The diagnostic performance of lung ultrasound for detecting COVID-19 in emergency departments: A systematic review and meta-analysis

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Abstract

Purpose: To perform a systematic review and meta-analysis of published literature investigating the use of lung ultrasound (LUS) on COVID-19 patients, in emergency point of care settings, and to determine its diagnostic value compared with lung computed tomography (LCT) diagnostic performance. Whilst using the real-time polymerase chain reaction test as the ‘gold standard’.

Methods: Literature searches were performed on MEDLINE, Embase, Web of Science, and PubMed databases for eligible studies. The LUS and LCT pooled diagnostic performance were measured using DerSimonian–Laird random effect method.

Result: Out of a total of 158 studies, 16 met the eligibility criteria and were included in this review. The pooled sensitivity, specificity, positive and negative likelihood ratios were 86.9%, 62.4%, 2.4 and 0.19, respectively for LUS and 93.5%, 72.6%, 3.3 and 0.05, respectively for LCT.

Conclusion: The lung ultrasound (LUS) demonstrated acceptable sensitivity but poor specificity when used independently to diagnose COVID-19 pneumonia patients in emergency departments, while the lung computed tomography showed higher performance. Thus, LUS can be used to supplement existing diagnostic tools and possibly for the triage of patients.

KEYWORDS
COVID-19, lung computed tomography, lung ultrasound, meta-analysis, systematic review

INTRODUCTION

The 2019 novel coronavirus disease (COVID-19) has caused a global emergency public health concern and been classified as a pandemic by the World Health Organization (WHO). COVID-19 targets the respiratory system and can be transmitted by humans through droplets or direct contact. The real-time polymerase chain reaction (RT-PCR) is the globally accepted ‘gold standard’ test used to diagnose a SARS-Cov-2 infection. The RT-PCR is not ideal for diagnosing COVID-19 because it has the following limitations: poor positivity percentage, high false negative, time-consuming, and contamination risks. Alternatively, lung X-ray computed tomography (LCT) shows higher sensitivity in the detection of COVID-19 infections compared to RT-PCR. CT has some limitations as it uses ionizing radiation and transferring the patient to a CT department could increase the contamination risk.

Point of care ultrasound (POCUS) plays a valuable role in the emergency department for the triaging of COVID-19 patients, by identifying if they can self-isolate at home or should be admitted. Lung ultrasonography (LUS) has been recently used to diagnose COVID-19 in the emergency setting, and it is considered a possible alternative option as a recent study reported a good correlation...
between LUS and LCT findings with an intraclass correlation coefficient of 80.3%. POCUS has several advantages over LCT, which are that it can be perfumed at the bedside, helping to reduce COVID-19 contamination risk, it can identify viral pneumonia and monitor the infection progress, non-ionizing, and equipment sterilization is straightforward. Furthermore, POCUS can provide an immediate diagnostic response at low cost. These advantages suggest that ultrasound can be a useful diagnostic tool during the COVID-19 pandemic and for other possible causes of pneumonia.

Previous literature regarding COVID-19 LUS limit the use of LUS for triaging and monitoring COVID-19 patients due to the lack of scientific information in the modalities efficacy. Recent studies have estimated the accuracy of LUS in diagnosing COVID-19 in the POC setting. However, there is a high variation in the methodology and results of these studies. The key discrepancy between studies is that their diagnostic accuracy could be due the different thresholds used to diagnose COVID-19 pneumonia ranging from any B-line to multiple zones affected. Various LUS scanning protocols were used for identifying COVID-19 pneumonia, which likely influenced the diagnostic accuracy. Many studies comprehensively scanned using 12 lung zone protocol. In contrast, others adopted limited views scanning technique, likely reducing sensitivity. POCUS is highly operator dependent, and operator experience could affect the studies diagnostic accuracy. Nevertheless, no previous review synthesized the available evidence diagnostic performance and functionality of this imaging approach to support clinical decision making. The objective of this study was to systematically assess the available published evidence, at the time of writing, and exam the diagnostic performance of LUS in detection of COVID infection in comparison to RT-PCR as a reference standard. In addition, the study intended to investigate the effect of the LUS protocol of scanning few lung areas in the LUS diagnostic performance. Furthermore, the study performed subgroup analysis to determine the LCT diagnostic performance from the available selected studies and compare it with LUS.

