care unit (ICU), LUS is a useful tool in monitoring disease progression as well as the effects of mechanical ventilation and recruitment manoeuvres of deaerated lung areas, mainly based on positive end-expiratory pressure (PEEP) titration and prone positioning. Again, this approach is not validated in the specific cohort of COVID-19 patients; however, it has demonstrated good results in patients with ARDS, especially when coupled with an integrated cardiac and diaphragmatic evaluation.[19] Several studies suggested the value of a lung aeration score to monitor the progression of lung aeration before and after extubation, and to predict extubation failure.[20,21] Therefore, we would suggest utilizing LUS as part of a wider extubation protocol that integrates the standard clinical assessment, ventilatory parameters, and lung mechanics along with the lung and diaphragmatic ultrasonographic findings.

Home monitoring

Another potential and novel application of LUS is home monitoring. LUS is a suitable tool to be applied in out-of-hospital settings, especially with handheld devices.[18] Bringing the diagnostic armamentarium to the patient, instead of bringing the patient to the hospital, can be extremely convenient in a pandemic situation with a high risk of viral spreading. LUS is the most suitable chest imaging tool for this approach. Symptomatic fragile patients who cannot easily access the hospital can be evaluated directly at home with a very sensitive examination for lung involvement, which can help in the decision-making before the availability of rRT–PCR results. LUS can be especially decisive with a clearly negative or clearly positive examination; in the case of more ambiguous cases, LUS could, at least in theory, lead to a higher number of hospitalizations, which is a risk that should be taken into account. However, LUS can help in the differential diagnosis of other acute conditions that may have caused undifferentiated symptoms in these patients, especially when coupled with a focus cardiac ultrasound (FoCUS).[22] With the need for strict physical distancing, a home-based evaluation can also significantly reduce the contact with other patients and the number of interactions with the healthcare personnel.

How to use lung ultrasound in COVID-19 patients

Machine setting

The convex or microconvex transducers are the most universally used for LUS, as they allow a good visualization of the parenchymal

