Review

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# The utility of lung ultrasound in COVID-19: A systematic scoping review

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## Abstract

**Introduction:** Lung ultrasound (LUS) has an established evidence base and has proven useful in previous viral epidemics. An understanding of the utility of LUS in COVID-19 is crucial to determine its most suitable role based on local circumstances.

**Method:** Online databases, specialist websites and social media platforms were searched to identify studies that explore the utility of LUS in COVID-19. Case reports and recommendations were excluded.

**Findings:** In total, 33 studies were identified which represent a rapidly expanding evidence base for LUS in COVID-19. The quality of the included studies was relatively low; however, LUS certainly appears to be a highly sensitive and fairly specific test for COVID-19 in all ages and in pregnancy.

**Discussion:** There may be LUS findings and patterns that are relatively specific to COVID-19; however, specificity may also be influenced by factors such as disease severity, pre-existing lung disease, operator experience, disease prevalence and the reference standard.

**Conclusion:** LUS is almost certainly more sensitive than chest radiograph for COVID-19 and has several advantages over computed tomography and real-time polymerase chain reaction. High-quality research is needed into various aspects of LUS including: diagnostic accuracy in undifferentiated patients; triage and prognostication; monitoring progression and guiding interventions; the persistence of residual LUS findings; inter-observer agreement and the role of contrast-enhanced LUS.

## Keywords

Lung ultrasound, focused ultrasound, point-of-care ultrasound, COVID-19, SARS-CoV-2

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## Introduction

### Rationale

Coronavirus disease 2019 (COVID-19) is caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and was declared a global pandemic on 11th March 2020 by the World Health Organisation. As of the 10th June, there have been over seven million confirmed cases and over 400,000 deaths.[1]

The evidence base for lung ultrasound (LUS) is well established. In 2008, LUS was found to have an accuracy of greater than 90% for some of the most common causes of dyspnea.[2] In 2011, an international panel of experts made evidence-based recommendations supporting the use of LUS in pneumothorax, interstitial

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syndrome, consolidation and effusion.[3] The evidence base for LUS continues to grow and recently there have been several large, high-quality studies assessing the accuracy of LUS in specific conditions. In 2015, a prospective study of over a 1000 patients found incorporation of LUS into clinical assessment significantly improved sensitivity (97%) and specificity (97.4%) for acute heart failure.[4] And in 2018, a meta-analysis of over 5000 patients found LUS to be 92% sensitive and 93% specific for community-acquired pneumonia.[5]

LUS has also proven useful during recent viral epidemics. In the 2009 influenza (H1N1) epidemic, LUS was found to be accurate in differentiating viral and bacterial pneumonia,[6] and during the avian influenza (H7N9) epidemics LUS was found to be superior to CXR (chest radiograph) with a sensitivity of 94% and specificity of 89%.[7,8]

By contrast, the sensitivity of CXR for COVID-19 has been estimated at between 59% and 69% in admitted patients,[9,10] and as low as 42% in symptomatic ambulatory patients.[11]

The sensitivity of RT-PCR (real-time polymerase chain reaction) for COVID-19 depends upon various factors including the site and quality of sampling, stage of disease, gene targets and disease prevalence.[12] A range of sensitivities has been reported[13] and whilst there is some degree of uncertainty, the sensitivity of RT-PCR using current techniques is estimated at 70%.[14]

CT (computed tomography) is highly sensitive for COVID-19 (estimated at between 97%[15] and 98%[16]), however LUS has several logistical advantages over CT. Firstly, hospitals may simply lack the capacity to perform CT as a routine screening test for COVID-19. Secondly, bedside LUS has been recommended to prevent nosocomial spread[17] and has indeed been shown to reduce healthcare worker exposure to COVID-19 by reducing the intra-hospital transfers associated with conventional imaging.[18] Other advantages of LUS over CT include reduced cost, repeatability, lack of radiation exposure and rapid image acquisition time.[19]

LUS has been shown to improve diagnostic accuracy in patients who present with acute respiratory symptoms[20] and is increasingly used by the frontline clinicians who assess these patients. Ultrasound machines continue to improve in quality, affordability and portability and new technologies such as remote teleguidance have the potential to further extend the accessibility of point-of-care ultrasound.

The LUS findings in COVID-19 are well described and include B lines, pleural line abnormalities and consolidation[21] (Figures 1 and 2). However, the most suitable role for LUS in COVID-19 is still unclear. Various roles have been proposed including triage, diagnosis, prognostication, severity scoring, monitoring progression and guiding interventions.[22] An understanding of the utility of LUS in COVID-19 is crucial for clinicians, departments and organisations to be able to determine its most suitable role based on local circumstances.

