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Lung ultrasound in COVID-19: Insights from the frontline and research experiences

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1. Introduction

Coronavirus disease 19 (COVID-19) has become a global threat. Its clinical course is different from other common illnesses and mortality remains high [1]. It is a challenge for clinicians to provide early diagnosis and to stratify patients at high risk of acute respiratory distress and death [2].

In order to diagnose Covid-19, clinicians initially had to rely on lung auscultation, chest x-ray, oxygen saturation, and reverse transcriptase-polymerase chain reaction (PCR) obtained from respiratory tract specimens [3] but their diagnostic accuracies are limited.

During the Covid-19 pandemic, lung ultrasound (LUS) has emerged as a useful tool, helping in different aspects of management. It is portable, quick, repeatable, easy to learn and with a high reproducibility [4]. It can reduce patient's exposure to ionizing radiation and contribute to the safety of 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.

Although there are different guidelines and recommendations about the use of LUS in patients with Covid 19 pneumonia, there is only emerging robust evidence about it and many recommendations are based on expert opinions [5-6]. In this article, we will review the role of LUS in the evaluation of COVID-19 pulmonary involvement and its applications for triaging, monitoring, and prognostic management of these patients.

2. How to perform LUS exam in Covid 19 patients

Coronaviruses can persist on inert surfaces for up to 3 days, facilitating autoinoculation when in contact with these surfaces [7]. Ultrasound machines vary in size from pocket size or handheld through to cart size machines. Handheld ultrasound devices can be easily covered with a sterile transducer sheath commonly used for ultrasound-guided central line placement and may be easier to maneuver, protect, and clean after use, minimizing viral contamination and spread.

Centers with the availability of more than one ultrasound machine could also designate one system for the evaluation of patients in whom risk of aerosolization is the highest in the COVID-19 area, to avoid contamination and nosocomial transmission (intubations, etc.). Unnecessary equipment should be removed from the ultrasound machine to minimize surface exposures. We should avoid transporting ultrasound machines across areas, unless an exhaustive cleaning protocol is followed, and avoid the use of the same machine for suspected and confirmed patients.

Fortunately, despite a significant level of contamination in the environment of patients affected by SARS-CoV-2, the samples obtained

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Table 1
Definition and interpretation of the main findings on Lung Ultrasound and Lung Score quantification.

LUS Finding	*Definition*	*Score*
A-lines	Horizontal reverberation artifacts parallel to the pleural line	0
B-lines	Hyperechoic vertical artifacts that arise from the pleural line, extending to the bottom of the screen without fading that erases the A-line artifact	
Isolated	Discrete, well demarcated B-lines; irregular/ fragmented pleural line can be present	1
Confluent	Multiple converging or coalescent B-lines. Small subpleural consolidations < 1cm and irregular/fragmented pleural line can be present	2
Subpleural consolidation	Hypoechoic area/consolidation greater than 1 cm in diameter	3
Lung Score Quantification	Sum up highest score of each of the 12 areas (superior and inferior of anterior, lateral, posterior right and left hemithorax)	0-36

LUS: Lung ultrasound

after cleaning with low-level hospital disinfectants have been negative and suggest adequate elimination of the virus [8]. A list of common disinfectants, how to use and the time required to be effective can be consulted from the provider of the ultrasound equipment, to ensure compatibility.

In addition to standard infection control recommendations, a "double step" wipe-down should be employed, initially by the provider involved in care of the patient then a second time by a clean provider outside the COVID-19 area.

3. Machine setting and technique

The exam can be performed with any probe taking into account its limitations. Linear, curvilinear, and phased array probes may be used, ideally using lung presets to enhance artifacts. If a dedicated preset is not available, machines should be set as follows: low mechanical index (0.7 or less); a single focus, positioned on the pleural line; no harmonic modality; no persistence. Lung ultrasound involves scanning the pleural line between the ribs, typically in multiple areas. Images are very easy to obtain, and there are fewer poor or difficult acoustic windows when compared to echocardiography or abdominal ultrasound.

In the past months, several imaging protocols have been proposed, based on the number of areas to explore. Contrasting the relevant role of LUS, there is no validated scanning protocol in COVID-19 patients. Currently, the main recommendation is to use previously validated schemes in conditions other than COVID-19. Whenever possible, a lower number of acquisition areas is preferred, but this could lead to underestimations. We suggest performing a 12-zone protocol including the inferior and superior aspects of the anterior, lateral and posterior areas of each hemithorax (Table 1).

