Review Article

The Role of the Lung Ultrasound in Coronavirus Disease 2019: A Systematic Review

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Abstract

The coronavirus disease 2019 (COVID-19) pandemic has now infected six million people and is responsible for nearly four hundred thousand deaths. We review the potential role of the lung ultrasound to evaluate its benefits and potential roles to compare it to the current gold standard of computed tomography. A literature search was carried out utilizing electronic search engines and databases with COVID-19. Keywords related to the lung ultrasound (LUS) were used to refine this search – only the relevant articles found are cited. This review showed that there exists a strong correlation between the CT and LUS scan in COVID-19. Prominent features include the vertical B-lines, thicker pleural lines, and subpleural consolidation. Potential roles include reducing transmission between health-care workers and monitoring the progress of the disease. However, the current research is scarce compared to well-established imaging modalities, and as such, there is a necessity for more research to confirm the findings of this review.

Keywords: Coronavirus, coronavirus disease 2019, ultrasound

Introduction

The coronavirus disease 2019 (COVID-19), which began as an outbreak in the city of Wuhan, Hubei Province in China, has led to a global pandemic which has severely impacted many countries worldwide. The disease is caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is phylogenetically linked with the genus betacoronavirus, which includes other coronaviruses such as SARS-CoV. Transmission of the COVID-19 virus is primarily through respiratory droplets and contact routes. It can lead to clinical features such as fever, cough, anosmia, myalgia, chest tightness, fatigue, and dyspnea.[1] According to the World Health Organization data as of the 6th of June 2020, there are 6,663,304 cases and 392,802 deaths globally.[2] The diagnosis of COVID-19 involves taking a swab from the nose and back of the throat and can be either self-administered or assisted. Patients are then further classified into those who are well enough to remain in the community and those who should be admitted as inpatients. A key aspect of the criteria for admission as inpatients is clinical or radiological evidence of pneumonia.[1]

Hence, various imaging modalities such as computed tomography (CT), positron emission tomography-CT, chest radiographs, lung ultrasound (LUS), and magnetic resonance imaging have been used to aid the diagnosis of COVID-19 as well as to determine disease progression and to assess the impact of treatment strategies on disease resolution.[3] This review will focus on the uses of ultrasound in the diagnosis and management of COVID-19, its advantages and disadvantages as well as future avenues of research.

Methods and Materials

Search strategy

A comprehensive literature search was conducted on PubMed, SCOPUS, Embase, Cochrane database, Google

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Scholar, and Ovid to identify articles that discussed the role of ultrasound in the diagnosis and management of COVID-19 following the protocol set by the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines.

Keywords used were: COVID-19, coronavirus, LUS, pneumonia, lung imaging, SAR-CoV-2, ultrasound, thorax, and pulmonary.

The search terms were used as keywords and in combination as MeSH terms to maximize the output from literature findings. The literature search was staged, by which a separate literature search was conducted for each section of this article; all the relevant studies were identified and subsequently summarised individually. If a paper reports on multiple aspects of the use of ultrasound, then the results were shared in the different parts of the review. Relevant articles have been cited and referenced within each section separately. No limit has been placed on publication time, while studies not written in the English language have been excluded. The search was conducted over the period of 1 week from 05/05/2020 ot 01/06/2020. All the relevant articles were identified and screened by two authors; the results of these are summarized in a narrative manner in the respective sections within the body of this review. Summary tables of each section are provided where appropriate.

Inclusion and exclusion criteria

Studies were included if they have discussed the role of ultrasound in either diagnosis or management of COVID-19. Exclusion criteria were editorials, consensus documents, commentaries, and studies with no particular definition of the role of ultrasound in COVID-19.

Data extraction

All articles screened by two authors, and any disagreement was reached by consensus or involvement of the third author. Data extracted by two authors and validated by the third author.

Quality assessment

The quality of each publication was evaluated by two independent reviewers. This review addressed key domains: the findings of LUS in COVID-19 and how it correlates with CT as well as the potential roles ultrasound can undertake.

Statistical analysis

It was not feasible to carry out an appropriate meta-analysis as there was not enough research data among studies in this field.