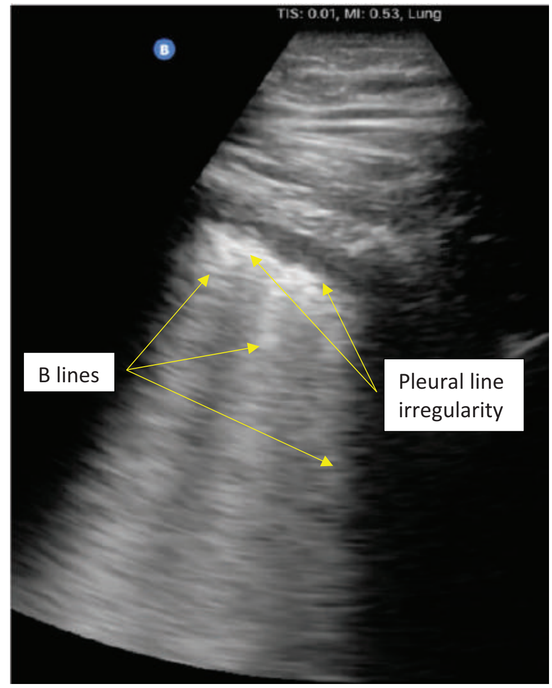


**Figure 1.** B lines and pleural line irregularity.

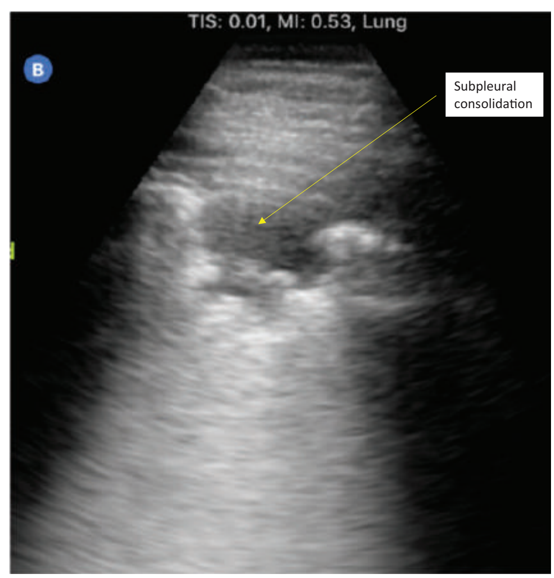


**Figure 2.** A small (or 'subpleural') consolidation.

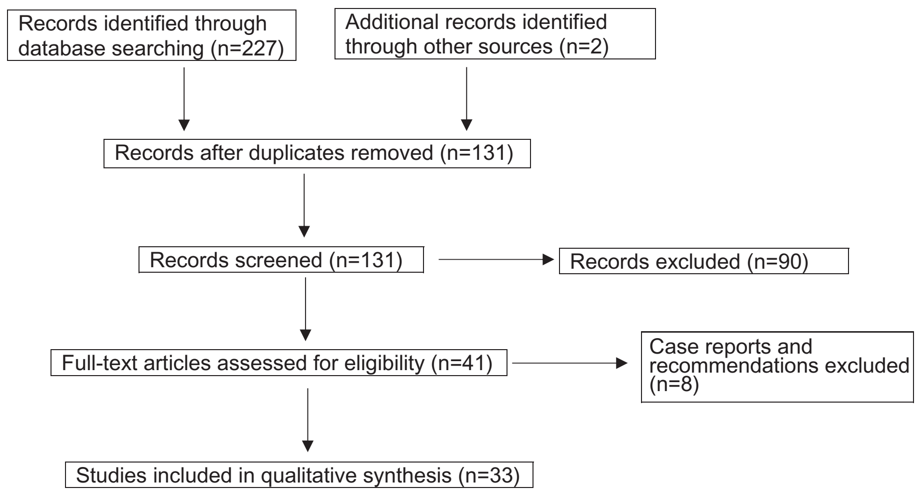


**Figure 3.** PRISMA flow diagram.

## Methods

### Protocol and registration

The protocol was drafted in line with PRISMA[23] and registered on https://figshare.com/ on 13 June 2020 (10.6084/m9.figshare.12478820).

### Inclusion and exclusion criteria

Included were any trials or case series that explored the utility of LUS and involved patients of any age with suspected or confirmed COVID-19. Excluded were case reports and recommendations as well as non-English and non-human studies.

### Search strategy

Traditional online databases were searched including: Medline, Embase, SCOPUS, The Cochrane Library, The TRIP database, Google Scholar and www.clinicaltrials.gov. Given the dynamic nature of the pandemic, other less traditional sources were also searched including point-of-care ultrasound (PoCUS) websites, specialty college websites, pre-publication websites and social media platforms (Appendix 1).