2 | METHODS

2.1 | Search strategy and terms

This systematic review and meta-analysis were carried out based on the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines. Searches were performed in MEDLINE, Embase, PubMed and Web of Science electronic databases for English-language and full-text available records. Two reviewers (RJ and AMA) performed the search from December 2019 to July 2021 to conduct eligible studies for the systematic review and meta-analysis. The search terms used among with search combinations as follows: (“COVID-19” OR “COVID” OR “Coronavirus” OR “2019 novel coronavirus” OR “2019-nCoV” OR “Wuhan Coronavirus” OR “SARS-CoV-2”) AND (‘lung’ OR “chest” OR “pulmonary” OR “thorax” OR “thoracic”) AND (“Ultrasound” OR “ultrasonography” OR “Point-of-care ultrasound” OR “POCUS”) AND (“emergency” OR “ER”). Discrepancies between the two reviewers were addressed and resolved by a third reviewer (JRM).

2.2 | Study eligibility

The systematic review and meta-analysis inclusion criteria were as follows: full-text available in the English language, adult patients (≥8 years old), Lung ultrasound was performed in the emergency department, or equivalent, and sensitivity and specificity were reported or the absolute numbers of true positives (TP), false positives (FP), true negatives (TN), and negatives (FN). Studies were excluded if they enroll pediatric patients, limited their analysis to the samples with only positive RT-PCR results, they were case series or reports, review articles, and editorials.

2.3 | Data extraction

The following data were extracted by three reviewers, first author, publication year, study design, sample size, mean age, gender distribution, LUS protocol, ultrasound parameters, features of LUS COVID-19 finding, and blinding status. Sensitivity and specificity of LUS were recorded, and the TP, TN, FP, and FN were calculated for each study to measure the pooled LUS diagnostic performance. From the included studies, six studies used LCT in conjunction with LUS. The TP, TN, FP, and FN were calculated to measure the pooled diagnostic performance of LCT. One of the included studies had two groups; high and moderate COVID-19 prevalence and this meta-analysis only included the moderate COVID-19 prevalence group to optimize its effect on the test performance and increase the power of the analysis.

2.4 | Quality assessment

The Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool was used by three reviewers to assess the quality of included studies. QUADAS-2 assesses diagnostic studies risk of bias in four sections, patient selection, index test, reference test, and flow and timing, where this appraised the applicability in the first three sections. Each domain was assessed using signaling questions; if all answered ‘yes’, the risk of bias is estimated to be low. While, if at least one question was answered ‘no’ that reveal that a high risk of bias potentially existed. Unclear risk of bias was indicated when any signaling question was ‘unclear’ as the study did not give sufficient information to respond to the question. Low risk bias was scored for the flow and timing section when the time interval was 14 days or less between the LUS and RT-PCR. Applicability concerns in the first domain were reported low when the patient selection and study setting match the review question, high when not matched, and unclear if insufficient information was given. In the second domain, if the interpretation of LUS influenced the diagnostic accuracy measurement, high applicability concern was indicated, low when it did not influenced study estimations and unclear.
when the effect on diagnostic accuracy estimation was unclear. Finally, the applicability concerns for reference standards were judged low as all studies involved samples that match the question of the study.

