Journal Pre-proof

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PII: S0301-5629(21)00190-3
DOI: https://doi.org/10.1016/j.ultrasmedbio.2021.04.011
Reference: UMB 12153

To appear in: *Ultrasound in Medicine and Biology*

Received date: 5 November 2020
Revised date: 16 March 2021
Accepted date: 12 April 2021

Please cite this article as: Samuel Pecho-Silva MSc. , Ana Claudia Navarro-Solsol MD. , Alvaro Taype-Rondan MSc. , Javier Torres-Valencia MD. , Kovy Arteaga-Livias MSc. , Daniel Albert Herriman MD. , Karim Acosta-Pinzas MD. , German Valenzuela-Rodriguez MD. , Joshuan J. Barboza MSc. , Vicky Panduro-Correa MSc. , Pulmonary ultrasound in the diagnosis and monitorization of coronavirus disease (COVID-19): a systematic review, *Ultrasound in Medicine and Biology* (2021), doi: https://doi.org/10.1016/j.ultrasmedbio.2021.04.011

Pulmonary ultrasound in the diagnosis and monitorization of coronavirus disease (COVID-19): a systematic review

Section: Original Article

Short Title: Pulmonary ultrasound for diagnosis of COVID-19

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Conflicts of Interest: The authors declare no conflict of interest.

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ABSTRACT

Systemize the evidence of pulmonary ultrasound (PU) use in diagnosis, monitorization or hospital discharge criteria for patients with COVID-19. Systematic review of evidence which utilized PU for diagnosis, monitorization, or as hospital discharge criteria for COVID-19 patients confirmed by RT-PCR between December 1st of 2019 and July 5th of 2020 compared with thoracic radiograph (TR), thoracic tomography (CT) and RT-PCR. Type of study, motives for PU, population, type of transducer and protocol, results of PU, and quantitative or qualitative correlation with TR and/or CT and/or RT-PCR were evaluated. Were evaluated 28 articles with 418 patients. Average age 50 years (SD 25.1 years), 395 adults and 23 children. 143 were women, 13 pregnant women. The most frequent result was diffuse, coalescent and confluent B-lines. The plural line was irregular, interrupted, or thickened. The presence of subpleural consolidation was noduliform, lobar, or multilobar. There was good qualitative correlation between TR and CT and a quantitative correlation with CT of r=0.65 (p<0.001). 44 patients were evaluated only with PU. PU is a useful tool for diagnosis, monitorization, and criteria for hospital discharge for patients with COVID-19.

Keywords: COVID-19, Pulmonary ultrasound, B-lines, Thoracic radiograph, Thoracic tomograph.

INTRODUCTION

Since the first cases were described in the province of Hubei in China the infection of coronavirus has become one of the most important infectious diseases of the century, and at the 20th of September almost 1 million deaths have been reported worldwide (Arteaga-Livias and Rodriguez-Morales 2020). Due to being a new disease, many questions of clinical characteristics, diagnosis, and treatment still remain (Dhama et al. 2020; Pecho-Silva et al. 2020).

The tools available for diagnosis and monitoring are important to ensure correct clinical decisions and a better comprehension of the evolution of the disease, as well as the possibility of complication of a patient with mild to moderate disease (Henriquez-Marquez et al. 2020). Diverse authors coincide in that pulmonary ultrasound (PU) can be used in diverse stages of the disease caused by coronavirus 2019 (COVID-19), including triage of asymptomatic patients, diagnosis, monitoring and follow-up, evaluation of response to treatment, aid in the decision to remove the patient from the mechanical ventilator and as a criterion for patient discharge (Gargani et al. 2020; Kristensen et al. 2014; Soldati et al. 2020). PU would also have an additional advantage over chest x-ray (CXR) and chest tomography (CT), as it is a procedure that can be performed with portable equipment, thereby minimizing patient mobilization and the number of healthcare personnel required, thus reducing the number of professionals exposed to a possible contagion (Convissar et al. 2020; Pecho-Silva 2020; Smith et al. 2020).

Some articles have been published about the use of PU in COVID-19, as well as reviews with less than 60 patients (Convissar et al. 2020; Smith et al. 2020). The number of articles published has increased rapidly, therefore it is imperative to have up-to-date data on this topic to help decision-making.