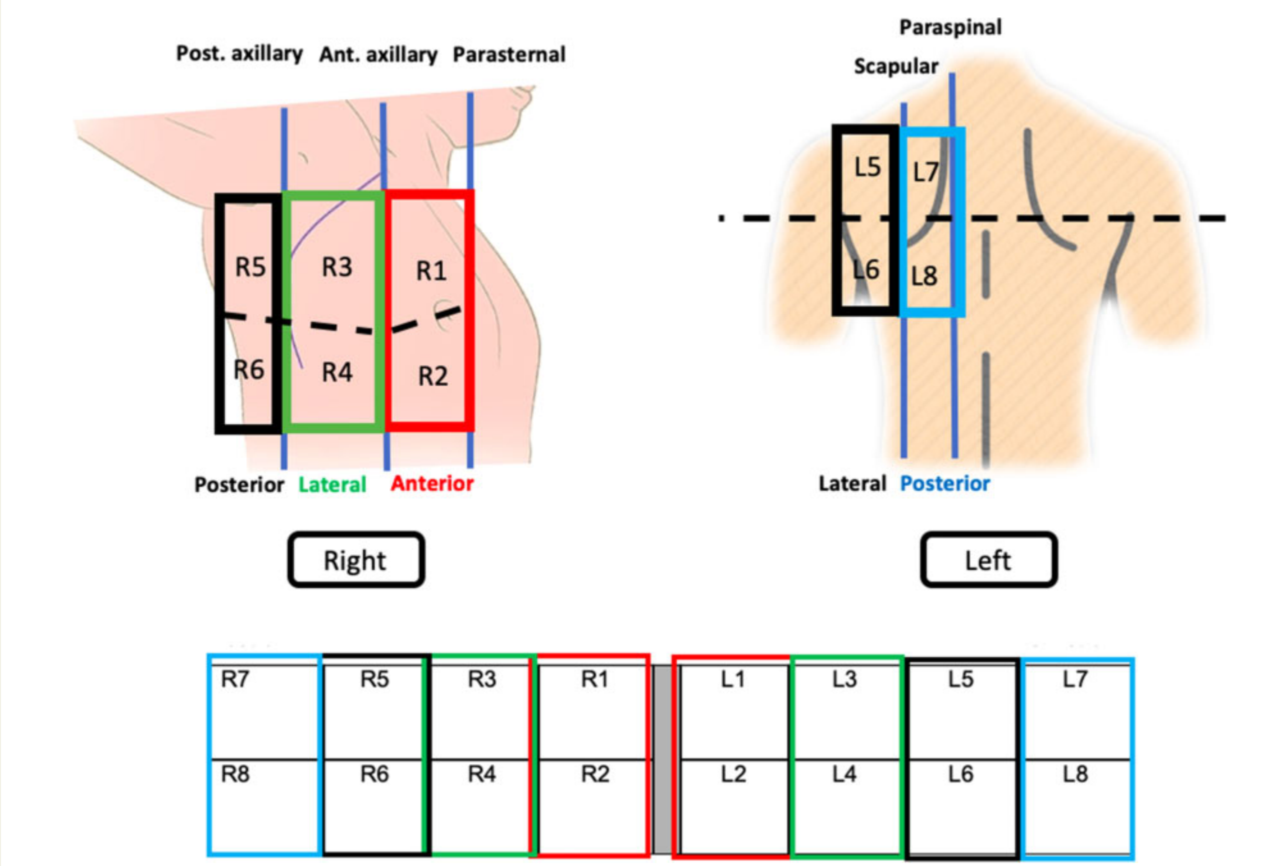


Figure 1 Proposal for lung ultrasound scanning scheme in COVID-19 patients (adapted from Bouhemad *et al.*[23]).

alterations while also providing a reasonable view of the pleural line. The examination should start by adjusting the machine on the lung pre-set (or abdominal pre-set if lung pre-set is not available), with a depth of ~8–10 cm (6–8 cm for slim subjects, 10–12 cm or more for obese subjects); gain should be optimized on the whole image, and the focus should be adjusted to the area of interest (e.g. the pleural line). The probe could be placed vertically perpendicular to the ribs (longitudinal approach) or horizontally along the intercostal spaces (transverse/oblique approach). Phased array transducers could also be used to visualize the parenchyma, albeit with more limited visualization of the pleura. Each point should be examined for at least one complete respiratory cycle (~5–6 s).

Scanning scheme

At the moment, there is no validated scanning scheme for COVID-19 patients. Therefore, it is advisable to rely on previously validated schemes that have already proven to be useful, although in different conditions, such as ARDS (*Figure 1*), which represents a good balance between being simple and comprehensive.[23] Whenever possible, we recommend to include the scanning of the posterior zones, where lung lesions are more commonly seen in these patients.[6] If the patient cannot move from the supine position, the posterolateral part of the chest can usually be scanned by turning the patient to his/her side. For these reasons, LUS scanning in COVID-19 patients should be as thorough as possible, and even if different schemes and areas are considered, in a given area, all available thoracic space should be checked, and the worst LUS picture should be considered.

LUS findings in COVID-19

COVID-19 presented a challenging clinical dilemma for clinicians at the frontline, with its atypical features which are different from the classical presentation of ARDS. Two different phenotypes have been described, at least in a theoretical model:[24] the more frequent phenotype 'L' typically presents with normal to mildly reduced lung compliance, albeit with a level of hypoxaemia disproportionate to the relatively preserved lung compliance, in which chest CT typically shows predominantly peripheral ground-glass opacifications that worsens with the progression of the disease. On the other hand, the less frequent phenotype 'H' is more similar to the classic ARDS presentation with reduced lung compliance and evidence of dense lobar consolidations on chest CT.

LUS is potentially able to distinguish these two phenotypes, based on the different signs and patterns. In COVID-19, we typically see various grades of multiple B-lines with patchy distribution. B-lines can be separated or coalescent, including pictures of sonographic 'white lung' (*Figure 2*). B-lines are often visible in the context of 'spared' areas of good aeration in which we see multiple horizontal A-lines that are reverberations of the pleural line. A recently described finding is