2.5 | Data synthesis and analysis

The rate of FN, FP, TP, and TN was calculated for all included studies. Meta-analysis was performed using OpenMetaAnalyst software (12.11.14 version) including the DerSimonian-Laird random effect method. The accuracy of LUS for COVID-19 diagnosis in emergency departments against the RT-PCR was determined by estimating the pooled sensitivity, specificity, positive likelihood ratio (PLR), negative likelihood ratio (NLR) and diagnostic odds ratio (DOR) with confidence intervals (CIs of 95%). The forest plot and the summary receiver operating characteristic (sROC) curve were constructed. Pooled sensitivity, specificity, and DOR were determined for the subgroup analysis of studies that used few lung zones scanning protocol. The pooled sensitivity, specificity, PLR, NLR and the sROC curve were generated for the subgroup analysis of studies that used LCT. The included studies variance and heterogeneity were evaluated using the test of the inconsistency ($I^2$) and $p$ values <0.05.

3 | RESULTS

3.1 | Search strategy

The search yielded 158 records, with 30 duplicated records that were removed. By reviewing each records’ title and abstract, 83 studies
| #  | Author          | Publication year | Study design            | Sample size | Mean age (year) | Gender male (%) | LUS protocol          | Ultrasound system\parameters                  | Diagnostic criteria for COVID-19 on LUS | Blinding status | Sensitivity (%) | Specificity (%) |
|----|----------------|------------------|--------------------------|-------------|-----------------|-----------------|---------------------|-----------------------------------------------|----------------------------------------|----------------|----------------|----------------|
| 1  | Bar et al.      | 2020             | Observational study      | 100         | 68.7 ± 16.4     | 41%             | The (BLUE) protocol | Ultrasound system: MindrayTM China/convex array transducer (C5-2) | Pleural line thickening and irregularity Focal or confluent B lines Consolidation | Blinded         | 96.8           | 62.3           |
| 2  | Colombi et al.  | 2020             | Retrospective study      | 239         | 73 ± 18.5       | 52%             | 12 zones protocol  | Esasote MyLab X7 or Philips Affiniti 70 used both convex transducer with 1–8 MHz and linear transducer with 3–17 MHz | Plural line thickening Multiple B lines Consolidations White lung | Unclear         | 92.6           | 30.5           |
| 3  | Favot et al.    | 2020             | Retrospective cohort study | 64          | 66 ± 14         | 63%             | Four zones in each hemithorax | Zonare Z1 Pro ultrasound system/convex transducer | Isolated and confluent B lines Subpleural consolidations No or small pleural effusions | Blinded         | 69.2           | 76             |
| 4  | Lieveld et al.  | 2020             | Multicenter prospective, observational study | 187         | 63.7 ± 15.7     | 57.8%           | Not specified       | Not specified | ≥3 B lines per intercostal space. 2 ≥ consolidation unilaterally or 1 ≥ bilaterally | Blinded         | 91.9           | 71.3           |
| 5  | Narinx et al.   | 2020             | Retrospective study      | 90          | 50.4 ± 16.3     | 45.6%           | The (BLUE) protocol | Philips/convex transducer 5 MHz, 8 cm depth | Pleural line thickening ≥3 B lines per intercostal space | Blinded         | 93.3           | 21.3           |
| 6  | Pare et al.     | 2020             | Retrospective cohort study | 43          | 52 ± 25         | 48.8%           | 12 zones protocol  | Used convex transducer in 86 of the sample and linear for the rest | Any B lines found Thin B lines of <3 mm represent the ground-glass opacities. | Blinded         | 88.9           | 56.3           |
| 7  | San et al.      | 2020             | Observational study      | 40          | 43.8 ± 16.6     | 50%             | Scanned with 6 zones | Mindray M7, China ultrasound system/ microconvex transducer of 2–6 MHz | Consolidation Bilateral B lines Air bronchogram Thickening of plural line | unclear          | 62.1           | 63.6           |