This review aims to systemize the published evidence on the use of PU in the diagnosis, follow-up and as a criterion for discharge of patients with COVID-19, and to evaluate its correlation with other diagnostic procedures such as CXR, CT and tests of reverse transcription polymerase chain reaction (RT-PCR).

MATERIALS AND METHODS

Search strategies.

This study was reported according to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) checklist. The protocol is available in the Figshare repository (Taype-Rondan 2020). A systematic search was carried out in the following databases (between December 1, 2019 to July 5, 2020), with the following terms shown below: ***Pubmed:*** ("2019/12/01"[Date - Publication]: "2020/07/05"[Date - Publication]) AND ([((lung or chest or pulmo* or thora*) and (ultraso* or sonog* or echography)) and (Covid* or SARS* or coronavirus*)]). ***Scopus:*** [(TITLE-ABS-KEY (*coronavirus OR sars* OR covid*) AND TITLE-ABS-KEY (ultraso* OR *sonography OR echography)) AND (LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019)) AND (LIMIT-TO (SUBJAREA , "MEDI")) AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Spanish"))]. ***Google Schoolar:*** [((lung or chest or pulmo* or thora*) and (ultraso* or sonog* or echography)) and (Covid* or SARS* or coronavirus*)].

Selection of studies

For this systematic review, all primary articles were included, including case series from more than one patient, as well as case reports (including letters to the editor); who have used the PU as part of the diagnostic evaluation and / or clinical follow-up and / or as a criterion for discharge of patients with COVID-19 confirmed by RT-PCR. Studies in which modifications had been made to the conventional PU technique were excluded.

The selection of articles was carried out independently by two investigators (SPS, ACNS). If there was no coincidence, a third investigator (JTV) decides to include or exclude the study. All the studies included in this systematic review had approval by the ethics committee.

Risk of bias.

The studies were rated for their quality according to the National Institutes of Health (NIH) Quality Assessment Tool for case series studies by two authors (KAL and VPC).

Extraction of data

The data from each study was extracted into a Microsoft Excel database designed for this purpose. The data of country, type of study, reason for which the PU was performed, population, type of transducer and evaluation protocol used, findings in the PU, and the qualitative and / or quantitative correlation reported between PU and other imaging techniques was collected. (CXR or CT).

Results

Search Strategy

The search strategy yielded 949 results and 510 duplicates records were removed. Of 439 records screened, 405 were excluded by title and abstract screening. Of 34 full-text articles assessed for elegibility, 6 articles were excluded, and 28 articles were included in qualitative analysis (Alkhafaji et al. 2020; Bar et al. 2020; Buonsenso et al. 2020a; Buonsenso et al. 2020b; Consoli et al. 2020; Denina et al. 2020; Duclos et al. 2020; Farrow et al. 2020; Feng et al. 2020; Huang et al. 2020 Inchingolo et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Shokoohi et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;) were included ***(Figure 1)***. The studies were classified as the following: 2 retrospective cohort studies that included 150 patients, 1 prospective cohort with 31 patients, a cross-sectional study with 26 patients, 14 case series that included between 3 and 30 patients, and 10 case reports. Of the articles, 26 were written in English, 1 in German and 1 in Chinese.

The 28 articles included a total of 418 patients with COVID-19 confirmed by RT-PCR. One hundred fifty patients were described in two retrospective cohorts, 31 patients in one prospective cohort study, 26 patients in one cross-sectional study, 201 patients in fourteen case series studies, and 10 patients in ten case reports studies. PU was performed in all 28 articles as part of the diagnosis, in 20 for clinical follow-up, in 5 as part of a routine procedure, and in 5 as an additional criterion to decide whether to discharge the patient from hospital or discharge from the unit of intensive care. The age of the patients was reported by 22/28 articles: one study (Feng et al. 2020) included 5 neonates aged 1 to 18 days, and another 21 articles registered 18 children or adolescents between 1 to 17 years and 395 Adults. In 22/28 articles the sex of the patients was described, finding 203 men and 143 women (Alkhafaji et al. 2020; Bar et al. 2020; Buonsenso et al. 2020a; Consoli et al. 2020; Denina et al. 2020; Duclos et al. 2020; Farrow et al. 2020; Feng et al. 2020; Huang et al. 2020; Inchingolo et al. 2020; Ji et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Shokoohi et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;) ***(Table 1)***.