An initial search strategy was formulated by MT and reviewed by AM using the PRESS checklist.[24] This initial search was performed on two databases (Medline and Embase) (Appendix 2). Keywords were identified from the above abstracts and another search was performed of all relevant databases (Appendix 3).

A screening and selection tool was applied to the identified studies by two independent reviewers (MT and AM) with a third reviewer (NM) available to resolve disagreements (Appendix 4). The reference lists from these included studies were then reviewed for further relevant studies. The authors of the included studies were contacted regarding relevant unpublished or recently published evidence.

Data were extracted on study design, numbers of participants, population and data relating to the utility of LUS in COVID-19. Given the heterogeneity of the data, findings are described in a narrative style.

## Results

*Selection of sources of evidence.* A flow diagram in line with PRISMA[23] is presented in Figure 3 and displays the number of studies screened, excluded and assessed.

### Characteristics of sources of evidence

A total of 33 studies were identified from countries including China, Italy, Spain, France, Turkey, the UK and the USA. The numbers of participants in each study ranged from 3 to 107.

The topics explored in each study are summarised in Table 1. The characteristics of each included study are summarised in Table 2.

### Studies that describe LUS findings in COVID-19

The LUS findings in COVID-19 were initially described as consisting of B lines, pleural line abnormalities and consolidations usually without pleural effusion.[21,25–28] Several other studies have described LUS findings in COVID-19 and seven such studies (122 patients) were included in a meta-analysis by Mohamed et al.[29] B lines were found to be the most common and consistent finding with a pooled proportion of 0.97 (95% CI: 0.94–1) whereas pleural line abnormalities, consolidations and pleural effusions were found to be less

**Table 1.** Topics explored by included studies

| Topics explored | Studies identified | |
|---|---|---|
| Description of LUS findings | 5 | |
| Comparison of LUS to a reference standard | 9 | 7 vs. CT and 2 vs. RT-PCR |
| Special groups | 7 | Three in pregnancy and four in children |
| Serial LUS imaging | 2 | |
| Technological innovation | 4 | |
| Reviews | 6 | One meta-analysis and five narrative |
| Total | 33 | |

LUS: lung ultrasound.

common and with high degrees of heterogeneity. Interestingly, Mohamed et al.[29] found pleural effusions to be the least common abnormal finding in COVID-19 with a pooled proportion of 0.14 (95% CI: 0–0.37), however, in Yang et al.[30] pleural effusions were common (present in 67 of 90 hemithoraces scanned).

## *Comparison of LUS to a reference standard (CT)*

In a single centre study by Tung-Chen et al.,[31] 51 adults presented to ED with confirmed or suspected COVID-19, both received CT and LUS and 67% were admitted. LUS was performed by a single, experienced operator blinded to CT and clinical findings. CT suggested COVID-19 in 37 patients and all 37 cases were identified by LUS (sensitivity 100%, specificity 79%). The area under the ROC (receiver operating characteristic) curve was greater for LUS (86%) than RT-PCR (63%) for detecting CT abnormalities.

Hankins et al.[32] also looked at presentations to ED with suspected COVID-19 and included 49 patients over the age of 14 however excluded those with underlying lung disease. Compared to CT, LUS had a sensitivity and specificity of 100% and 80% respectively when performed by the treating clinician however this fell to 92% and 37% when the images were reviewed in isolation. Compared to CT, the sensitivity of CXR and crackles on auscultation was extremely poor (25% and 8%, respectively).

Yang et al.[30] took a different approach, comparing lung regions rather than individual patients. They investigated 29 adult patients with confirmed COVID-19 by dividing their lung fields into 12 regions. Almost two-thirds (63%) of lung regions displayed abnormal findings on LUS (three or more B lines, consolidation or pleural effusion) compared to just 39% on CT (ground-glass opacity, consolidation or pleural effusion). The authors concluded that LUS was more sensitive at identifying the above findings than CT.

Benchoufi et al.[33] and Lu et al.[34] both examined whether LUS could accurately predict severity of disease on CT. In Benchoufi's study,[33] 107 adult patients presenting to ED with suspected COVID-19 were included, 86 of whom tested positive. When LUS was considered as a four-category ordinal scale of severity, there was moderate agreement with CT, kappa 0.52 (0.38–0.66), however, when this was reduced to a binary outcome (normal vs. pathologic) there was strong correlation (sensitivity 95%, specificity 83%). The study by Lu et al.[19] included 30 adult patients admitted with confirmed COVID-19. The ability of LUS to predict the severity of COVID-19 compared to CT for no, mild, moderate and severe disease was 93%, 77%, 77% and 93% respectively. Two further studies, in which a combined total of 20 adult patients received both LUS and CT found a strong correlation between LUS and CT.[34,35]

## *Comparison of LUS to a reference standard (RT-PCR)*

In Peyrony et al.,[36] 47 patients presented to an ED with suspected COVID-19 and received LUS. The presence of bilateral B lines had a sensitivity and specificity of 77% and 89% respectively.