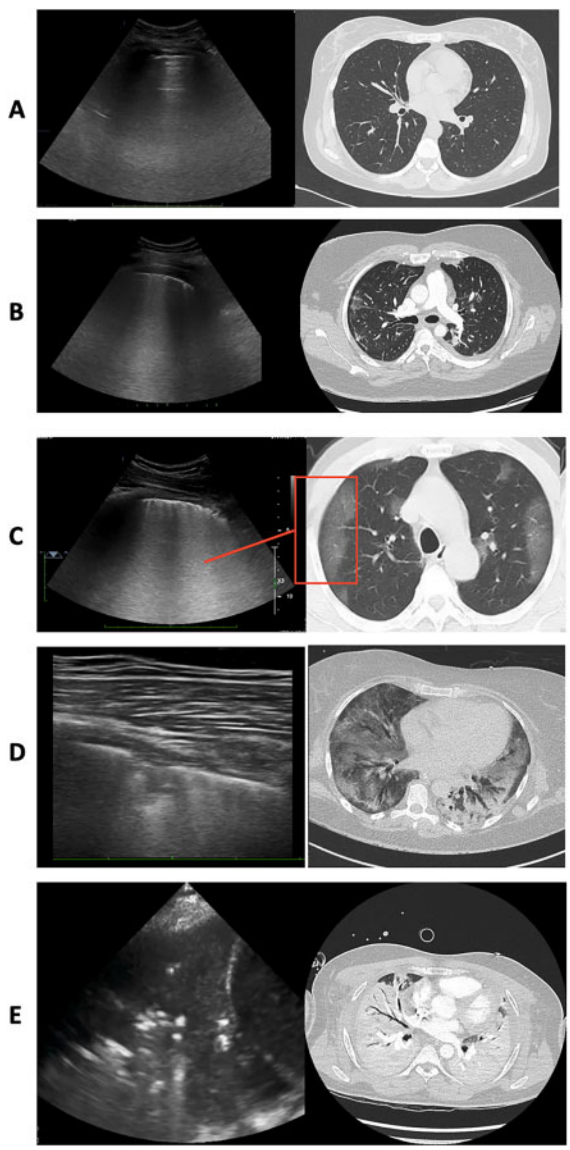


Figure 2 LUS findings correlated to chest CT progressing from normal aeration (*A*), to progressively more deaerated conditions: coalescent B-lines (*B* and *C*), small peripheral consolidation (*D*), large consolidation (*E*). The red box in (*C*) shows an area of ground-glass opacification on CT corresponding to confluent B-lines on LUS.

observed in most patients in the early phases of COVID-19 pneumonia: it is a shiny 'light beam' (Supplementary material online, *Video S1*), that is a band-like artefact, often appearing and disappearing with respiration.[9,10] Other common findings in COVID-19 are an irregular 'fragmented' pleural line with small peripheral consolidations (Supplementary material online, *Video S2*). Larger consolidations characterize the phenotype 'H' or a superimposed bacterial pneumonia (Supplementary material online, *Video S3*), and it is debeated whether they may represent pulmonary infarctions. Large pleural effusions are not commonly seen, whereas trivial localized pleural effusion can be visualized in the context of more deaerated areas. *Table 2* and *Figure 2* summarize the common LUS findings in COVID-19.

Lung ultrasound aeration score

Using a standardized scanning scheme enables us to assign a score to each lung zone and, therefore, assess the overall lung aeration. As for the scanning scheme, in the absence of a standardized score for COVID-19 patients, it is reasonable to rely on a previously validated score.[23]

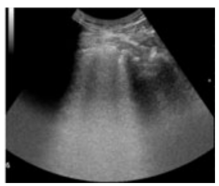
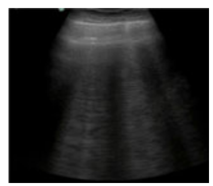
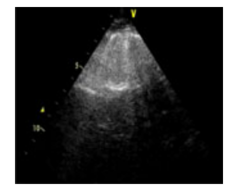
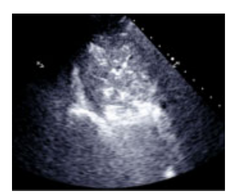
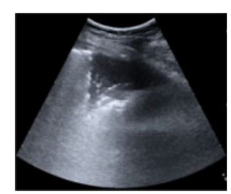
Score 0: predominant A-lines or <3 separated B-lines.
Score 1: at least three B-lines or coalescent B-lines occupying ≤50% of the screen without a clearly irregular pleural line. *Score 1p*: at least three B-lines or coalescent B-lines occupying ≤50% of the screen with a clearly irregular pleural line.
Score 2: coalescent B-lines occupying >50% of the screen without a clearly irregular pleural line. *Score 2p*: coalescent B-lines occupying >50% of the screen with a clearly irregular pleural line.
Score 3: large consolidations (at least >1 cm). It is useful to characterize the consolidation (hypoechoic, tissue-like, air or fluid bronchogram, etc.),
Presence of pleural effusion should always be reported as well.