Of the patients included, 13 were pregnant with an average gestation of 23.4 weeks (SD: 11.5 weeks) at the time of diagnosis (Buonsenso et al. 2020b; Inchingolo et al. 2020; Yassa et al. 2020). It was reported that the 13 fetuses did not present alterations during gestation and four deliveries were reported with products without infection at birth.

Characteristics of the PU procedure:

In 20 of the 28 studies the PU was a bedside procedure, while the remaining 8 studies transferred the patients to a specific area for the procedure. Regarding the transducer used, 19 articles reported this variable, of which 17 used a linear or convex transducer (Bar et al. 2020; Buonsenso et al. 2020a; Consoli et al. 2020; Farrow et al. 2020; Huang et al. 2020; Inchingolo et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Reisinger and Koratala 2020; Shokoohi et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Yang et al. 2020; Yassa et al. 2020;). In 15 of the 28 articles the ultrasound evaluation protocol used was mentioned. In 7 articles a protocol of 12 zones was used (Buonsenso et al. 2020a; Mongodi et al. 2020; Musolino et al. 2020; Peng et al. 2020; Shokoohi et al. 2020; Yang et al. 2020; 2020), in 4 articles a protocol of 6 zones was used (Alkhafaji et al. 2020; Farrow et al. 2020; Reisinger and Koratala 2020; Yasukawa and Minami 2020), in 1 article a protocol with 14 zones was used (Yassa et al. 2020) and in 3 articles a protocol of 8 zones was used (Bar et al. 2020; Nouvenne et al. 2020; Tung-Chen 2020).

Comparison with CXR and CT:

Two hundred seventy seven of 418 patients did not undergo CXR (Bar et al. 2020; Buonsenso et al. 2020b; Duclos et al. 2020; Huang et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;), including 7 of the 13 pregnant women. 56 patients of the 418 did not undergo CT (Bar et al. 2020; Buonsenso et al. 2020b; Duclos et al. 2020; Huang et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;) including 10 of the 13 pregnant women. 44 patients out of the 418 underwent neither CXR nor CT, being evaluated only by PU and RT-PCR (Bar et al. 2020; Buonsenso et al. 2020b; Duclos et al. 2020; Huang et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;). In the 5 articles that included these 44 patients, the authors did not describe a different clinical course from the rest of the patients evaluated with CXR and / or CT.

Due to the type of articles found in this systematic review, the global quantitative correlation of PU with CXR and / or CT could not be assessed, therefore we report the qualitative result described by the authors. Of the 14 articles that evaluated the qualitative correlation between the findings of PU and CXR, in 12 of them they considered it good and 2 (including the cohort of 84 patients) reported that PU was superior to CXR (Alkhafaji et al. 2020; Mongodi et al. 2020). Likewise, of the 20 studies that evaluated the qualitative correlation between PU and CT, 18 considered it good and 2 reported that PU was superior to CT (Feng et al. 2020; Yang et al. 2020) ***(table 1)***. Only the cross-sectional article reported a quantitative correlation between PU and CT, indicating that it was good with r = 0.65 and p <0.001 (Nouvenne et al. 2020).

In total, considering all procedures performed in studies that used CXR or CT (even repeat examinations), we found that PU was performed 18 times more than that of CXR, and 12 times more than that of CT. The cohort of 84 patients reported that PU reduced the use of CXR and CT by 31.8% before the use of PU to 3.6% after the use of this procedure (Mongodi et al. 2020).