4. Image interpretation

Lung parenchyma involvement due to COVID-19 will initially start at the distal subpleural space and progress to more central lobar regions.

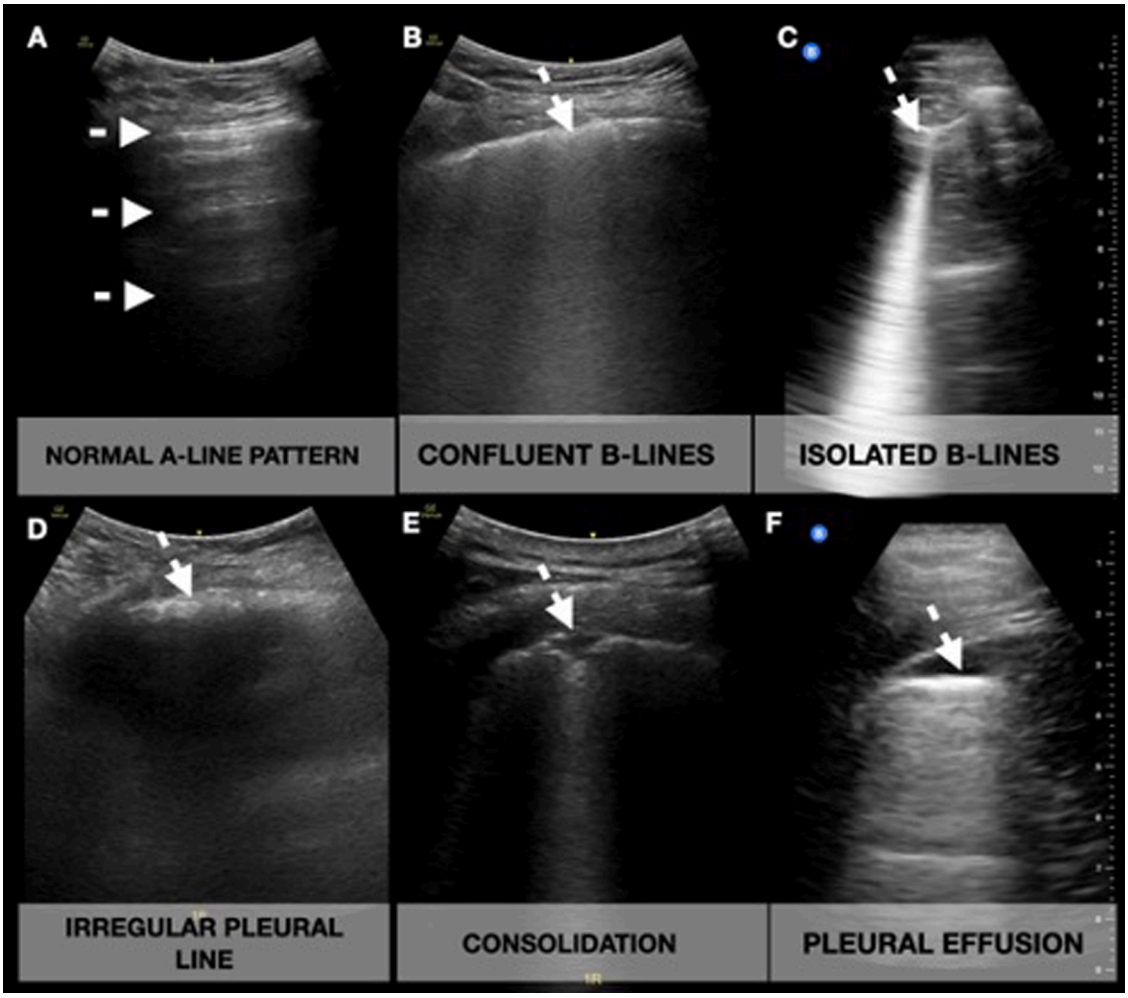

Fig. 1. Lung ultrasound patterns in patients with Covid-19 pneumonia.