The final score is obtained by summing up the scores of each area. The letters 'p' are not counted in the score: this is a more qualitative information, which is anyway useful because they are very frequent in COVID-19 , which is compatible with the pathophysiology of the condition. It is, however, not demonstrated yet that this kind of pure 'deaeration score'—often used in other conditions such as pneumonia and ARDS—can be enough to characterize these patients. On the one hand, it is established that a higher sonographic deaeration score indicates a less aerated lung, thus a worse pulmonary involvement; on the other hand, in COVID-19 patients, the different LUS patterns and their distribution may be more relevant to guide the clinicians' choice on different approaches, especially when characterizing patients into the aforementioned theoretical phenotypes.[3,24]

Differences from other LUS patterns

LUS is often used in the differential diagnosis of acute dyspnoea and respiratory symptoms. Other acute conditions, such as cardiogenic and non-cardiogenic pulmonary oedema, pulmonary embolism, or bacterial pneumonia, can still be a cause of relevant symptoms and poses challenges in the differential diagnosis of patients suspected of having COVID-19 pneumonia. In these cases, the integration with the patient's medical history, physical examination, and other findings is even more important than usual. LUS findings in COVID-19 have, however, some peculiarities that can at least orientate the diagnosis, with a varying degree of probability, according to the presence or absence of the typical COVID-19 LUS patterns (*Table 2*). It must always be remembered that the time lapse between the examination and the day of symptom onset is crucial to contextualize the sensitivity and specificity of the LUS signs, i.e. a negative LUS scanning very close to symptom onset cannot exclude the possibility of progression of the disease to pneumonia. Indeed, LUS diagnosis of a mild degree of

Table 2 Main LUS differences between COVID-19 involvement and other conditions that may yield respiratory symptoms

	COVID-19 pneumonia	Cardiogenic pulmonary oedema	ARDS	Bacterial pneumonia	Chronic interstitial lung disease (pulmonary fibrosis)
B-lines	Patchy, non-gravity related distribution Separated and more often coalescent Very defined spared areas Light beam	Homogeneous, gravity-related distribution Usually separated or coalescent in more severe cases No spared areas	Patchy, non-gravity-related distribution Separated and more often coalescent Spared areas	Visible in the case of focal interstitial syndrome	Usually more prevalent at lung bases Usually separated B-lines or coalescent in more severe cases Usually no spared areas
Pleural line	Often irregular and 'fragmented'	Usually thin and regular	Irregular and 'fragmented'	Not visible in the spot of consolidation	Always very irregular in moderate/severe cases
					
Consolidations	Usually small peripheral consolidations Larger consolidations in more advanced phases or with superimposed bacterial pneumonia.	Usually not present unless compressive atelectasis with large pleural effusion	Frequent small peripheral consolidations and larger consolidations	Usually large, hypoechoic or tissue-like	Rarely present and usually small in acute phases (i.e. alveolitis)
Pleural effusion	Large pleural effusion rare Trivial localized pleural effusion in the context of more deaerated areas	Frequent, variable size Trasudate, not complex appearance Usually bilateral (often larger on the right side)	Usually not large	Usually not large	Rare, unless in very advanced cases or acute phases Usually not large
					

pneumonia in a patient with typical symptoms for many days may identify a better prognosis.

Cardiogenic pulmonary oedema

When only considering LUS signs, patients with cardiogenic pulmonary oedema usually show multiple, diffuse, bilateral B-lines which are separated in the earlier phases and tend to be more confluent and numerous in more advanced cases.[25] In terms of semi-quantification, when B-lines are confluent and it is difficult to enumerate them one by one, it is the percentage of 'white' (the hyperechoic signal generated by B-lines) below the pleural line that should be considered, and divided by 10 (i.e. 50% of white screen of B-lines below the pleural line equals ∼5 B-lines), at least when using a cardiac probe in the transverse approach; this percentage method can be easily applied to the convex probe as well, for a better standardization.[11] In cardiogenic pulmonary oedema, B-lines tend to follow a quite homogenous, gravity-related distribution over the chest, so it would be improbable to find many B-lines on the anterior chest and no B-lines or many fewer B-lines at the lung bases. By the same principle, spared areas are usually not present. The pleural line has a thin and regular appearance, even in elderly patients, and a frankly irregular 'fragmented' pleural line or peripheral small consolidations are rare, unless there is a relevant alveolar oedema.