Pulmonary Ultrasound findings and their correlation with CT findings

In ***table 2*** the PU findings are shown. All articles (Alkhafaji et al. 2020; Bar et al. 2020; Buonsenso et al. 2020a; Buonsenso et al. 2020b; Consoli et al. 2020; Denina et al. 2020; Duclos et al. 2020; Farrow et al. 2020; Feng et al. 2020; Huang et al. 2020; Inchingolo et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Shokoohi et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;) report the presence of B-lines: coalescent, multifocal, diffuse, confluent or “white lung”. The alteration of the pleural line was reported in 25 of 28 articles: irregular, thickened, interrupted. The alteration of the pulmonary parenchyma was reported as: presence of lobar, multilobar or noduliform subpleural consolidations with bilateral and posterior distribution. The presence of dynamic air bronchogram was described in 4 studies

(Consoli et al. 2020; Huang et al. 2020; Mongodi et al. 2020; Shokoohi et al. 2020). An article did not describe the presence or absence of pulmonary alterations (Inchingolo et al. 2020). An article indicated that no alterations to pulmonary parenchyma was found (Reisinger and Koratala 2020). Pleural effusion was reported in only one article (Denina et al. 2020). The presence of pneumothorax was only reported in one article (Consoli et al. 2020).

Table 3 shows the findings in PU reported in the 28 articles (Alkhafaji et al. 2020; Bar et al. 2020; Buonsenso et al. 2020a; Buonsenso et al. 2020b; Consoli et al. 2020; Denina et al. 2020; Duclos et al. 2020; Farrow et al. 2020; Feng et al. 2020; Huang et al. 2020; Inchingolo et al. 2020; Ji et al. 2020; Lomoro et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Palmese et al. 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Shokoohi et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;) included in this rapid systematic review, which have been grouped according to the location of the lesions: pleural line, presence of B-lines, lung parenchyma or pleural cavity, and its comparison with CT lesions due to COVID-19 (Figure 2).

Discussion

Results:

The results of the PU are similar and consistent between the different articles including this systematic review and simultaneously concur with the results of the systematic revisions and narratives (Ai et al. 2020; Antúnez-Montes and

Buonsenso 2020; Convissar et al. 2020; Fang et al. 2020; Fiala 2020; Fraile Gutiérrez et al. 2020; Mohamed et al. 2020; Ojha et al. 2020; Smith et al. 2020) and correlate in a qualitative manner with the results of the disease COVID-19 observed in CT (Ai et al. 2020; Fang et al. 2020; Ojha et al. 2020; Pan et al. 2020) and is summarized in ***Table 3***.

Characteristics

Our results show that PU has been used in various stages of the disease (diagnosis, follow-up and as an evaluation for discharge, and to observe the resolution of the lesions in a progressive manner) in an adequate manner and with benefits for the patient. We have included 418 patients, indicating that the use of PU continues to spread in patients with COVID-19, previous reviews have included fewer than 60 patients (Convissar et al. 2020; Smith et al. 2020) and a recent systematic review with meta-analysis included 122 patients (Mohamed et al. 2020) although More evidence is still required to define the usefulness of the PU in each of these stages.

The protocols of 12 zones are the most used in the articles reviewed (Buonsenso et al. 2020a; Huang et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Peng et al. 2020; Shokoohi et al. 2020; Yang et al. 2020;) including the study of cohorts of 84 patients, followed by the protocols of 6 zones (Alkhafaji et al. 2020; Farrow et al. 2020; Reisinger and Koratala 2020; Yasukawa and Minami 2020). However, these variants in the protocols used did not affect the presence or absence of pathological findings in PU or their way of being reported. It might be convenient to propose the use of the 12-zone protocol as it is the most widely used. Also, convex and linear transducers were the most used, which is important because most conventional ultrasound equipment have these transducers.

Other aspects to consider for the use of PU:

PU has other benefits, such as a greater availability compared to CT and RT-PCR, low cost per examination, ease of access, shorter time for the procedure, dynamic and repeated evaluation of pulmonary parenchyma, accessibility to bedridden patients, safety for pregnant women, ease of integration of telemedicine in zones which lack trained specialists, and immediate results unlike that of RT-PCR (Alkhafaji et al. 2020; Bar et al. 2020; Buonsenso et al. 2020a; Buonsenso et al. 2020b; Consoli et al. 2020; Convissar et al. 2020; Denina et al. 2020; Duclos et al. 2020; Farrow et al. 2020; Feng et al. 2020; Gargani et al. 2020; Huang et al. 2020; Inchingolo et al. 2020; Ippolito et al. 2020; Ji et al. 2020; Kristensen et al. 2014; Lomoro et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Musolino et al. 2020; Nouvenne et al. 2020; Ojha et al. 2020; Palmese et al. 2020; Pan et al. 2020; Pecho-Silva 2020; Peng et al. 2020; Poggiali et al. 2020; Reisinger and Koratala 2020; Schiaffino et al. 2020; Shokoohi et al. 2020; Smith et al. 2020; Soldati et al. 2020; Thomas et al. 2020; Tung-Chen 2020; Xing et al. 2020; Yang et al. 2020; Yassa et al. 2020; Yasukawa and Minami 2020;).