The different findings we will be able to detect are as follows (Fig. 1):

- A-lines: horizontal reverberation artifacts parallel to the pleural line.
- B-lines: hyperechoic vertical artifacts that arise from the pleural line, extending to the bottom of the screen without fading that erases the A-line artifact.
- Isolated B-lines: discrete, well demarcated B-lines.
- Confluent B-lines: multiple converging or coalescent B-lines.
- Irregular pleural line: indented or broken pleural line.
- Subpleural consolidations: hypoechoic areas. Small subpleural consolidation with diameter <1cm are frequently present in association with an interstitial pattern. Wider consolidation with or without air bronchogram are not common in the early phase of the disease and are more frequently observed in the lower posterior lung regions.
- Pleural effusion:. Although small entity of fluid are frequently detected, a significant pleural effusion is not commonly present and should raise concern of a comorbid disease [9].

Although these typical findings are easy to distinguish, LUS is still operator dependent. There are different clinical indications that might prompt its use and might pose a challenge to correctly interpret and integrate these findings. Therefore, patient disposition should be an integration based on the whole patient evaluation and not only the lung ultrasound findings.

Moreover, given that Covid-19 is a systemic disease, in some patients a multiorgan ultrasonographic approach rather than solely lung ultrasound should be considered. In addition to lung ultrasound, focused cardiac ultrasound and venous compression ultrasonography of the lower limbs can be performed in order to detect or discard deep venous thrombosis and right ventricular dysfunction in the context of an acute pulmonary embolism, or a left ventricular dysfunction due to an acute myocarditis [10].

5. Quantification (Lung score)

The lung ultrasound score is a formula that can help us objectively quantify COVID-19–associated lung injury. This score may also be used to monitor the degree of lung aeration [10]. According to the severity of lung injury a different score is given to each lesion. Although different methods have been described, most of the studies used a scoring system based on 12 regions and a 0 to 3 grading: 1 point for focal B lines, 2 points for confluent B lines (small subpleural consolidation <1cm can be present), 3 points for subpleural consolidation > 1cm. Pleural irregularity/fragmentation -that is commonly found in association with B lines, is considered *per-se* in some studies. By summing the highest score at each zone, we obtain the patient's Lung Score, ranging from 0 to 36. A score of 1-7 is considered a mild involvement of the lungs, 8-18 moderate and 19-36 severe [11].

Table 1 sumarizes US findings and an example of LUS scoring system.

5.1. Pitfalls

LUS is non-specific, and the described findings may be consistent with COVID-19 but also may be found in other conditions including other viral or bacterial pneumonias, heart failure, malignancy, pulmonary infarction and preexisting interstitial lung disease.

Although auscultation or chest radiographs correlate poorly with the clinical picture as compared with computed tomography or ultrasound imaging, LUS has some caveats. For instance, it reflects only the lesions in the lung surface, and not necessarily, the degree of the whole lung aeration, as there are certain lobes that do not have contact with the pleura or only in a small area.

6. Utility: discarding other diseases and complications

LUS can help to determine the presence of synchronous or comorbid diseases, such as heart failure or lobar pneumonia (viral or bacterial). While not typical of COVID-19, LUS may also identify and exclude other pulmonary complications including pneumothorax, due to barotrauma, and significant pleural effusions. These findings should trigger the initiation or adjustment of therapy [6].

6.1. Standardization is needed

Additionally, the development of a more standardized approach, detailing the landmarks, image settings, acquisition protocol and lung scoring system, will allow comparisons and reproducibility across different studies and exams, as well as facilitate research on pattern recognition with artificial intelligence algorithms and telematic applications [12].

6.2. The value of LUS in a pandemic setting

Since the beginning of the pandemic of SARS-COV-2, people have been searching for methods to obtain a fast and reliable diagnosis of infection in order to isolate and treat the infected patients, and prevent nosocomial transmission.

The SARS-CoV-2 reverse transcriptase polymerase chain reaction (PCR) assay is the gold standard for COVID-19 diagnosis. Although it is highly specific, it has limited sensitivity, long turnaround times and there is a worldwide shortage of test capacity. Serological tests are not useful in acute cases, and reliable rapid antigen tests have their limitations. This hampers immediate triage and decision-making. Moreover, microbiological tests do not give insight into lung involvement. Correct assessment of lung involvement is thus crucial for appropriate triage, clinical management and efficient allocation of scarce medical resources. The World Health Organization (WHO) recently advocated chest imaging, especially when PCR results are not readily available, or the initial PCR is negative but clinical suspicion of COVID-19 remains high. However, chest radiography (CXR) sensitivity is low [13, 14].