Non-cardiogenic pulmonary oedema

Patients with ARDS have the most similar LUS pattern to COVID-19 patients, with patchy, non-gravity-related distribution of B-lines, irregular pleural line, and consolidations of different sizes, from small peripheral consolidations to larger ones with tissue-like appearance. Probably the most relevant difference between COVID-19 pneumonia and a more 'classical' ARDS LUS pattern is the lack of initial correlation between the severity of the LUS picture and the clinical situation, with sometimes relatively asymptomatic COVID-19 patients with normal or close to normal oxygen saturation values and very advanced LUS abnormalities (usually seen in intubated patients in other ARDS conditions). Pleural effusion is also usually larger and more frequent in classical ARDS.

Bacterial pneumonia

In bacterial pneumonia, LUS usually shows consolidations of variable size, but often quite large and with a tissue-like appearance, which can be present in the more advanced phases of COVID-19, but not typically in the early phases. B-lines can be present as a 'focal interstitial syndrome': multiple B-lines in one area of the chest usually indicate the perilesional oedema either of a consolidation that is not peripheral enough to be seen by LUS, or of a consolidation not yet established in the lung parenchyma, so through B-lines we are visualizing the partial deaeration step, preceding the (almost) total deaeration phase.[13] Other vertical artefacts can be seen arising from the outer contour of a consolidation, which should not be considered as B-lines. Instead, the vertical artefacts arising from the pleural line around a consolidation should be considered as B-lines, indicating exudative peri-consolidative oedema.

Chronic interstitial lung disease

Patients with chronic interstitial lung disease, such as pulmonary fibrosis, have a LUS pattern of multiple B-lines, usually bilateral, and firstly diffuse at the lung bases.[26] In the very early phases, the pleural line can be relatively spared, showing a normal appearance, whereas in more advanced phases, the pleural line is progressively more irregular and 'fragmented'.[27] It is important to remember that irregularities of the sonographic pleural line should not be considered as anatomical correlates of real alterations of the pleura, which is not directly affected *per se* in these conditions. So, the 'pleural line' is a sonographic concept that is not directly related to the anatomical and physiological concept of the pleura. This is why it is always advisable to indicate this ultrasound structure as the 'pleural line' and not the 'pleura'. Peripheral consolidations and pleural effusion are rare, and usually visible only in the very acute phases of the interstitial lung disease, such as in acute alveolitis.

Integration with other imaging and clinical findings

LUS has high sensitivity and low specificity for a variety of lung pathologies, similarly to other diagnostic modalities. However, integrating LUS findings with the clinical context and the other diagnostic tools significantly increases its overall accuracy. A key value of LUS and other point-of-care tests is that they enable the clinicians to deliver a personalized care to patients, rather than the traditional protocolized approach which is increasingly challenged nowadays, especially in the context of high patient heterogeneity in critical care environments.[28] Keeping in mind the limited usefulness of this tool, as well as all other imaging tools, when used in isolation, and always integrating LUS with all other available findings and the clinical context, is mandatory to gain the highest level of information and to avoid gross mistakes.

Pitfalls

Lack of robust evidence

The COVID-19 pandemic has created a huge interest in LUS. Indeed, its use is rational during the overall course of the disease (*Table 1*). However, given the time constraints of the specific situation, to date there are no robust data on its accuracy as a diagnostic test, its real prognostic relevance, and cut-off values that can help orientate in the clinical decision-making, nor solid indications on timing and approaches to monitor patients (daily, twice daily, only clinically based, etc.). These data are very likely to be shared with the scientific community quite soon, but for the moment we have to rely more on experience rather than evidence. The balance between communicating the relevant information as soon as possible, and the time and sample size populations to do so appropriately is very delicate and sometimes difficult to set, but researchers should carefully monitor the scientific robustness of shared data, avoiding quick conclusions based on limited or biased study populations. On the other hand, according to the experience and reports of many groups throughout the world, LUS, even with a rather empirical approach, has been reported as extremely useful to support the decision-making in COVID-19 patients; thus, the paucity of grounded established literature—which is lacking anyway also for most of the tools we are currently using—should not discourage clinicians from its clinically integrated, appropriate, and responsible use.