Regarding the learning process, the authors of some included articles have mentioned that its implementation is short and therefore feasible (Ippolito et al. 2020; Lu et al. 2020; Mongodi et al. 2020; Ojha et al. 2020; Pan et al. 2020; Pecho-Silva 2020; Schiaffino et al. 2020; Shokoohi et al. 2020; Smith et al. 2020; Yang et al. 2020). PU also has the benefit that the cleaning and disinfection of the equipment is much easier and faster than that of the CXR or CT equipment and the same disinfection protocols are used.

In addition, portable PU equipment is becoming less expensive and with higher resolution, and allowing the transmission of images via Wi-Fi or Bluetooth, so only a single healthcare personnel would have to approach the patient to perform the procedure while the rest can receive the images outside the patient's isolation room without exposing themselves to potential contagion (Antúnez-Montes and Buonsenso 2020; Buonsenso et al. 2020a; Fraile Gutiérrez et al. 2020; Gargani et al. 2020; Mohamed et al. 2020; Musolino et al. 2020; Shokoohi et al. 2020; Tung-Chen 2020). Up to now, no contraindications to the use of the PU or any complications from its use have been described.

What does the literature say about Pulmonary ultrasound in coronavirus disease (COVID-19)?

So far, the PU is a useful tool for diagnosis, monitoring, and criteria for hospital and ICU discharge for patients with COVID-19. Up to now, no contraindications to the use of the PU or any complications from its use have been described. The findings in PU are similar between the different authors and correlate qualitatively well with the tomographic findings and better than the X-ray findings in patients with Covid-19. The use of PU could replace in selected cases chest radiography and / or tomography in the diagnosis and follow-up of patients with Covid-19 (Convissar et al. 2020; Smith et al. 2020).

Findings from this study

This review has grouped the largest number of patients with covid-19 evaluated with PU until now. Findings in PU of multifocal, multilobar, subpleural, posterior alterations of the pleural line of the coalescent, irregular, interrupted, thickened type together with alterations of the pulmonary parenchyma of multilobar or lobar distribution, with dynamic air bronchogram, are frequent findings and consistent with Covid-19 and aid in diagnosis, follow-up, evaluation of response to treatment and as criteria for discharge from the intensive care unit or hospital. The PU could replace the chest-x ray and could reduce the exposed to ionizing radiation to the patient and also reducing the displacement of the patient from his unit and thus exposing less staff and other patients to the intranosocomial transmissibility of Covid-19.

A suggested acquisition protocol:

- Use convex or linear transducers. The latter are preferable to study the detail of the pleural and subpleural alterations.
- Use a single–focal point or multifocusing modality and set the focal point on the pleural line.
- Preferably, scans need to be intercostal 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, 12 areas in total should be evaluated: anterior midclavicular upper and lower in the right and in the left; posterior paraspinal (apical, medial, and basal), right and left; and lateral axillary (medial) right and left.

Limitations:

Some of the limitations of this systematic review have to do with the quality of the evidence that comes from only two retrospective cohort studies, one from a prospective cohort and one from a cross-sectional one, and the remaining letters to the editor, case series and case reports. Another limitation is the different evaluation protocols used to carry out the PU. A final limitation would be that the PU does not allow the detection of lesions that are not subpleural or peripheral, however, this would also be of little relevance since COVID-19 lesions are usually subpleural or peripheral and therefore evaluable by the PU (Convissar et al. 2020; Mohamed et al. 2020; Poggiali et al. 2020; Smith et al. 2020; Soldati et al. 2020).