There has been a lot of interest in the role of CT-scanning (low dose) in diagnosing viral pneumonia and grading the amount of lung involvement. Dutch radiologists developed a grading system (CO-RADS) which assesses the suspicion for pulmonary involvement of COVID-19 on a scale from 1 (very low) to 5 (very high). The system is meant to be used in patients presenting with moderate to severe symptoms of COVID-19 [15].

There are some reports about diagnostic accuracy of LUS in Covid-19 patients. Recently, Volpicelli et al proposed a lung ultrasound (LUS)-based diagnostic approach to patients suspected of COVID-19, combining the LUS likelihood of COVID-19 pneumonia with patient's symptoms and clinical history, obtaining a high sensitivity in identifying patients with positive RT-PCR [16].

We can also highlight a multicenter study on the role of Lung Ultrasound Scanning in SARS-COV-2 infection performed by Lieveld et al. Patients who were referred to the Emergency Department for evaluation underwent CT-scanning with CO-RADS grading and a Lung Ultrasound. The ultrasound operator was unaware of the CT-scan result and the radiologist was unaware of the lung ultrasound result. In lung ultrasound both sides of the chest were scanned in a systematic manner (6 sides on each hemithorax and the scan results were graded). In keeping with pre-specified criteria LUS was deemed positive if there were three or more B-lines and/or consolidation in two or more zones unilaterally or in one or more zones bilaterally. When COVID-19 features were not found or just in one zone unilaterally, the scan was deemed negative. With this approach SARS-COV-2 pneumonia was diagnosed accurately, with a sensitivity of 91.9%. More importantly, this study was able to exclude pneumonia very reliably with a Negative Likelihood ratio of 0.1 for comparison of Lung Ultrasound vs PCR. This means that if the lung

Table 2
Studies assessing the diagnostic accuracy of LUS.

Author	*N° patients*	*Setting*	*Primary Outcome*	*Protocol*	*Main Results (note)*
Tung-Chen et al. [11]	51	ED	LUS vs Chest CT	12 regions/0-36 score	LUS has similar accuracy compared with chest CT in the detection of lung abnormalities. PPV of 92.5% and NPV of 100.0%. Good correlation between LUS score and CT total severity score (intraclass correlation coefficient: 0.803, $p < 0.001$).
Volpicelli et al. [16]	1462	ED	LUS pattern + clinical phenotype vs RT-PCR swab test	4 patterns of probability: High LUS, Intermediate LUS, Alternative LUS, and Low LUS	HighLUS and IntLUS showed a sensitivity of 90.2% in identifying patients with positive RT-PCR. Higher values in the mixed (94.7%) and severe phenotype (97.1%). The HighLUS showed a specificity of 88.8%. At multivariate analysis, the HighLUS was a strong independent predictor of RT-PCR positivity (odds ratio 4.2, confidence interval 2.6–6.7, $p<0.0001$).
Lieveld et al. [17]	187	ED	LUS vs Chest CT	12 regions/qualitative evaluation	LUS and CT had comparable diagnostic accuracy for COVID-19 pneumonia; AUROC was 0.81 (95% CI 0.75–0.88) for LUS and 0.89 (95% CI 0.84–0.94) for CT.
Sorlini et al. [18]	384	ED	LUS vs RT-PCR swab test	12 regions/ qualitative evaluation	A suggestive LUS evaluation predicts COVID-19 pneumonia and swab test positivity with a sensitivity of 92% and a specificity of 64.9%. in patients with suspected respiratory infection. PPV: 88.6%; NPV: 73.3%

LUS: Lung ultrasound; AUROC: area under the receiver operating characteristic; PPV: positive predicted value; NPV: negative predicted value; RT-PCR: real time - polymerase chain reaction

ultrasound was negative, SARS-COV-2 pneumonia was improbable. Furthermore, patients with a normal or only slightly abnormal scan could be sent home safely, if they had no other reason for admission [17].

To conclude, in a pandemic setting lung ultrasound can diagnose and grade SARS-COV-2 pneumonia with excellent reliability. Lung ultrasound has many advantages compared to CT-scanning. It is cheaper, the handheld device is easy to clean and the lung scanning can be integrated into the anamnesis and physical examination of the patient. Furthermore, the images can be discussed immediately, even with the patient present.

Table 2 presents a schematic summary of studies assessing the diagnostic accuracy of LUS in Covid-19 patients.