| 8  | Schmid et al.   | 2020             | Retrospective study      | 135         | 61 ± 18         | 54.1%           | 12 zones protocol  | Not specified | Bilateral appearance one feature, or 2 ≥ unilateral more: ≥3 B Lines<1.5 cm subpleural consolidation Small or no pleural effusion | Blinded         | 76.9           | 77.1           |
| 9  | Tung-chen et al.| 2020             | Prospective study        | 51          | 61.4 ± 7.7      | 54.9%           | 12 zones protocol  | Hand-held (Butterfly IQ) system. Convex transducer with 1.5–4.5 MHz | Bilateral Isolated or confluent B lines Irregular pleural line | Blinded         | 98             | 76.8           |
| #  | Author            | Publication year | Study design                     | Sample size | Mean age (year) | Gender male (%) | LUS protocol | Ultrasound system/parameters | Diagnostic criteria for COVID-19 on LUS | Blinding status | Sensitivity (%) | Specificity (%) |
|----|-------------------|------------------|----------------------------------|-------------|----------------|-----------------|--------------|-------------------------------|-------------------------------------------|----------------|----------------|-----------------|
| 10 | Bosso et al.      | 2021             | Case-control study               | 53          | 65.5 ± 17      | 69.8            | 12 zones protocol | (Samsung HM70A ultrasound system/both convex and linear transducers) | Thickening of pleural line >3 mm ≥3 B lines in a reign Lung consolidations | Blinded        | 73.1           | 88.9            |
| 11 | Brenner et al.    | 2021             | Retrospective cohort study       | 174         | 53.1 ± 16.8    | 52.9            | 12 zones protocol | Not specified | Multiple and confluent B lines Lung consolidations | Blinded        | 86             | 71.6            |
| 12 | Gibbons et al.    | 2021             | Single-center, prospective, observational study | 110         | 61 ± 19.3      | 46.4            | Four zones in each hemithorax | hand-held (Butterfly IQ) system with (Guilford, CT) probe connected to Apple iPad. | ≥3 B lines Irregular and thickening of pleural line. Coalescent B lines Lung consolidations | No             | 97             | 13.6            |
| 13 | Pivetta et al.    | 2021             | Prospective cohort study         | 228         | 57.7 ± 20.7    | 48.7            | 12 zones protocol | curvilinear transducer with 5 to 3 MHz or cart-based device is used or a handheld system (Butterfly IQ) using 3 MHz. | Subpleural consolidations Pleural line thickening or irregularity | Blinded        | 94.4           | 95              |
| 14 | Sorlini et al.    | 2021             | Retrospective single-center study | 384         | 65.4 ± 17.1    | 62.8            | 12 zones protocol | Not specified | The following features in 2 ≥ zone: ≥3 B lines Irregular pleural line Coalescent B lines Lung consolidations | Unclear        | 92             | 64.9            |
| 15 | Tung-chen et al.  | 2021             | Prospective study                | 96          | 68.16 ± 17.5   | 47.9            | 12-zones protocol | Cart-based device (GE LOGIQ e) convex transducer with 1.5–4.5 MHz. Hand-held (Butterfly IQ) with (Guilford, CT) probe. | Isolated and confluent B lines bilaterally Irregular pleural lines Lung consolidations | Blinded        | 87             | 33.3            |
| 16 | Zanforlin et al.  | 2021             | Retrospective single-center study | 111         | 55 ± 21        | 52              | Each lung was divided to ten zones | Portable (M-Turbo, Sonosite Fujifilm)/depth of 6 cm/Convex transducer with 5–2 MHz. | Any of the following features: Pleural irregularities White lung Surface or deeper consolidations | Unclear        | 65.9           | 70              |
were excluded through screening the titles and abstracts. The remaining records were read and the records that did not fulfill the eligibility criteria were excluded as presented in the PRISMA flowchart Figure 1. Sixteen records were eligible, fulfilled the study inclusion criteria, and were included in the systematic review and meta-analysis.