The studies found show that in the world more experience is accumulating on the use of PU in patients with COVID-19, even in pregnant women and children. In addition, they report adequate sensitivity and specificity for the diagnosis of COVID-19, and no articles have been published that have found that PU is not useful or that it is harmful to the patient. This suggests that PU is an advantageous tool. However, studies of higher methodological quality are required to corroborate the current findings.

Acknowledgements: None

Sources of funding: This research has not received specific funding from public sector agencies, the commercial sector or non-profit organizations.

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Table 1. Characteristics of included articles

N	Author (Country)	Motive *	Population: N (M|F)**	Trans***	Protocol	CXR Correlation ****	CT Correlation ****
Retrospective cohort							
1	Mongodi (Italy)(Mongodi et al. 2020)	D, M, Dis	Hospitalized adults in ICU: 84 (65|19)	Ln/Sec	12 zones	Superior	Good
2	Palmese (Italy)(Palmese et al. 2020)	D, M, Dis	Hospitalized adults in ICU: 66 (36|30)	NR	NR	NP	Good
Prospective cohort							
3	Bar (France)(Bar et al. 2020)	D, M	Hospitalized adults: 31 (11|20)	Cvx	8 zones	NP	Good
Cross-sectional study							
4	Nouvenne (Italy)(Nouvenne et al. 2020)	D	Hospitalized adults: 26 (14|12)	Ln/Cvx	8 zones	NP	Good r=0.65 (p<0.001)
Case series							
5	Lu (China)(Lu et al. 2020)	D, M	Hospitalized adults: 30 (NR)	NR	NR	NP	Good

6	Yang (China)(Yang et al. 2020)	D, M	Hospitalized adults: 29 (18|11)	Cvx	12 zones	NP	Superior
7	Lomoro (Italy)(Lomoro et al. 2020)	D, M, R	Hospitalized adults: 22 (NR)	Ln/Cvx	NR	Yes, good in 11	Yes, good in 16
8	Peng (China)(Peng et al. 2020)	D	Adults: 20 (NR)	NR	12 zones	NP	Good
9	Huang (China) (Huang et al. 2020)	D, M	Hospitalized adults: 20 (11|9)	Ln/Cvx	12 zones	NP	Good
10	Xing (China)(Xing et al. 2020)	D, M	Hospitalized adults: 20 (12|8)	NR	NR	NP	NP
11	Poggliani (Italy)(Poggiali et al. 2020)	D	Hospitalized adults: 12 (9|3)	NR	NR	NP	Good
12	Yasukawa (US)(Yasukawa and Minami 2020)	D, M	Hospitalized adults: 10 (7|3)	Sec	6 zones	NP	Yes, good in 1
13	Musolino (Italy)(Musolino et al. 2020)	D, R	Hospitalized children: 10 (6|4)	Ln/WL	12 zones	Yes, good in 2	Yes, good in 1

14	Yassa (Turkey)(Yassa et al. 2020)	D, M, Dis	Hospitalized pregnant women: 8 (0|8)	Cvx	14 zones	3/8 Good	5/8 Good
15	Denina (Italy)(Denina et al. 2020)	R	Hospitalized children: 8 (5|3)	NR	NR	Yes, good in 7	Good
16	Feng (China)(Feng et al. 2020)	D, M	Hospitalized children: 5 (3|2)	NR	NR	Good	Superior
17	Buonsenso (Italy)(Buonsenso et al. 2020b)	D, M	Hospitalized pregnant women in ICU: 4 (0|4)	NR	NR	Yes, good in 2	NP
18	Shokoohi (Spain) (Shokoohi et al. 2020)	D, M	Hospitalized adults in UCI: 3 (1|2)	Ln/WL	12 zones	Good	Good
Case Reports							
19	Thomas (US)(Thomas et al. 2020)	D, M	Hospitalized adult: 1 female	Cvx	NR	Good	NP
20	Buonsenso (Italy)(Buonsen	D, M	Hospitalized adult: 1	Cvx/WL	12 zones	Good	Good