Expertise

LUS in COVID-19 is not a basic examination, as it requires an advanced expertise in signs and patterns. To gain meaningful information, the sonographer cannot be a complete novice, especially if he/she has no previous experience with any US technique at all. Handling the probe correctly over the chest and finding more subtle pathological areas requires some skills that cannot usually be acquired in a couple of days. However, given the relatively limited amount of knowledge that even advanced LUS embodied, a reasonable requirement can be derived from a study on training for LUS score measurement in critically ill patients, where the authors suggested 25 ultrasound examinations supervised by a physician with expertise in bedside LUS, including appropriate recognition of normal aeration, interstitial syndrome, alveolar oedema, and lung consolidations. Recognition of pneumothorax is not included in this training, and this should be taken into account.[29]

New methods for automated computer-aided measurements of lung aeration could be considered as 'a second opinion' in order to reduce inter- and intraobserver variability, when LUS is handled by novice sonographers, with the advantage of a more standardized quantitative approach for monitoring, and faster data analysis when applied to large sets of data.[30,31]

Risk of spreading the infection

Performing LUS in COVID-19 patients is different from other conditions, because this poses a biological risk of infection for the operator, as well as not negligible logistic issues for the management of the echo machines. The risk of infection can be significantly limited by a proper protection of the operator, and a correct cleaning of the probes and machine, for which there are specific indications in dedicated papers.[32] However, we should consider that colleagues are often working in very stressful and challenging situations, where the distance between the 'ideal' world of optimum personal protective equipment and procedures has to be matched with clinical needs, time constraints, and intense fatigue. Procedural errors can be numerous and highly risky for the operators and the overall system.

Conclusions

The COVID-19 pandemic has further highlighted the usefulness of LUS in different clinical scenarios, underlining its advantages in terms of availability, operator- and patient-friendliness, relatively low cost and expertise needed, and high sensitivity. COVID-19 pulmonary involvement can benefit from LUS scanning at all steps of its management, from home monitoring to mechanical ventilation titration. Operators who largely employ LUS in the clinical decision-making should be aware of the potential pitfalls of the technique, especially contextualized in this very peculiar situation, where robust evidence is still missing due to the time contingency. A proper acknowledgement of LUS advantages and limitations is needed to fully benefit from this undoubtedly game-changer bedside imaging approach.[17]

Supplementary material

Supplementary material is available at *European Heart Journal Cardiovascular Imaging* online.

Acknowledgements

We are deeply grateful to all our colleagues, who are facing the COVID-19 pandemic with extreme dedication and self-sacrifice. In particular, we thank Professor Lorenzo Ghiadoni, Dr Greta Barbieri, Dr Stefano Spinelli, Dr Lorenza Pratali, Professor Francesco Forfori, and Professor Federico Franchi. Our sincere gratitude goes to all the doctors, nurses, and healthcare personnel throughout the world who are risking their lives to assist with and cure these patients.