### 3.2 The included study characteristics

Table 1 shows a summary of the extracted data. The total of number patients in the included 16 studies were 2105 (mean age: 60.4 years, standard deviation: ±7.82 years). All included studies were performed in the emergency department. Ten studies followed the 12-zone lung protocol, and two studies used bedside lung ultrasound in the emergency protocol (BLUE). In contrast, three studies did not scan the posterior lung areas, as in the 12-zone protocol, and two were scanned four lungs' areas in each hemithorax. The LUS imaging COVID-19 manifestation is comparable among the included studies of ≥3 B lines per intercostal space, pleural line irregularity, and consolidations.

There is variation among the studies on the number of features present to confirm the presence of COVID-19 pneumonia. For example, some studies confirmed COVID-19 if two or more zones show one of the features or unilateral zone appearance of two or more features. In contrast, other studies defined COVID-19 if any feature exists either in one or more zone. Various ultrasound systems were used among the studies, with the handheld system (Butterfly IQ) used in four of included studies to reduce the infection risk as it can be easily sterilized. Convex transducers were used in six of the included studies to show lung pathology extent. In comparison, two studies used the linear transducer besides the convex transducer to assess plural line thickness and regularity. However, one study used a convex transducer in 86% and a linear transducer in 14% of the samples. Unfortunately, four of the included studies did not record either the ultrasound system, or type of the transducer used.

### 3.3 Quality assessment

Figure 2 shows the QUADAS-2 assessment for the 16 included studies. In patient selection domain, a high risk of bias and applicability concern were reported for the studies that used case-control design and inconsecutive patient selection. The index test, a high risk of bias and applicability was judged for one study that did not blind during the LUS interpretation of the RT-PCR results. All included studies used acceptable reference standard (RT-PCR), and therefore, presented a low risk of bias and applicability. High risk of bias was demonstrated in the flow and timing domain for the studies reporting more than a 14-day interval between the RT-PCR and LUS, and if not all the patients had RT-PCR test.

### 3.4 Diagnostic performance of LUS against the RT-PCR

Figure 3 presents the pooled sensitivity, specificity, PLR and NLR. The pooled sensitivity and specificity of LUS for diagnosing COVID-19 pneumonia in the emergency were 86.9% (95% CI: 80.9%–91.3%; p < .001), and 62.4% (95% CI: 49.4%–73.9%; p < .001) respectively. The overall pooled PLR and NLR were 2.39 (1.86, 3.09) and 0.19 (0.14, 0.25), respectively. In addition, the LUS DOR was 12.8 (95% CI: 7.15–22.92), and the AUC was 71%. High heterogeneity for sensitivity and specificity was recorded between included studies at 78.4% and 92.1%, respectively.

### 3.5 Subgroup analysis of studies using fewer lung regions protocol

For three studies that used a four and six lung regions protocol, which did not scan the posterior lung areas, their pooled sensitivity of LUS...
in diagnosing COVID-19 pneumonia was 80.2% (95% CI: 63.8%–90.2%; p < .001), and the pooled specificity was 48.4% (95% CI: 21.4%–76.3%; p < .001). In addition, the LUS DOR was 5.01 (95% CI: 2.88–8.75).

3.6 | Subgroup analysis of LCT diagnostic performance

Subgroup analysis was done for studies that performed LCT in consecutive samples besides the LUS against the RT-PCR. The pooled sensitivity, specificity for the six studies included in LCT analysis were 93.5% (95% CI: 85.9%–97.2%; p = .052) and 72.6% (95% CI: 61.4%–81.5%; p = .001) respectively. The overall pooled PLR and NLR were 3.3 (3.4, 4.5) and 0.05 (0.02, 0.12), respectively. The DOR was 41.38 (95% CI: 23.94–71.51). The LCT sROC AUC was 93%.

Figure 4 shows that the lung computed tomography (LCT) has greater summary receiver operating characteristic (green curve) compared to the lung ultrasound (black curve) indicating higher LCT diagnostic performance.