	so et al. 2020a)		male				
21	Reisinger (US)(Reisinger and Koratala 2020)	D, M	Hospitalized adult: 1 female	Cvx/WL	6 zones	NP	NP
22	Ji (China)(Ji et al. 2020)	D	Hospitalized adult: 1 female	Cvx	NR	NP	Good
23	Tung-Chen (Spain)(Tung-Chen 2020)	D, M, Dis	Hospitalized adult: 1 male	Cvx/WL	8 zones	NP	NP
24	Inchingolo (Italy)(Inchingolo et al. 2020)	D	Hospitalized pregnancy: 1 female	Cvx	NR	Good	NP
25	Farrow (US)(Farrow et al. 2020)	D	Hospitalized adult: 1 female	Cvx	6 zones	Good	Good
26	Alkhafaji (US)(Alkhafaji et al. 2020)	D, M	Hospitalized adult: 1 male	Ln	6 zones	Superior	NP
27	Duclos (France)(Duclos et al. 2020)	D, M	Adult in ICU: 1 male	NR	NR	NP	Good
2	Consoli	D, M	Hospitalize	Cvx	NR	Good	Good

8	(Italy)(Consoli et al. 2020)		d adult: 1 male				

*Motive: D=Diagnosis, M=Monitorization, R=Routine, Dis=Discharge

**Population: number of cases (male | female). Abbreviations: ICU: Intensive care unit.

***Trans: Transducer utilized. Cvx: Convex. Ln: Linear. WL: Wireless. Sec: Sectorial.

****CT. Thoracic tomography. TR: Thoracic radiograph. NR: No report. NP: Not performed. Good or superior correlation: based on the author's qualitative report, statistical testing was not performed.

Table 2. Results of informed pulmonary ultrasound of COVID-19 patients informed by included the articles

N*	B-Lines	Pleural line	Consolidation
Retrospective Cohort			
1	Yes, Multifocal, Coalescent	Non-sliding, Irregular	Multilobar, Lobar, Dynamic air bronchogram
2	Yes, Focal and multifocal, Diffuse	Irregular, Interrupted	Multilobar
Prospective Cohort			
3	Yes, Confluent	Thickened	Consolidated
Transversal			

4	Yes, Diffuse, Coalescent	Irregular	Microconsolidations and consolidations
Case Series			
5	Yes, Interstitial syndrome	NR	Present, lobar, Posterior, Subpleural, Peripheral
6	Interstitial syndrome	Irregular, thickened	Multilobar, Subpleural, Posterior
7	Yes, Diffuse	Irregular	Subpleural, Bilateral, Posterior
8	Yes, Diffuse, Bilateral	Thickened, Irregular	Subpleural, Bilateral, Posterior
9	Yes, Coalescent, Confluent	Thickened Irregular	Nodular consolidation, Bronchogram, Patches, Bilateral
10	Yes, Confluent, Diffuse	Irregular, Interrupted	Bilateral, Multilobar
11	Yes, Diffuse	Irregular	Subpleural, Occasional, Bilateral
12	Yes, Confluent, White lung	Irregular	Subpleural, Lobar, Bilateral
13	White lung	Irregular	Subpleural, Posterior, Bilateral
14	Yes, Bilateral, Coalescent	Irregular	Subpleural, Bilateral, Pleural effusion
15	Yes, Confluent	NR	Subpleural
16	Yes, White lung	Irregular	Small, Subplerual
17	Yes, Diffuse	Irregular	Consolidation, Bilateral, Posterior

18	Yes, Coalescent	Irregular, Thickened	Lobar, Bilateral
Case Reports			
19	Yes, Posterior, Bilateral	Thickened	Bilateral
20	Yes, Coalescent	NR	Subpleural nodular
21	Yes, Coalescent	Irregular	No
22	Yes, Coalescent	Irregular	Subpleural, Present
23	Yes	Irregular	Subpleural, Unilateral
24	Yes, White lung	Thickened	NR
25	Yes, Diffuse	Irregular	Present
26	Yes, Multifocal	Regular, Thickened	Subcentimetric, Lobar, Posterior
27	Yes, Diffuse and Coalescent	Irregular	Multilobar, Bilateral
28	Yes, Multifocal and Coalescent	Thickened, Non-sliding	Pneumothorax, Dynamic air bronchogram

*According to the numeration of table 1.