6.3. Prognostic value of LUS in Covid-19 patients

Literature assessing a possible prognostic role of LUS in COVID-19 has been growing quickly in the last few months. Risk stratification in the ED could aid early recognition of patients who will develop an adverse event or, conversely, furnish parameters for safe discharge.

Three studies analyzed the association between LUS scores and adverse events in patients admitted to the ED. The studies were conducted in three hospitals in hard-hit areas during the first 'wave' of the COVID-19 pandemic. Garcia de Alencar et al performed LUS in 180 patients admitted to the ED [19]. In this context, they observed a significant association between LUS score and either mortality, ICU admission or endotracheal intubation. Nevertheless, important possible confounders, for example indexes of clinical severity, were not considered in the predictive analysis model. The prognostic value of LUS was confirmed by Secco et al showing in 312 ED admitted patients that a LUS score > 13 had a 77.2% sensitivity and a 71.5% specificity (AUC 0.814; $p < 0.001$) in predicting mortality [20]. In a recently published study conducted in the ED of a large hospital in Milan, Italy, Tombini and co-authors performed LUS in 255 patients. The categorized value of LUS

Table 3
Studies assessing the prognostic value of LUS in the Emergency Department and in non-ICU wards.

Author	*N° patients*	*Setting*	*Primary Outcome*	*N° of considered regions/Score range*	*Main Results (note)*
Garcia de Alencar J. et al. [19]	180	ED	Death from any cause	12/0-36	LUS score predicts death, OR 1.13. Secondary outcomes: ICU admission (LUS score OR 1.14), endotracheal intubation (LUS score OR 1.17) (47 patients already intubated at admission; P/F median 120)
Secco et al. [20]	312	ED	30-days mortality	12/0-36	LUS score > 13 had a 77.2% sensitivity and a 71.5% specificity in predicting mortality. Discharged patients had LUS score < 7, no readmission. (P/F mean 306 (37-704))
Tombini et al. [21]	255	ED	Composite of endotracheal intubation, no active further management, or death	12/0-36	LUS score > 20 predicts primary outcome with OR 2.52. LUS score < 10 predicts secondary outcome (discharge from the ED) with OR 20.9
Ji et al. [22]	280	Non-ICU wards	In-hospital mortality	12/0-36	LUS + age + lymphocyte count + comorbidities better predict primary or secondary (ARDS) outcomes than clinical variables only. LUS score > 12 predicts primary or secondary outcomes with 91.9% sensitivity and 90.5% specificity
Rubio-Gracia J et al. [23]	130	Non-ICU wards	Composite of in-hospital death and ICU admission	12/0-48	LUS score > 22 independently predicts primary outcome
Casella et al. [24]	190	Non-ICU wards	Composite of in-hospital death and ICU admission	11/0-33	LUS score at admission predicts primary outcome in the univariate model but in the multivariate model P/F is the only predictive variable. At 72 hours a LUS score predicts the primary outcome with OR 1.36. A LUS score of 9 at admission rule out death and ICU transfer with sensitivity 100%; specificity 45%
Lieveld et al. [25]	114	ED	Composite of 30-days mortality or ICU admission	12/0-36	LUS score ≥ 12 was associated with a primary outcome within 30 days with HR 5.59. LUS score <12 was associated with shorter admission duration with HR 2.24 (secondary outcome)

LUS: Lung ultrasound; OR: odds ratio; HR: hazard ratio; P/F=arterial oxygen partial pressure/fractional inspired oxygen ratio

score (LUS score >20) was independently associated with the composite outcome of death, need for mechanical ventilation and dispatch for no active further management, together with age, body mass index, P/F and cardiovascular morbidity/hypertension. On the other hand, a LUS score <10 was an independent predictor for a safe discharge from the ED [21].

Some data are now available regarding the prognostic value of LUS when performed in patients hospitalized in non-ICU wards, either at admission or in repeated sessions after 48-72 hours. In a prospective, single-center, observational study including 280 consecutive patients, Ji and co-workers showed that adding the LUS score to Age, Lymphocytes count and comorbidity allowed to predict adverse events (death, ARDS) with a better accuracy with respect to clinical variables alone [22].

A Spanish study reported an unchanged LUS score at 48-72 hours, while a significant reduction was detected at discharge. These authors found that categorized LUS score at admission (>22) independently predicted the composite death/ICU outcome in a multivariate model where some comorbidities and clinical/laboratory variables were also considered [23].