References

1. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, Liu L, Shan H, Lei CL, Hui DSC, Du B, Li LJ, Zeng G, Yuen KY, Chen RC, Tang CL, Wang T, Chen PY, Xiang J, Li SY, Wang JL, Liang ZJ, Peng YX, Wei L, Liu Y, Hu YH, Peng P, Wang JM, Liu JY, Chen Z, Li G, Zheng ZJ, Qiu SQ, Luo J, Ye CJ, Zhu SY, Zhong NS; China Medical Treatment Expert Group for Covid-19. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med* 2020;**382**:1708–1720.
2. Rodriguez-Morales AJ, Cardona-Ospina JA, Gutiérrez-Ocampo E, Villamizar-Peña R, Holguin-Rivera Y, Escalera-Antezana JP, Alvarado-Arnez LE, Bonilla-Aldana DK, Franco-Paredes C, Henao-Martinez AF, Paniz-Mondolfi A, Lagos-Grisales GJ, Ramírez-Vallejo E, Suárez JA, Zambrano LI, Villamil-Gómez WE, Balbin-Ramon GJ, Rabaan AA, Harapan H, Dhama K, Nishiura H, Kataoka H, Ahmad T, Sah R; Latin American Network of Coronavirus Disease 2019-COVID-19 Research (LANCOVID-19). Clinical, laboratory and imaging features of COVID-19: a systematic review and meta-analysis. *Travel Med Infect Dis* 2020; **34**:101623.
3. Marini JJ, Gattinoni L. Management of COVID-19 respiratory distress. *JAMA* 2020;doi: 10.1001/jama.2020.6825.
4. Fang Y, Zhang H, Xie J, Lin M, Ying L, Pang P, Ji W. Sensitivity of chest CT for COVID-19: comparison to RT–PCR. *Radiology* 2020; doi: 10.1148/radiol.2020200432.
5. Ai T, Yang Z, Hou H, Zhan C, Chen C, Lv W, Tao Q, Sun Z, Xia L. Correlation of chest CT and RT–PCR testing in coronavirus disease 2019 (COVID-19) in China: a report of 1014 cases. *Radiology* 2020;doi: 10.1148/radiol.2020200642
6. Bernheim A, Mei X, Huang M, Yang Y, Fayad ZA, Zhang N, Diao K, Lin B, Zhu X, Li K, Li S, Shan H, Jacobi A, Chung M. Chest CT findings in coronavirus disease-19 (COVID-19): relationship to duration of infection. *Radiology* 2020;doi: 10.1148/radiol.2020200463.
7. Gargani L, Picano E. The risk of cumulative radiation exposure in chest imaging and the advantage of bedside ultrasound. *Crit Ultrasound J* 2015;**7**:4.
8. Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Briganti DF, Perlini S, Torri E, Mariani A, Mossolani EE, Tursi F, Mento F, Demi L. Is there a role for lung ultrasound during the COVID-19 pandemic? *J Ultrasound Med* 2020; doi: 10.1002/jum.15284.
9. Volpicelli G, Lamorte A, Villén T. What's new in lung ultrasound during the COVID-19 pandemic. *Intensive Care Med* 2020;doi: 10.1007/s00134-020-06048-9.
10. Volpicelli G, Gargani L. Sonographic signs and patterns of COVID-19 pneumonia. *Ultrasound J* 2020;**12**:22.
11. Gargani L. Ultrasound of the lungs: more than a room with a view. *Heart Fail Clin* 2019;**15**:297–303.
12. Mojoli F, Bouhemad B, Mongodi S, Lichtenstein D. Lung ultrasound for critically ill patients. *Am J Respir Crit Care Med* 2019;**199**:701–714.
13. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, Melniker L, Gargani L, Noble VE, Via G, Dean A, Tsung JW, Soldati G, Copetti R, Bouhemad B, Reissig A, Agricola E, Rouby JJ, Arbelot C, Liteplo A, Sargsyan A, Silva F, Hoppmann R, Breitkreutz R, Seibel A, Neri L, Storti E, Petrovic T; International Liaison Committee on Lung Ultrasound (ILC-LUS) for International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med* 2012;**38**:577–591.
14. Peng QY, Wang XT, Zhang LN; Chinese Critical Care Ultrasound Study Group (CCUSG). Findings of lung ultrasonography of novel corona virus pneumonia during the 2019–2020 epidemic. *Intensive Care Med* 2020;**24**:143.
15. Anderson KL, Fields JM, Panebianco NL, Jenq KY, Marin J, Dean AJ. Inter-rater reliability of quantifying pleural B-lines using multiple counting methods. *J Ultrasound Med* 2013;**32**:115–120.
16. Gargani L, Sicari R, Raciti M, Serasini L, Passera M, Torino C, Letachowicz K, Ekart R, Fliser D, Covic A, Balafa O, Stavroulopoulos A, Massy ZA, Fiaccadori E, Caiazza A, Bachelet T, Slotki I, Shavit L, Martinez-Castelao A, Coudert-Krier MJ, Rossignol P, Kraemer TD, Hannedouche T, Panichi V, Wiecek A, Pontoriero G, Sarafidis P, Klinger M, Hojs R, Seiler-Mußler S, Lizzi F, Onofriescu M, Zarzoulas F,

Tripepi R, Mallamaci F, Tripepi G, Picano E, London GM, Zoccali C. Efficacy of a remote web-based lung ultrasound training for nephrologists and cardiologists: a LUST trial sub-project. *Nephrol Dial Transplant* 2016;**31**:1982–1988.