NR: No report

Table 3. Pulmonary ultrasound findings and their correlation with Thoracic Tomograph in the diagnosis of pleuroparenchymal disease of COVID-19

Thoracic Tomograph	Pulmonary Ultrasound
Pleural thickening	Thickening and irregularity of the pleural wall
Subpleural ground-glass opacities	B-lines (multifocal, discrete, confluent)
Reticular interstitial lesions	Confluent B-lines
Subpleural consolidation	Subpleural consolidations with dynamic air bronchogram
Translobar consolidation	Translobar consolidation
Rare presence of pleural effusion	Rare presence of pleural effusion
Multilobar, basal, posterior	Multilobar, basal, posterior

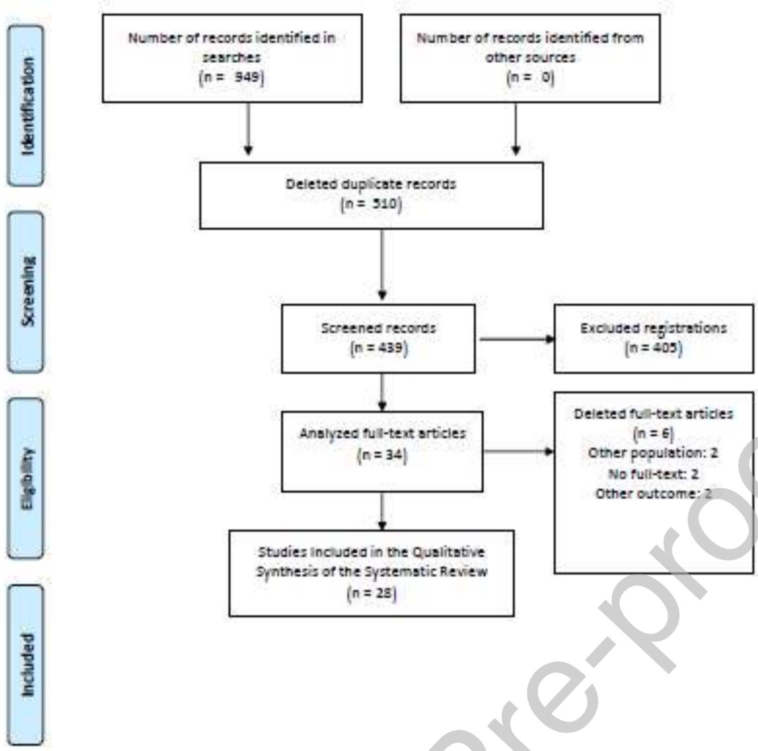


Figure 1. Article selection flowchart.

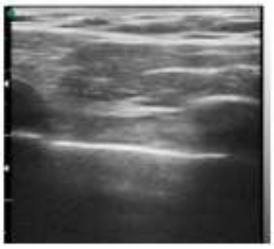
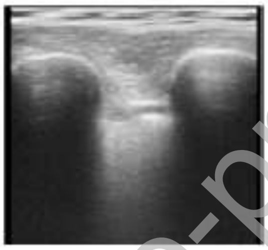
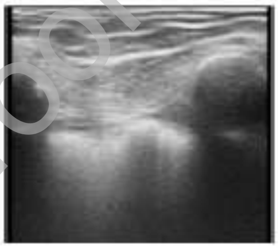
Pulmonary Phase IIA Image A	Pulmonary Phase IIB Image B	Hyperinflammation Phase Image C
• Development of B-lines. • The pleural line begins to become irregular. • Areas with B-lines are adjacent to normal areas of lung sliding and A-lines.	• B-lines continue to increase in number and distribution. • Thickening and irregularity of the pleural wall. • B-lines (multifocal, discrete, confluent). • Begin to affect the upper and anterior areas of the lungs. • Small consolidations increase in number and size.	• Subpleural consolidations with dynamic air bronchogram. • Extensive coalescent B-lines affect different areas of the lungs. • Confluent B-lines. • Translobar consolidation with or without air bronchograms. • Pleural effusions are small or rare.
		

Figure 2. A simplified description of the main lung ultrasound findings by stage of COVID-19 disease.

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