Results

A total of 57 articles were found. After removal of duplicates, 29 articles were used for full-text screening with seven studies included in our analysis. In addition, three case reports were further included to highlight previous evidence. The complete PRISMA flow chart is reported in Figure 1. The features of the LUS in COVID-19 patients along with two potential roles for the use of the LUS, were highlighted as a result of the search. The study characteristics are summarized in Tables 1 and 2.

Lung ultrasound in coronavirus disease 2019

In the rapidly evolving field of COVID-19, the gold standard for both diagnosis and management is high-resolution CT. The typical pathological changes seen in this imaging modality are numerous. A prominent feature is a ground-glass opacity making the pulmonary vasculature visible along with consolidation following inflammatory exudation accompanied by an air bronchus sign. Other signs include vascular lesions, a halo sign, fibrous lesions, and an interlobular interval line shadow superimposed on the ground glass opacity– typically referred to as a paving stone sign.[14]

However, given that the LUS can adequately identify pathological changes in the lung parenchyma that may not be apparent in chest radiography, there exists a role for the supplementation of clinical care of COVID-19 patients with the LUS. For this, it is important to highlight the pathological changes detected in the LUS.

In all seven studies, the primary indication of pathology seen in the majority of patients is the presence of B-lines. Generally, the normal lung presents with A lines– the horizontal artifacts which arise from the pleural line. However, in the COVID-19 lung, these have been replaced by so-called B-lines, which are vertical artifacts arising from a loss of normal lung aeration.[15] Of note, there are different variations of B-lines with many different versions present in COVID-19 patients. Of the ten patients included by Yasukawa and Minami, all of the patients presented with five or more B lines – known as the glass rockets.[4] In turn, the presence of glass rockets is correlated with ground-glass opacities seen in CT.[16] Nonetheless, there are multiple presentations of B-lines detected in COVID-19: focal, multifocal, and confluent B-lines were all noted by various studies.[5,6]

Other common findings include the thickening of the pleural line in patients reflecting the inflammatory thickening of the visceral and parietal pleura.[5,6] Another sign was the prominence of subpleural consolidation.[4,6-8] However, the prevalence of this sign among the studies was rarer than the presence of B-lines or thicker pleural lines. Only three out of 12 patients presented with subpleural consolidation in a study conducted by Poggiali *et al*., while in a different sample of 22 patients subpleural consolidation was present in six patients.[6,8] Subpleural consolidation was also highlighted by the available case reports.[11,12]

Finally, an extremely rare sign was the presence of pleural effusion reported by numerous studies but in small proportions compared to sample size. In regard to the work conducted by Lomoro *et al*. and Soldati *et al*., there was only one patient with pleural effusion in 22 and three patients, respectively, while Yasukawa and Minami found no pleural effusion in 10 patients.[4,6,7]

Beyond the pathological changes noted by the LUS, a case series of four pregnant women in Rome, Italy, presented by Buonsenso *et al*. details how the LUS was more sensitive than