Bar et al.[37] studied 100 adults presenting to an ED with suspected COVID-19. There were 31 patients who tested RT-PCR positive but CT results were not recorded. The combination of qSOFA (quick sequential organ failure assessment) score and LUS gave an area under the ROC curve of 0.82 with sensitivity and specificity of 97% and 62% respectively.

**Table 2.** Characteristics of included studies

| Author and country | Date | Study design | Sample size | Population | Main findings and conclusions |
|---|---|---|---|---|---|
| **Studies that describe the LUS findings in COVID-19** | | | | | |
| Huang et al. China[21] | 28 February 2020 | Single centre, retrospective, observational cohort | 20 | Admitted adults with non-critical COVID-19 | LUS findings included: B-lines, pleural line abnormalities, subpleural consolidations and localized pleural effusions.<br>Colour Doppler imaging showed reduced blood supply within consolidation |
| Lomoro et al. Italy[25] | 1 April 2020 | Single centre, retrospective, observational cohort | 32 | Adults with confirmed COVID-19 | LUS findings included: diffuse B lines (100%), subpleural consolidations (27%)<br>LUS has an important role in COVID-19 |
| Peng et al. China[26] | 12 March 2020 | Single centre, retrospective, observational cohort | 20 | Adults with confirmed COVID-19 | LUS findings included: Pleural line abnormalities, B-lines and consolidations<br>LUS has major utility for management of COVID-19 |
| Yasukawa and Minami, USA[27] | 24 April 2020 | Single centre, retrospective, observational cohort | 10 | Admitted adults with confirmed COVID-19 | LUS findings included: B-lines, pleural line abnormalities (10/10), subpleural consolidations (5/10)<br>LUS has multiple advantages compared to other imaging modalities |
| Volpicelli et al. Italy[28] | 4 May 2020 | Unpublished single centre, retrospective, observational cohort | N/a | N/a | LUS revealed 'light beams' in 48/49 patients diagnosed with COVID-19 |
| **Comparison of LUS to a reference standard (CT)** | | | | | |
| Yang et al. China[30] | 25 May 2020 | Multi-centre, blinded, retrospective cohort | 29 | Admitted adults with confirmed COVID-19 pneumonia | 340 positive regions on LUS vs. 209 on CT<br>LUS is more sensitive than chest CT in detecting lesions such as alveolar- |

(continued)

**Table 2.** Continued

| Author and country | Date | Study design | Sample size | Population | Main findings and conclusions |
|---|---|---|---|---|---|
| | | | | | interstitial disorders, consolidation and PE in COVID-19 |
| Tung-Chen et al. Spain[31] | 12 May 2020 | Single centre, prospective, blinded trial | 51 | Adults presenting to ED with suspected COVID-19 | LUS Sensitivity 100%, Specificity 79%<br>AUC (ROC) 86% vs. 63% LUS vs. PCR for detection of CT abnormalities<br>LUS displayed similar diagnostic accuracy to chest CT |
| Hankins et al. USA[32] | 9 June 2020 | Single centre, retrospective, observational cohort | 49 | Adults presenting to ED with suspected COVID-19 | 33% of symptomatic patients with normal vital signs had LUS findings consistent with COVID-19<br>LUS sensitivity 100%, specificity 80% compared to CT |
| Benchoufi et al. France[33] | 4 May 2020 | Multi-centre, prospective, blinded, observational study | 107 | Adults with suspected COVID-19 | LUS score performed well at predicting CT severity: AUC 0.93, Sensitivity 95%, Specificity 83% |
| Lu et al. China[19] | 6 April 2020 | Single centre, blinded, retrospective cohort | 30 | Admitted adults with confirmed COVID-19 | Moderate agreement between LUS and CT: kappa 0.53<br>LUS diagnostic accuracy varied with severity: Mild 77%, Moderate 77%, Severe 93%<br>Average LUS scan time 5–8 min |
| Poggiali et al. Italy[34] | 13 March 2020 | Single centre, retrospective, observational cohort | 12 | Adults presenting to ED with confirmed COVID-19 | Strong recommendation to use LUS for early diagnosis in ED |
| Lyu et al. China[35] | 10 April 2020 | Single centre, retrospective, observational cohort | 8 | Adults with confirmed severe or critical COVID-19 | LUS findings included: pleural line abnormalities (8/8), B-lines (8/8), consolidations (3/8) and effusion (1/8)<br>LUS correlated closely with HRCT |

(continued)