4 | DISCUSSION

This systematic review and meta-analysis were aimed to assess the diagnostic performance of LUS in COVID-19 pneumonia. Sixteen studies out of a total of 158 studies from the literature search and screening method met the inclusion criteria. Due to the extreme demand for quick test to investigate COVID-19 in emergency combined with other tests drawbacks, the literature proposed various use of Lung ultrasound (LUS) include diagnosis and monitoring progression of COVID-19. The clinical manifestations of LUS COVID-19 varied among the included studies, with many of the studies reporting multiple B-lines, plural line thickening and subpleural consolidation. In contrast, two studies used low threshold as a single B-line to indicate positive LUS results and they report poor LUS specificity of 76% and
Various study used 12 lung zones protocol with a convex transducer used for identifying COVID-19 pneumonia as proposed systematically scanning more lung zones enhance the diagnostic accuracy and show extent of disease. In contrast, some studies adopted limited zones scanning protocol and revealed less diagnostic performance.

Most of the included studies blinded the ultrasound operators to the RT-PCR results thus enhance the credibility of the study and minimize bias. Ultrasound is operator dependent the study did not investigate the ultrasound operators’ expertise due to the lack of such information in the majority of included studies.

The meta-analysis reveals that LUS has a high sensitivity of 86.9% and poor specificity of 62.4% for the diagnosis of COVID-19 pneumonia compared to RT-PCR. The RT-PCR was reported to have a sensitivity of 70%. Therefore, LUS had a higher sensitivity to determine true positive results of 86.9%, and a low rate of false-negative results compared to RT-PCR. In contrast, the poor specificity of LUS can result in a high rate of false positives. The pooled PLR of 2.39 indicates that COVID-19 patients have a greater two- to threefold chance of having LUS positive COVID-19 pneumonia results compare to non-COVID patients. The pooled NLR of 0.19 shows that if the LUS result is negative, the probability the patient has COVID-19 pneumonia is 19%. The DOR of 12.8 (95% CI: 7.15–22.92) and sROC AUC of 71% indicate moderate level of overall LUS accuracy for diagnosing COVID-19. The DOR is valuable for evaluating diagnostic test performance; however, the likelihood ratios are clinically significant.

Several factors can explain the low specificity of LUS. COVID-19 features are generally non-characteristic and can be found in other pathologies such as pulmonary edema, atelectasis and pulmonary fibrosis. Furthermore, B-lines can be found in healthy patients depending on their age. Another factor is that a few studies used an extremely low threshold for diagnosing COVID-19 as they considered any patient showing a single B-line as COVID-19 positive.

An additional reason for the high false-positive rate of LUS might be due to the poor sensitivity of RT-PCR, while most reported results consider it an assured reference test. Nevertheless, a patient with negative RT-PCR and positive LUS results could be COVID-19 infected.

A recent meta-analysis estimated the diagnostic value of studies that used LUS to assess the COVID-19 severity and reported 87.6% sensitivity and 80.5% specificity in severe cases. In their methods, they did not specify a patient age group or reference standard as any study reporting the sensitivity and specificity were eligible, which included 15 studies. The reference test was RT-PCR in six studies, LCT in seven studies, and other laboratory tests in two studies. Using various reference standards might explain the higher specificity they reported compared to the current results. Furthermore, in the previous meta-analysis, 75% of included studies had significant selection bias as the majority included confirmed COVID-19 in their analysis and not all operators were blinded. This may explain the higher specificity. In contrast, this meta-analysis excluded studies that only included confirmed COVID-19 to reduce the selection bias and increase the accuracy of the present meta-analysis estimations.

Our results showed that the LUS pooled sensitivity of studies using four and six lung zones without scanning the posterior lung area was reduced to 80.2%, and poor specificity of 48.4% might significantly increase a false-positive rate. This suggests that scanning the patients with fewer reigns would lower the LUS diagnostic accuracy and should be avoided. The lower sensitivity and specificity could be because when less lungs regions were examined by the operator, LUS can fail to provide a true representation of the disease. Alternatively, studies that scanned few lung areas can result in missing various normal lung areas, therefore reduce the true negative rate. Thus, the LUS sensitivity and specificity increased when systematically scanning more zones as most COVID-19 changes appeared in the posterior lung, which they suggested can spare the use of additional imaging and reduces the false-negative rate.