In a prospective study conducted in an Italian Internal Medicine ward, Casella et al reported in this Journal data collected in 190 consecutive patients. Although LUS score at admission was not retained in the multivariate analysis where only P/F predicted death/ICU admission outcome, it independently predicted the development of respiratory failure needing treatment with continuous positive airway pressure. Moreover, LUS performed after 72 hours seemed to be a reliable prognostic tool allowing identification of patients likely to die or be transferred to ICU, as demonstrated by an independent association with the primary outcome. Interestingly, data were confirmed even when a LUS score derived from the anterolateral region evaluation was used; this finding suggests that a limited approach, easily applicable even in bedridden, difficult to mobilize patients, can be sufficient when monitoring the evolution of COVID-19 pneumonia. When performing ROC analysis, a total LUS score of 9 at admission was a reliable cut-off value to rule out death and ICU transfer (sensitivity 100%; specificity 45%), while at 72 hours a cut-off value of 17 accurately predicted the primary outcome (sensitivity 89%; specificity 85%). These data support a possible role of LUS in the choice of the best intensity care setting for the patient [24].

All these data seem to indicate LUS as a promising prognostic tool in COVID-19. Nevertheless, some important considerations are needed. First, studies in general show some relevant methodological differences, mainly regarding the protocol used to perform the examinations and, thus, to compute the LUS score. As an example, almost all the six studies here presented show some differences either in the number of examined regions or in grading severity so it is beyond doubt that standardization is paramount and metanalyses are needed for a step towards unequivocal evidence-based use of LUS in the prognostic stratification of COVID patients.

Table 3 presents a schematic summary of studies assessing the prognostic value of LUS in Covid-19 patients evaluated in the emergency department and in non-ICU wards.

7. Conclusions

LUS can help in triage, diagnosis and prognostic evaluation in patients with Covid-19 and therefore help in guiding the patient́s location, intensity of care and treatment adjustments. It may be used at the ED but also in wards and nursing homes. More studies and research, including clinical trials and metanalysis are needed to keep on defining the role of LUS in Covid-19. Moreover, a standardized examination protocol is also needed. But one thing is for sure: handheld LUS is here to stay.

Declaration of competingInterest

The authors declare they have no conflict of interest.

References

[1] World Health Organization (WHO). Coronavirus Disease (COVID-19) Situation Report 30 march 2021. Available online: https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19—31-march-2021.

[2] [No authors listed]. Risk stratification of patients admitted to hospital with covid-19 using the ISARIC WHO Clinical Characterisation Protocol: development and validation of the 4C Mortality Score. BMJ 2020 Nov 13;371:m4334. https://doi.org/10.1136/bmj.m4334.

[3] Gandhi RT, Lynch JB, Del Rio C. Mild or moderate Covid-19. N Engl J Med 2020; 383:1757–66. https://doi.org/10.1056/NEJMcp2009249.

[4] Kumar A, Weng Y, Graglia S, Chung S, Duanmu Y, Lalani F, Gandhi K, Lobo V, Jensen T, Nahn J, Kugler JJ. Interobserver agreement of lung ultrasound findings of COVID-19. Ultrasound Med 2021 Jan 11. https://doi.org/10.1002/jum.15620.

[5] Gargani L, Soliman-Aboumarie H, Volpicelli G, Corradi F, Pastore MC, Cameli M. Why, when, and how to use lung ultrasound during the COVID-19 pandemic: enthusiasm and caution. Eur Heart J Cardiovasc Imaging 2020;1(21):941–8. https://doi.org/10.1093/ehjci/jeaa163.

[6] Hussain A, Via G, Melniker L, Goffi A, Tavazzi G, Neri L, Villen T, Hoppmann R, Mojoli F, Noble V, Zieleskiewicz L, Blanco P, Ma IWY, Wahab MA, Alsaawi A, Al Salamah M, Balik M, Barca D, Bendjelid K, Bouhemad B, Bravo-Figueroa P, Breitkreutz R, Calderon J, Connolly J, Copetti R, Corradi F, Dean AJ, Denault A, Govil D, Graci C, Ha YR, Hurtado L, Kameda T, Lanspa M, Laursen CB, Lee F, Liu R, Meineri M, Montorfano M, Nazerian P, Nelson BP, Neskovic AN, Nogue R, Osman A, Pazeli J, Pereira-Junior E, Petrovic T, Pivetta E, Poelaert J, Ma IWY, Hussain A, Wagner M, Walker B, Chee A, Arishenkoff S, Buchanan B, Liu RB, Mints G, Wong T, Noble V, Tonelli AC, Dumoulin E, Miller DJ, Hergott CA, Liteplo AS. Canadian internal medicine ultrasound (CIMUS) expert consensus statement on the use of lung ultrasound for the assessment of medical inpatients with known or suspected coronavirus disease 2019. J Ultrasound Med 2020 Dec 4. https://doi.org/10.1002/jum.15571.