**Table 2.** Continued

| Author and country | Date | Study design | Sample size | Population | Main findings and conclusions |
|---|---|---|---|---|---|
| **Comparison of LUS to a reference standard (PCR)** | | | | | |
| Peyrony et al. France[36] | 21 May 2020 | Single centre prospective trial | 47 | Adults presenting to ED with suspected COVID-19 | LUS sensitivity 77%, specificity 89%<br>LUS increased the likelihood of identifying COVID-19 in patients presenting to ED |
| Bar et al. France[37] | 10 June 2020 | Single centre, prospective, blinded trial | 100 | Non-pregnant adults without chronic interstitial lung disease presenting to ED with suspected COVID-19 | Integrated assessment with LUS had a sensitivity of 97% and specificity of 62% for COVID-19<br>The association of LUS and qSOFA could facilitate more effective triage of patients presenting to the ED |
| **Special groups (paediatrics)** | | | | | |
| Musolino et al. Italy[38] | 24 April 2020 | Multicentre, retrospective, observational cohort | 10 | Admitted children with confirmed COVID-19 | LUS was useful in diagnosing and monitoring paediatric COVID-19 pneumonia |
| Feng et al. China[39] | 2 May 2020 | Single centre, retrospective, observational cohort | 5 | Admitted neonates with confirmed COVID-19 | 5/5 LUS positive vs. 3/5 CT.<br>LUS is superior to CXR and CT |
| Gregorio-Hernandez et al. Spain[40] | 5 June 2020 | Single centre, retrospective, observational cohort | 3 | Admitted neonates with confirmed COVID-19 | LUS showed: B-lines, consolidation and spared areas<br>LUS could be of value when managing COVID-19 in neonates |
| Denina et al. Italy[41] | 21 April 2020 | Single centre, retrospective, observational cohort | 8 | Admitted children with confirmed COVID-19 pneumonia | Ultrasound may be a reasonable method to detect lung abnormalities in children with COVID-19 |
| **Special groups (obstetrics)** | | | | | |
| Buonsenso et al. Italy[42] | 26 April 2020 | Single centre, retrospective, observational cohort | 4 | Pregnant women admitted with confirmed COVID-19 | 4/4 had B-lines and pleural irregularity<br>LUS was more sensitive than CXR |

(continued)

**Table 2.** Continued

| Author and country | Date | Study design | Sample size | Population | Main findings and conclusions |
|---|---|---|---|---|---|
| Giannini et al. Italy[43] | 29 May 2020 | Single centre, retrospective, observational cohort | 5 | Pregnant women admitted with confirmed COVID-19 | LUS findings substantially overlapped with those described in COVID-19 |
| Yassa et al. Turkey[44] | 1 June 2020 | Single centre, retrospective, observational cohort | 8 | Pregnant women with confirmed COVID-19 | 7/8 women significant changes on LUS Treatment was commenced or changed in 87.5% of patients |
| **Serial LUS imaging** | | | | | |
| Xing et al. China[51] | 28 April 2020 | Single centre, retrospective, observational cohort | 20 | Admitted adults with confirmed moderate to critical COVID-19 pneumonia | LUS findings peaked in second week, some resolution by fourth week |
| Shokoohi et al. USA/Spain[52] | 28 May 2020 | Case series | 3 | Physician patients with confirmed COVID-19 | LUS findings began at symptom onset and resolved within 14 days |
| **Technological innovation in LUS** | | | | | |
| Dong et al. China[54] | 27 April 2020 | Review | n/a | n/a | Artificial Intelligence or other quantitative image analysis methods are recommended in COVID-19 imaging |
| Roy et al. Italy[55] | 14 May 2020 | Article | n/a | n/a | A deep model of automatic analysis from an annotated LUS data set achieved 'satisfactory results' on all tasks including predicting disease severity |
| Evans et al. China[56] | 21 April 2020 | Article | n/a | n/a | Robotic ultrasound equipment is being used at Zhejiang Provincial People's Hospital in Hangzhou, China |

(continued)