17. Narula J, Chandrashekhar Y, Braunwald E. Time to add a fifth pillar to bedside physical examination: inspection, palpation, percussion, auscultation, and insonation. *JAMA Cardiol* 2018;**3**:346–350.
18. Cardim N, Dalen H, Voigt JU, Ionescu A, Price S, Neskovic AN, Edvardsen T, Galderisi M, Sicari R, Donal E, Stefanidis A, Delgado V, Zamorano J, Popescu BA. The use of handheld ultrasound devices: a position statement of the European Association of Cardiovascular Imaging (2018 update). *Eur Heart J Cardiovasc Imaging* 2019;**20**:245–252.
19. Mayo P, Volpicelli G, Lerolle N, Schreiber A, Doelken P, Vieillard-Baron A. Ultrasonography evaluation during the weaning process: the heart, the diaphragm, the pleura and the lung. *Intensive Care Med* 2016;**42**:1107–1117.
20. Soummer A, Perbet S, Brisson H, Arbelot C, Constantin J-M, Lu Q, Rouby JJ; Lung Ultrasound Study Group. Ultrasound assessment of lung aeration loss during a successful weaning trial predicts postextubation distress. *Crit Care Med* 2012;**40**:2064–2072.
21. Mojoli F, Bouhemad B, Mongodi S, Lichtenstein D. Lung ultrasound for critically ill patients. *Am J Respir Crit Care Med* 2019;**199**:701–714.
22. Neskovic AN, Skinner H, Price S, Via G, De Hert S, Stankovic I, Galderisi M, Donal E, Muraru D, Sloth E, Gargani L, Cardim N, Stefanidis A, Cameli M, Habib G, Cosyns B, Lancellotti P, Edvardsen T, Popescu BA; Reviewers: This document was reviewed by members of the 2016–2018 EACVI Scientific Documents Committee. Focus cardiac ultrasound core curriculum and core syllabus of the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* 2018;**19**:475–481.
23. Bouhemad B, Mongodi S, Via G, Rouquette I. Ultrasound for 'lung monitoring' of ventilated patients. *Anesthesiology* 2015;**122**:437–447.
24. Gattinoni L, Chiumello D, Caironi P, Busana M, Romitti F, Brazzi L, Camporota L. COVID-19 pneumonia: different respiratory treatment for different phenotypes? *Intensive Care Med* 2020;doi: 10.1007/s00134-020-06033-2.
25. Gargani L, Frassi F, Soldati G, Tesorio P, Gheorghiade M, Picano E. Ultrasound lung comets for the differential diagnosis of acute cardiogenic dyspnoea: a comparison with natriuretic peptides. *Eur J Heart Fail* 2008;**10**:70–77.
26. Gargani L, Doveri M, D'Errico L, Frassi F, Bazzichi ML, Delle Sedie A, Scali MC, Monti S, Mondillo S, Bombardieri S, Caramella D, Picano E. Ultrasound lung comets in systemic sclerosis: a chest sonography hallmark of pulmonary interstitial fibrosis. *Rheumatology (Oxford)* 2009;**48**:1382–1387.
27. Gargani L, Bruni C, Romei C, Frumento P, Moreo A, Agoston G, Guiducci S, Bellando-Randone S, Lepri G, Belloli L, Della Rossa A, Delle Sedie A, Stagnaro C, De Nes M, Salvadori S, Mosca M, Falaschi F, Epis O, Picano E, Matucci-Cerinic M. Prognostic value of lung ultrasound B-lines in systemic sclerosis. *Chest* 2020;doi: 10.1016/j.chest.2020.03.075.
28. Vincent J. The coming era of precision medicine for intensive care. *Crit Care* 2017;**21**:314.
29. Rouby JJ, Arbelot C, Gao Y, Zhang M, Lv J, An Y, Wang C, Bin D, Barbas CSV, Dexheimer Neto FL, Prior Caltabeloti F, Lima E, Cebey A, Perbet S, Constantin JM; APECHO study group. Training for lung ultrasound score measurement in critically ill patients. *Am J Respir Crit Care Med* 2018; doi: 10.1164/rccm.201802-0227LE.
30. Raso R, Tartarisco G, Matucci Cerinic M, Pioggia G, Picano E, Gargani L. A soft computing-based B-line analysis for objective classification of severity of pulmonary edema and fibrosis. *JACC Cardiovasc Imaging* 2015;**8**:495–496.
31. Brusasco C, Santori G, Bruzzo E, Trò R, Robba C, Tavazzi G, Guarracino F, Forfori F, Boccacci P, Corradi F. Quantitative lung ultrasonography: a putative new algorithm for automatic detection and quantification of B-lines. *Crit Care* 2019;**23**:288.
32. Skulstad H, Cosyns B, Popescu BA, Galderisi M, Salvo GD, Donal E, Petersen S, Gimelli A, Haugaa KH, Muraru D, Almeida AG, Schulz-Menger J, Dweck MR, Pontone G, Sade LE, Gerber B, Maurovich-Horvat P, Bharucha T, Cameli M, Magne J, Westwood M, Maurer G, Edvardsen COVID-19 pandemic and cardiac imaging: EACVI recommendations on precautions, indications, prioritization, and protection for patients and healthcare personnel. *Eur Heart J Cardiovasc Imaging* 2020;doi: 10.1093/ehjci/jeaa072.