[7] Gibson LE, Bittner EA, Chang MG. Handheld ultrasound devices: An emerging technology to reduce viral spread during the Covid-19 pandemic. Am J Infect Control 2020;48:968–9. https://doi.org/10.1016/j.ajic.2020.05.041.

[8] Ong SWX, Tan YK, Chia PY, Lee TH, Ng OT, Wong MSY, et al. Air, surface environmental, and personal protective equipment contamination by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) from a symptomatic patient. 2020;323:1610-1612. doi: 10.1001/jama.2020.3227.

[9] Tung-Chen Y, Algora-Martín A, Llamas-Fuentes R, Rodríguez-Fuertes P, Virto AMM, Sanz-Rodríguez E, et al. Point-of-care ultrasonography in the initial characterization of patients with COVID-19. Med Clin (Barc) 2021 Jan 28. https://doi.org/10.1016/j.medcli.2020.12.007. S0025-7753(21)00015-4.

[10] Smith MJ, Hayward SA, Innes SM, Miller ASC. Point-of-care lung ultrasound in patients with COVID -19 – a narrative review. Anaesthesia 2020;75:1096–104. https://doi.org/10.1111/anae.15082.

[11] Tung-Chen Y, Martí de Gracia M, Díez-Tascón A, Alonso-González R, Agudo-Fernández S, Parra-Gordo ML, et al. Correlation between chest computed tomography and lung ultrasonography in patients with coronavirus disease 2019 (COVID-19). Ultrasound Med Biol 2020;46:2918–26. https://doi.org/10.1016/j.ultrasmedbio.2020.07.003.

[12] Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Briganti DF, 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;39:1413–9. https://doi.org/10.1002/jum.15285.

[13] Pare JR, Camelo I, Mayo KC, Leo MM, Dugas JN, Nelson KP, Baker WE, Shareef F, Mitchell PM, Schechter-Perkins EM. Point-of-care lung ultrasound is more sensitive than chest radiograph for evaluation of COVID-19. West J Emerg Med 2020;21: 771–8. https://doi.org/10.5811/westjem.2020.5.47743.

[14] Mateos González M, García de Casasola Sánchez G, Muñoz FJT, Proud K, Lourdo D, Sander J-V, Jaimes GEO, Mader M, Canora Lebrato J, Restrepo MI, Soni NJ. Comparison of Lung ultrasound versus chest X-ray for detection of pulmonary infiltrates in COVID-19. Diagnostics 2021;11:373. https://doi.org/10.3390/diagnostics11020373.

[15] Lieveld AWE, Azijli K, Teunissen BP, van Haaften RM, Kootte RS, van den Berk IAH, van der Horst SFB, de Gans C, van de Ven PM, Nanayakkara PWB. Chest CT in COVID-19 at the ED: validation of the COVID-19 reporting and data system (CO-RADS) and CT severity score: a prospective, multicenter, observational study. Chest 2021;159:1126–35. https://doi.org/10.1016/j.chest.2020.11.026.

[16] Volpicelli G, Gargani L, Perlini S, Spinelli S, Barbieri G, Lanotte A, Casasola GG, Nogué-Bou R, Lamorte A, Agricola E, Villén T, Deol PS, Nazerian P, Corradi F, Stefanone V, Fraga DN, Navalesi P, Ferre R, Boero E, Martinelli G, Cristoni L, Perani C, Vetrugno L, McDermott C, Miralles-Aguiar F, Secco G, Zattera C, Salinaro F, Grignaschi A, Boccatonda A, Giostra F, Infante MN, Covella M, Ingallina G, Burkert J, Frumento P, Forfori F, Ghiadoni L, on behalf of the International Multicenter Study Group on LUS in COVID-19. Lung ultrasound for the early diagnosis of COVID-19 pneumonia: an international multicenter study. Intensive Care Med 2021:1–11. https://doi.org/10.1007/s00134-021-06373-7.