**Table 2.** Continued

| Author and country | Date | Study design | Sample size | Population | Main findings and conclusions |
|---|---|---|---|---|---|
| Soldati et al. Italy[57] | 23 April 2020 | Case series | 3 | Adults with confirmed COVID-19 | Noted incomplete enhancement of consolidations suggesting ischaemia or necrosis |
| **Reviews** | | | | | |
| Smith et al. UK[58] | 9 April 2020 | Narrative review | 11 studies | Case reports, case series, recommendations and letters | LUS may have a key role to play in the clinical management of patients with COVID-19–associated lung injury |
| Kulkarni et al. UK/USA[59] | 28 April 2020 | Narrative review | 8 studies | Case reports, case series and letters | POCUS has a high sensitivity for the pulmonary manifestations of COVID-19 |
| Convissar et al. USA[60] | 30 April 2020 | Narrative review | 5 studies | Case reports and case series | LUS has a potential role as a safe and effective bedside option in COVID-19 |
| Lepri et al. Italy/UK/China[61] | 7 May 2020 | Narrative review | 4 studies | Case reports and case series | LUS will likely play an important role in the management of COVID-19 patients |
| Sultan et al. USA[62] | 15 May 2020 | Narrative review | 14 studies | Case reports and case series | LUS findings have demonstrated high diagnostic accuracy, comparable to CT |
| Mohamed et al. USA[29] | 2 June 2020 | Systematic review and meta-analysis | 7 studies<br>122 patients | Studies that report frequency of abnormalities detected by LUS in COVID-19 | LUS findings included:<br>B pattern 0.97 (0.94–1)<br>Pleural abnormality 0.7 (0.13–1)<br>Pleural thickening 0.54 (0.11–0.95)<br>Consolidations 0.39 (0.21–0.58)<br>Pleural effusion 0.14 (0–0.37)<br>POCUS will likely play a vital role in the future triage, diagnosis, management, and follow-up of COVID-19 patients |

LUS: lung ultrasound.

**Table 3.** Levels of evidence of included studies

| Level of evidence | Number of studies | Author/s |
| --- | --- | --- |
| 1a | 0 | |
| 1b | 0 | |
| 1c | 0 | |
| 2a | 0 | |
| 2b | 3 | Benchoufi et al., Tung-Chen et al., Peyrony et al. |
| 2c | 0 | |
| 3a | 8 | Smith et al., Kulkarni et al., Convissar et al., Lepri G et al., Sultan et al., Mohamed et al., Evans et al., Dong et al. |
| 3b | 17 | Huang et al., Peng et al., Lomoro et al., Yasukawa et al., Poglialli et al., Lu et al., Lyu et al., Walsh et al., Yang et al., Bar et al., Decina et al., Gregorio-Hernandez et al., Yassa et al., Musolino et al., Buonsenso et al., Giannini et al., Feng et al. |
| 4 | 3 | Xing et al., Shokoohi et al., Soldati et al. |
| 5 | 1 | Volpicelli et al. |
| n/a | 1 | Roy et al. |

### *Special groups*

Four paediatric studies were identified comprising 26 patients, all admitted with confirmed COVID-19 and ranging from neonatal to 15 years of age. In Musolino et al.,[38] Feng et al.[39] and Gregorio-Hernandez et al.,[40] all 18 patients (10 children and 8 neonates) demonstrated LUS findings. In the work by Denina et al.,[41] five of the eight children demonstrated LUS findings (one of four children with mild disease but all four cases of moderate to severe disease).

Three obstetric studies were identified comprising 16 patients, all admitted with confirmed COVID-19. All eight patients in the reports by Buonsenso et al.[42] and Giannini et al.[43] demonstrated typical LUS findings, while Yassa et al.[44] found seven of eight women in their study demonstrated LUS findings and LUS changed clinical management in 87.5% of cases.

## Discussion

### *Methodology*

There were various issues regarding the methodology of the included studies including convenience sampling, unrepresentative populations (often only admitted patients), lack of power calculations, variability of index test (operator experience, scanning protocol), variability of reference standard (CT, single RT-PCR test, multiple RT-PCR tests) and reproducibility. A summary of the levels of evidence of the included studies according to the Oxford centre for evidence-based medicine[45] is displayed in Table 3.

### *Comparison of LUS to a reference standard*

CT is highly sensitive for COVID-19[15,16] and therefore is generally assumed to be the reference standard for LUS. However this assumption was challenged by Yang et al.[30] and Feng et al.[39] who concluded that LUS may in fact be more sensitive than CT.

The included studies suggest that LUS is highly sensitive for COVID-19. However, sensitivity may be affected by factors including disease severity and scanning technique. Lu et al.[19] and Denina et al.[41] both found LUS to have greater sensitivity in more severe disease. Regarding LUS technique, various protocols have been suggested ranging from a limited scan of just the anterolateral zones to a comprehensive ‘lawnmower’ technique where the transducer is slid along each intercostal space. Given the disease is known to have a patchy distribution[21] it would be plausible that a more comprehensive protocol would be more sensitive however there is also evidence that LUS findings do not depend on the number of zones assessed.[46]

RT-PCR testing is highly specific but relatively insensitive.[14] LUS specificity may therefore be underestimated in studies where LUS is compared only to RT-PCR. For example, in the work by Bar et al.[37] specificity was 62% (vs. RT-PCR) but in Tung-Chen et al.[31] specificity was 79% (vs. CT).