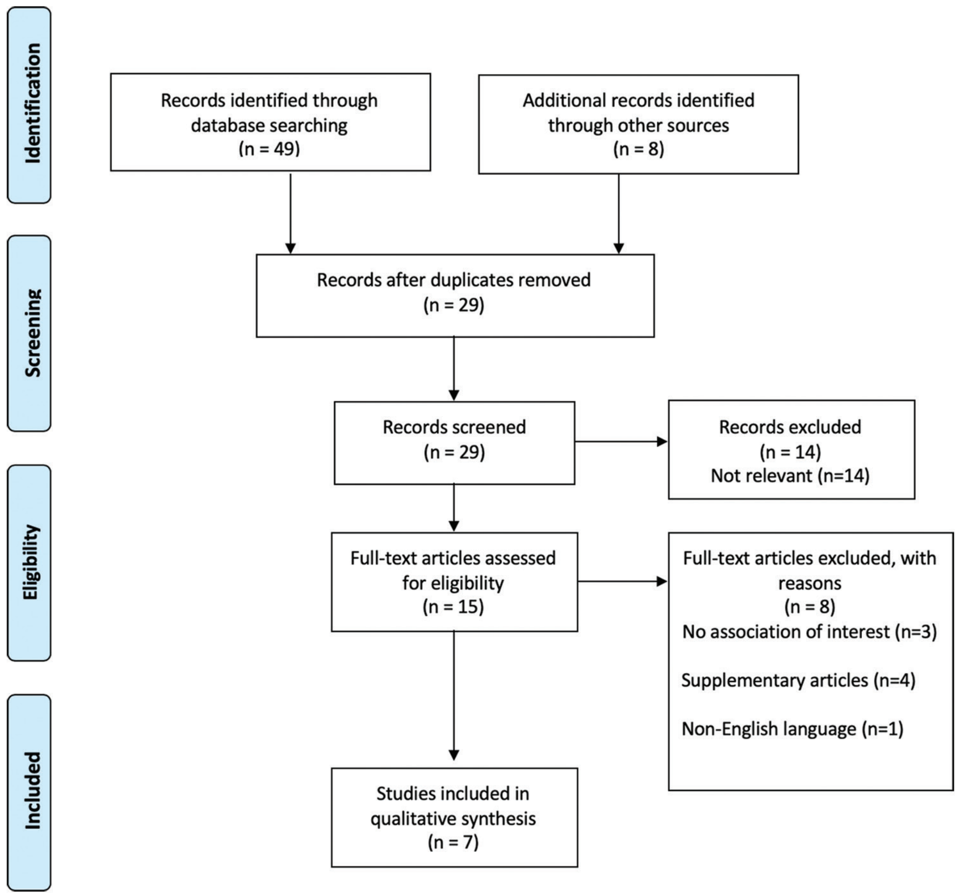

Figure 1: Preferred Reporting Items for Systematic Reviews and Meta-analysis flow chart

the chest radiograph in detecting COVID-19.[9] While efforts are made to stress the utility of CT in detecting COVID-19, there exists small populations where this may not be feasible, and as such, it would be important to consider an LUS as opposed to a chest radiograph. Similar findings were also detailed by a case report.

One key finding was that there exists a strong correlation between the CT and LUS scan in COVID-19. A cohort of 12 patients in Piacenza, Italy, underwent both LUS and CT scans.[8] In these patients, the findings of both imaging modalities were strongly correlated, and both modalities were able to independently detect the presence of COVID-19 pneumonia– suggesting the LUS has a role in aiding clinical decision-making where a CT may not be available. However, this study is only comprised of 12 patients and any extrapolations are subsequently difficult and would require clear evidence of repeatability. Another study by Huang *et al.* also suggested a strong correlation between CT and LUS. This study explored the association between ultrasonic and CT manifestations in 20 con-critical COVID-19 patients. High-resolution CT images tended to show ground-glass opacity and air bronchograms whilst LUS findings tended to show B lines. However, this study is again limited due to its small sample size and the fact that no control studies were conducted. This study indicated that as findings correlate between the two imaging modalities, there is use for LUS in the diagnosis and treatment of COVID-19 in noncritical patients and in scenarios where a CT scan is inappropriate or difficult to obtain.[10]

Potential uses of lung ultrasound

Through reviewing the literature there has been identified three main applications of ultrasound in COVID-19, which will be discussed further.

The first main advantage is that ultrasound equipment used can be properly cleaned and disinfected between patient uses compared to the traditional stethoscopes used to auscultate lung bases. A study by Ong *et al*. found that there was significant environmental contamination from patients with COVID-19 through respiratory droplets and fecal shedding, which supports the need to adhere to strict hygiene guidelines to avoid transmission of the disease.[17] Hence, the use of ultrasound technology can minimize the risk of infection between patients and reduce the spread of the virus while also aiding in its diagnosis and management.

A second potential use of LUS is in the monitoring of pathological progression of COVID-19 pneumonia, which in turn helps prognostic stratification, and monitoring of patients with pneumonia as well as enabling monitoring of the effect of