[17] Lieveld AWE, Kok B, Schuit FH, Azijli K, Heijmans J, van Laarhoven A, Assman NL, Kootte RS, Olgers TJ, Nanayakkara PWB, Bosch FH. Diagnosing COVID-19 pneumonia in a pandemic setting: Lung Ultrasound versus CT (LUVCT) - a multicentre, prospective, observational study. ERJ Open Res 2020;21(6): 00539–2020. https://doi.org/10.1183/23120541.00539-2020.

[18] 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. Internal and Emergency Medicine 2020. https://doi.org/10.1007/s11739-020-02524-8.

[19] Garcia de Alencar JC, Meirelles Marchini JF, Oliveira Marino L, Costa Ribeiro SC, Gasparotto Bueno C, Paro da Cunha V, Lazar neto F, Brandao Neto RA, Possolo Souza H. Lung ultrasound score predicts outcomes in COVID-19 patients admitted to the emergency department. Ann Intensive Care 2021;11(11):6. https://doi.org/10.1186/s13613-020-00799-w.

[20] Secco G, Delorenzo M, Salinaro F, Zattera C, Barcella B, Resta F, Sabena A, Vezzoni G, Bonzano M, Briganti F, Cappa G, Zugnoni F, Demitry L, Mojoli F, Baldanti F, Bruno R, Perlini S. GERICO (Gruppo Esteso RIcerca COronarovirus) Lung US Pavia Study Group. Lung ultrasound presentation of COVID-19 patients: phenotypes and correlations. Intern Emerg Med 2021 Mar 1:1–11. https://doi.org/10.1007/s11739-020-02620-9. Epub ahead of print. PMID: 33646508; PMCID: PMC7917171.

[21] Tombini V, Di Capua M, Capsoni N, Lazzati A, Bergamaschi M, Gheda S, Ghezzi L, Cassano G, Albertini V, Porta L, Zacchino M, Campanella C, Guarnieri L, Cazzola KB, Velati M, Di Domenico SL, Tonani M, Spina MT, Paglia S, Bellone A. Risk Stratification in COVID-19 Pneumonia - Determining the Role of Lung Ultrasound. Ultraschall Med 2021. https://doi.org/10.1055/a-1344-4715.

[22] Ji L, Cao C, Gao Y, Zhang W, Xie Y, Duan Y, Kong S, You M, Ma R, Jiang L, Liu J, Sun Z, Zhang Z, Wang J, Yang Y, Lv Q, Zhang L, Li Y, Zhang J, Xie M. Prognostic value of bedside lung ultrasound score in patients with COVID-19. Crit Care 2020; 22(24):700. https://doi.org/10.1186/s13054-020-03416-1.

[23] Rubio-Gracia J, Giménez-López I, Garcés-Horna V, López-Delgado D, Sierra-Monzón JL, Martínez-Lostao L, Josa-Laorden C, Ruiz-Laiglesia F, Pérez-Calvo JI, Crespo-Aznarez S, García-Lafuente J, Peña Fresneda N, Amores Arriaga B, Gracia-Tello B, Sánchez-Marteles M. Point-of-care lung ultrasound assessment for risk stratification and therapy guiding in COVID-19 patients. A prospective non-interventional study. Eur Respir J 2021;25:2004283. https://doi.org/10.1183/13993003.04283-2020.

[24] Casella F, Barchiesi M, Leidi F, Russo G, Casazza G, Valerio G, Torzillo D, Ceriani E, Del Medico M, Brambilla AM, Mazziotti MA, Cogliati C. Lung ultrasonography: A prognostic tool in non-ICU hospitalized patients with COVID-19 pneumonia. Eur J Intern Med 2021;85:34–40. https://doi.org/10.1016/j.ejim.2020.12.012.

[25] Lieveld AWE, Kok B, Azijli K, Schuit FH, van de Ven PM, de Korte CL, Nijveldt R, van den Heuvel FMA, Teunissen BP, Hoefsloot W, Nanayakkara PWB, Bosch FH. Assessing COVID-19 pneumonia-Clinical extension and risk with point-of-care ultrasound: A multicenter, prospective, observational study. J Am Coll Emerg Physicians Open 2021 May 1;2(3):e12429. https://doi.org/10.1002/emp2.12429.