Operator experience may also affect specificity as an expert will be able to better correlate different LUS patterns with different disease processes. Benchoufi et al.,[33] state that specificity was 83%, however, this was based on the LUS being simply normal or pathologic. Peyrony et al.[36] achieved a slightly higher specificity of 89%, however, this was based on only the presence of bilateral B lines. A more nuanced LUS assessment may lead to greater specificity.

There may be particular LUS findings and patterns that are more specific for COVID-19. In Volpicelli and Gargani[47] the authors described a LUS artefact called 'light beam', defined as a broad, lucent, band-shaped, vertical artefact moving rapidly with sliding and arising from a regular pleural line. The authors stated that in a series of 100 patients (unpublished data) this finding was present in 48 of 49 patients with confirmed COVID-19 but in none of 12 patients with negative swabs and alternative diagnoses. Furthermore, Soldati et al.[48] argued that relative specificity can be attributed to the classic bilateral, patchy distribution with spared areas and multifocal confluent B lines ('white lung'), especially in relatively young patients without a history of lung disease.

There is a spectrum of LUS findings in COVID-19 ranging from subtle to highly suggestive. Many studies have focused on LUS severity scores; however, in terms of diagnostic utility, an assessment of likelihood rather than severity may be more useful. The differential diagnosis of each specific patient will also influence which LUS findings are most specific to COVID-19. If the alternative is pulmonary oedema, the presence of pleural thickening and irregularity may be relatively specific for COVID-19. However, if the alternative is pulmonary fibrosis this finding would not be discriminating. In the work by Hankins et al.,[32] diagnostic accuracy was higher when LUS was interpreted by the treating clinician as opposed to being reviewed in isolation, highlighting the importance of integrating LUS findings with clinical findings. This Bayesian approach of combining a pre-test probability with PoCUS findings is well described.[49]

It should be noted that all of the included studies were conducted during a period of high disease prevalence and it is likely that measures of diagnostic accuracy will be affected by fluctuations in disease prevalence over time.[50]

## Serial LUS imaging

In Xing et al.,[51] 20 adult patients with confirmed COVID-19 underwent 36 scans at various time intervals after onset of symptoms. The authors found that the extent of LUS findings reached a peak at the second week and then there was gradual improvement (but not complete resolution) until the fourth week. On the other hand, three physicians with confirmed COVID-19 monitored themselves at home and in all cases the LUS findings had resolved by day 14.[52] More information is urgently needed regarding the persistence of LUS findings as clinicians will be increasingly encountering patients who may have recently recovered from COVID-19.

## Interobserver agreement

Good interobserver agreement of LUS findings was found between experts[37] and between experts and novices.[33] However, it was noted that removal of the practical element of novice training significantly reduced interobserver agreement.[33] It was also noted that interobserver agreement varied between different LUS findings, being highest for consolidation and lowest for pleural thickening.[32]

Interobserver agreement will depend on the extent of training the novice has received and a wide array of training protocols have been described. Benchoufi et al.[33] found that only 30 minutes of theoretical and 30 minutes of practical training was required. However, it has previously been suggested that 25 scans may be necessary to achieve competency in LUS.[53]

Further studies relating to interobserver agreement are warranted however it appears the element of practical training is important. Novel technologies such as remote teleguidance could help to achieve this.

## Technological innovation in LUS

New technologies may play an important role in augmenting the potential utility of LUS in COVID-19. Several avenues are currently being explored including artificial intelligence, deep learning, robotic LUS and contrast-enhanced LUS.

Dong et al.[54] stated that artificial intelligence or other quantitative image analysis methods were urgently needed to maximise the value of imaging modalities including LUS. A deep model of automatic analysis was created by Roy et al.[55] and the authors noted that this achieved 'satisfactory results' on all tasks including predicting disease severity. Interestingly, Evans et al.[56] noted that robotic ultrasound equipment is already being used at Zhejiang Provincal People's Hospital in Hangzhou, China.

Contrast-enhanced ultrasound (CEUS) was used on three patients with confirmed COVID-19 by Soldati et al.[57] Perfusion defects were noted within the subpleural lesions and the authors concluded this was at least in part caused by ischaemic or necrotic changes rather than inflammation or atelectasis. This is consistent with the findings of Huang et al.[21] who noted the lack of colour Doppler signal within subpleural consolidations in COVID-19. If these peripheral lung lesions are in fact infarcts this may have major implications for clinical management and therefore this question deserves further attention.

### *Special groups*

The issue of ionizing radiation is of great concern in children and pregnant women. Several small studies were identified that examined the utility of LUS in COVID-19 in these patient groups and suggested that LUS is as useful as it is in non-pregnant adults.

### *Limitations*

The recent emergence and dynamic nature of the COVID-19 pandemic has led to the rapid publication of research and it is inevitable that new studies will continue to be released before this review is published.