Table 1: Study characteristics

Author	Study design	Country	Cohort size	Radiological findings on ultrasound	Additional features
Yasukawa and Minami[4]	Retrospective, observational	America	10	All patients had glass rocket sign, with half presenting with the Birolleau variant. All patients also had thick, irregular pleural lines with subpleural consolidations in five out of 10 patients	Correlation with CT (not assessed) Disinfection protocols: Disinfectant wipes were used after each use on the tablet and probe Monitoring disease course (not assessed) Pregnant women assessed (not assessed)
Peng *et al*.[5]	Prospective, observational	China	12	B lines found in most patients – with a confluent pattern. Thickened pleural lines and small consolidation present. Pleural effusion is rare. All abnormalities were distributed across multiple lobes	Correlation with CT (not assessed) Disinfection protocols (not reported) Monitoring disease course (not assessed) Pregnant women assessed (not assessed)
Lomoro *et al*.[6]	Retrospective, observational	Italy	22	Multiple different patterns of B lines (focal, multifocal, and confluent). Subpleural consolidation and thickened pleural lines are present but rare	Correlation with CT (not assessed) Disinfection protocols (not reported) Monitoring disease course (not reported) Pregnant women assessed (not reported)
Soldati *et al*.[7]	Prospective, observational	Italy	3	Key findings were the presence of B lines – often confluent and patchy in appearance. All patients presented with subpleural consolidation; however thickened pleural lines were not present. Only one of three patients presented with pleural effusion and even this was described as minimal	Correlation with CT (not assessed) Disinfection protocols (not reported) Monitoring disease course (not reported) Pregnant women assessed (not reported)
Poggiali *et al*.[8]	Prospective, observational	Italy	12	Most common finding was diffuse B line pattern, with only 3 patients showed posterior subpleural consolidations with no mention of thickened pleural lines	Correlation with CT: Strong correlation between CT and LUS findings specifically regarding bilateral lung involvement and ground glass opacity Disinfection protocols (not reported) Monitoring disease course (not reported) Pregnant women assessed (not assessed)
Buonsenso *et al*.[9]	Prospective, observational	Italy	4	Multiple B-lines seen across all four patients; small consolidations seen without any thickening to the pleural lines. Irregular pleural lines seen in all four patients as well	Correlation with CT (not assessed) Disinfection protocols: Probe and tablet kept in sterile covers replaced after each use Monitoring disease course: Multiple LUS recordings taken through 4 days Pregnant women assessed: All cases in this study were pregnant women
Huang *et al*.[10]	Retrospective, observational	China	20	Visible B lines were present in many patients alongside pleural thickening and subpleural consolidation was also noted. "White lung" sign was also present	Correlation with CT: Case-by-case correlation between LUS and CT demonstrated Disinfection protocols: 75% alcohol was used disinfect the device while film was used to protect the device Monitoring disease course (not assessed) Pregnant women assessed (not assessed)

CT: Computed tomography, LUS: Lung ultrasound

Table 2: Case reports

Author	Country	Comments
Buonsenso *et al*.[11]	Italy	Areas of thick confluent B-lines with small subpleural consolidations with an irregular pleural line. Compared to a control of COVID-19 test negative patient
Thomas *et al*.[12]	Canada	After 10 days of symptoms onset – a LUS revealed multifocal B-lines, pleural thickening and subpleural consolidation
Kalafat *et al*.[13]	Turkey	Thick B-lines and lung consolidation alongside thickened pleura in a pregnant woman detected alongside CT scan

CT: Computed tomography, LUS: Lung ultrasound, COVID-19: Coronavirus disease 2019

therapeutic strategies. Current clinical evidence suggests that findings on LUS of patients with COVID-19 pneumonia are characteristic of the disease. These findings are primarily those detailed above. The evolution of these consolidations as they extend through the lung surface indicate respiratory insufficiency and the need for invasive ventilatory support in these patients.[18] This suggests that LUS has a place in the diagnosis and management of COVID-19. However, it is important to note that LUS cannot detect deep lesions within the lung and cannot detect pneumonia that does not extend to the pleural surface, meaning LUS may need to be used alongside CT scan images.

The third major use of LUS in COVID-19 would be in pregnant women and intensive care patients in whom decision with regards to weaning from ventilation will be required. As LUS is portable and allows of point of care use for the rapid assessment of SARS-CoV-2 severity, it can be used in intensive care patients to make decisions regarding their need for ventilation and to assess the effect of treatment strategies. The use of LUS in pregnant women is particularly important as unlike CT scanning, exposure to radiation, which can be harmful to the baby, is avoided. An article by Moro *et al*. proposes a possible procedure for carrying out LUS in pregnant women. This procedure involves various steps for disinfection, positioning the patient in supine, prone, left- and right-sided positions, and assessing for the following ultrasound parameters associated with COVID-19: pleural line (regular or irregular); B-lines (sporadic, multi-confluent); white lung and the presence of subpleural consolidations.[19]

Discussion

The global pandemic of COVID-19 is one that has spread rapidly and placed enormous strain on clinical care provision. The variation of symptoms, severity, and presentation makes decisions regarding diagnosis and management increasingly difficult. As such, it is vital to make maximum use of all available and appropriate facilities to ease the burden on healthcare. While CT is the gold standard, it exists in a difficult scenario. Radiology suites can become hubs of transmission following continual use by infective patients – requiring constant cleaning and disinfection – placing further stress on an imaging modality with a difficult logistical situation. Similarly, the risks associated with radiation exposure to patients have to be considered in the continual use of CT scans.[20]

It is here that the LUS presents an alternative route to gain valuable insight into the status of a COVID-19 patient. This review has established the typical findings of an LUS in a COVID-19 patient: the presence of B-lines, pleural thickening, subpleural consolidations are among those that are most prominent, while pleural effusions are not typically seen. Along this line, we have suggested a few potential roles for the LUS: uses in reducing nosocomial transmission, monitoring the progress of patients, and a possible role in sub-populations who are vulnerable to COVID-19 but are similarly ill-suited to a CT such as pregnant women. In Table 3, we have compiled a comparison of the advantages to the disadvantages regarding the use of LUS in this pandemic. It is important to highlight that the weight of evidence regarding CT is, at the moment, much higher. As such it is vital to stress the LUS should only be considered as adjacent tool which has its own utility but currently cannot replicate the sensitivity and specificity of CT scans. Importantly, the LUS cannot be used in deeper lesions, and CT is vital here.

Future avenues of research

Whilst this article highlights important uses of LUS in COVID-19 future research must focus on how LUS can be readily applied in a clinical setting. This would involve having to create guidelines for assessing the severity of COVID-19 pneumonia and applying these guidelines in multi-center studies with large sample sizes to determine their effectivity in the diagnosis and prognostication of COVID-19. Furthermore, a large amount of resources must be used to upscale and upskill the existing ultrasound workforce on the principles of LUS in patients with COVID-19, especially in the two patient groups who would most appear to benefit from the use of LUS-pregnant women and patients in intensive care.

Limitations

While this review provides a basis for the application of LUS in COVID-19, it is also pertinent to highlight some of its limitations. Currently, there is a sparsity of research looking into the role of LUS. Many of the studies identified in our search would not be considered strong,[21] and therefore, there are challenges extrapolating further conclusions. The largest cohort presented was just 22 patients, while it is difficult to conduct research in an on-going pandemic, we urge for more analysis to be conducted in the hope of providing different ways to address the burden of COVID-19. Another such aspect of the presented research is the lack of detailed operational procedure reporting that, in turn, minimizes the potential to draw conclusive comparisons. This could be addressed by the proposals to standardize the procedure of LUS in patients with COVID-19.[18] Here, there is a detailed operational procedure accompanied by potential image acquisition and scoring system that would contribute to the meaningful discussion regarding the results of individual studies. Alongside this, there

Table 3: Advantages and disadvantages of lung ultrasound in coronavirus disease 2019

Advantages	Disadvantages
Point of care use allows rapid assessment of SARS-CoV-2 severity and enables tracking of the evolution of disease	LUS cannot detect deep lesions within the lung
Absence of radiation is useful in pregnant women with COVID-19	LUS cannot detect pneumonia that does not extend to the pleural surface
Low cost of LUS compared to other imaging modalities	Existing ultrasound workforce needs to be upscaled and upskilled through education on the principles of LUS in patients with COVID-19
Prevents disease transmission between patients	

LUS: Lung ultrasound, COVID-19: Coronavirus disease 2019, SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2 have been reports that the B-lines seen in lung pathology are relatively difficult to reproduce, and there exists variability between the reproduction of the B-lines depending on the transducer used.[22] Hence, due to the limitations associated with the studies included in this review, further multicenter trials with increased patient numbers will be needed to properly assess the utility of ultrasound in the diagnosis and management of COVID-19.

Conclusion

Ultimately, there is a well-established burden on radiology suites in the COVID-19 pandemic. It is possible that some of this can be alleviated through the integration of the LUS as a more common imaging modality and therefore plays a vital role in aiding clinicians.

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Conflicts of interest

There are no conflicts of interest.

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