A thorough and systematic literature search was performed including non-traditional sources (see Appendix 1), however, all relevant evidence may not have been identified due to publication bias and non-English language publications being excluded.

### *Recommendations*

High-quality research is needed to better define the utility of LUS in COVID-19 and thus inform clinicians of its most suitable role in a local context. Although LUS findings in COVID-19 are now well described, further research is needed regarding the relative specificity of the various LUS findings and patterns. High-quality, prospective studies assessing diagnostic accuracy in undifferentiated patients in an era of lower prevalence would also be of great value. The role of LUS in triage, prognostication, severity scoring, monitoring progression and guiding interventions has not yet been adequately explored. An understanding of the persistence of residual LUS findings post infection will be increasingly important going forwards. Larger studies assessing interobserver agreement would both estimate reproducibility but may also help inform necessary training standards for novices. Further research into contrast-enhanced LUS and colour Doppler is warranted as this may significantly augment traditional LUS and contribute to a broader understanding of the disease process. International consensus is required regarding training standards, scanning protocols and an appropriate reference standard.

## Conclusion

The evidence base for LUS in COVID-19 is rapidly expanding but the methodological quality of the identified studies was relatively low.

It is difficult to make a precise estimate of diagnostic accuracy of LUS in COVID-19 as both sensitivity and specificity may be influenced by various factors including disease severity, pre-existing lung disease, scanning protocol, operator experience, disease prevalence and the reference standard. However, LUS appears to be a highly sensitive and fairly specific test for COVID-19 in all ages and in pregnancy. LUS is almost certainly more sensitive than CXR and has several advantages over CT and RT-PCR.

### Ethics approval

NA (review paper only).

### Contributors

Writing of manuscript: MMT, AM; Critical review of manuscript: NM, CM, RJ.

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## Appendix 1. Extended literature search

Specialised point-of-care ultrasound websites

- Zedu Ultrasound Training Solutions: https://www.ultrasoundtraining.com.au/news/covid-19-pocus-resources
- Ultrasound G.E.L. Podcast: Gathering Evidence from the Literature: https://www.ultrasoundgel.org/articles

Specialty college websites

- Royal College of Emergency Medicine: https://www.rcemlearning.co.uk/research/
- Intensive Care Society: https://ics.ac.uk/ICS/ICS/FUSIC/FUSIC_COVID-19.aspx

Pre-publication websites

- MedRxiv, The preprint server for health sciences: https://www.medrxiv.org
- Figshare: https://figshare.com/browse

Social media

- Twitter hashtag: #pocusforcovid

## Appendix 2. Initial search

Databases to be searched:

1. Ovid MEDLINE® to 13th June 2020
2. Embase 1974–2020 13th June 2020

Search strategy:

1. Lung OR chest OR thorax OR thoracic
2. Ultrasound OR ultrasonography OR sonography
3. COVID OR COVID-19 OR coronavirus OR SARS-CoV 2
4. 1 AND 2 AND 3
5. 4 AND remove duplicates

## Appendix 3. Second search

Databases to be searched:

1. Ovid MEDLINE® and Epub Ahead of Print, In-Process and Other Non-Indexed Citations, Daily and Versions 1946 to 13th June 2020.
2. Embase 1974–2020 13th June
3. Scopus
4. The Cochrane Library
5. The TRIP database
6. Google Scholar
7. www.clinicaltrials.gov
8. JBI Database of Systematic Reviews and Implementation Reports
9. Cochrane Database of Systematic Reviews
10. Cumulative Index to Nursing and Allied Health Literature (CINAHL)
11. Evidence for Policy and Practice Information (EPPI)
12. Epistemonikos

Second search strategy:

1. Lung OR chest OR thorax OR thoracic OR pulmonary
2. Ultrasound OR ultrasonography OR sonography OR ultrasonic
3. COVID OR COVID-19 OR coronavirus OR SARS
4. 1 AND 2 AND 3
5. 5 AND remove duplicates

## Appendix 4. Screening and selection tool

| LUS in COVID-19: Screening and selection tool | | |
|---|---|---|
| Reviewer name: | | Date: |
| Title: | | |
| Author name: | Year: | Journal: |
| | Inclusion criteria | Exclusion criteria |
| Diagnostic test: | ☐ LUS | |
| Population: | ☐ Patients of any age with suspected or confirmed COVID-19 | |
| Concept: | ☐ Utility of LUS | |
| Context: | ☐ Clinical management of COVID-19 | |
| Study design: | ☐ Case series | ☐ Case reports |
| | ☐ Experimental or observational studies | ☐ Recommendations |
| | ☐ Reviews | |
| Overall decision: | ☐ Included | ☐ Excluded |