The subgroup analysis results of the studies that used LCT along with LUS to diagnose COVID-19 show that LCT has 93.5% sensitivity, which is comparable to the LUS. However, LCT had higher specificity of 72.6% compared to LUS, therefore a lower false-positive rate. The LCT has a greater PLR of 3.32 compared to LUS, which indicates greater chance for COVID patient of having positive results. In contrast, the LCT has lower NLR of 0.05 compared to LUS indicating a 5% chance of a patient being COVID-19 infected and has LCT negative results. Furthermore, the LCT has a DOR of 41.38 and sROC AUC of 93%, implies an excellent level of overall LCT accuracy for diagnosing COVID-19 infection more powerful than LUS diagnostic performance. The meta-analysis subgroup LCT analysis is comparable to a recently published meta-analysis that reports that the CT has pooled sensitivity of 91% (95% CI: 82%–98%) and specificity of 77.5% (95% CI: 25%–100%). The LCT has greater pooled specificity than LUS that could be because LUS can illustrate only the peripheral lung areas. LUS only display the peripheral lung areas, which is 1/16 of lung size, and it is challenging to view pneumonia far from the pleura or apical area. In contrast, LCT can show the extent of lung involvement beyond the peripheral regions.

The heterogeneity of the 16 included studies was high for both sensitivity and specificity of LUS and LCT as they are above 50%, despite the meta-analysis strict inclusion criteria. The potential explanations for the high heterogeneity are the difference in the included studies scanning protocols, imaging system and parameters, the prevalence of COVID-19. Another major factor of heterogeneity is the image scoring and interpretation variation among the studies.

The meta-analysis results indicate that LUS has higher sensitivity compared to RT-PCR and comparable to the LCT. However, the LUS has poor specificity, which results in an increase in the false-positive rate. Although the overall meta-analysis results indicate that LUS has adequate diagnostic performance. It should not be relied on as a sole diagnostic tool and should be used along with RT-PCR and clinical evaluation. However, LUS could be useful for patients with negative RT-PCR results but significant clinical COVID-19 suspicion, especially when the LCT results are suggestive. For asymptomatic patients presenting in emergency departments could be the preferred screening test as it is less time consuming. However, patients with severe symptoms or high-risk (having history of pulmonary or cardiovascular disease), the LCT would be more beneficial either to confirm COVID-19 pneumonia or other pathology. A recent study report that 17% of...
pregnant women had initially a negative RT-PCR, but abnormal LUS result before repeating the RT-PCR later which showed positive. In addition, present study state that three patients were RT-PCR negative and had LUS positive findings suggestive of COVID-19. One was finally diagnosed with viral bronchiolitis, and the others with lung cancer metastasis. The LUS can be beneficial for infection control during the pandemic. For instance, the use of the stethoscope is limited and portable handheld ultrasound systems can reduce the infection risk by performing the scan at the patient bedside and use plastic sheet or bag for coverage.

4.1 | Limitations

This meta-analysis has some limitations, which must be considered. Firstly, the study only includes articles published in the English language, which could introduce publication bias. Secondly, due to the meta-analysis inclusion criteria only a relatively small number remained in this study. However, those included did have a large patient cohort (n = 2105). Thirdly, the subgroup analysis estimations were constructed using the few available studies, which might not provide sufficient statistical power in the estimations. Readers should be cautious when extrapolating these results.

4.2 | Future direction

Further research should be undertaken to investigate the pooled sensitivity and specificity for different scoring systems of LUS as it could affect the ultrasound diagnostic performance. A further study could investigate the role of characteristic signs such as the light beam artifact for detection of COVID pneumonia.

5 | CONCLUSION

This is the first systematic review and meta-analysis done to evaluate the diagnostic performance of LUS for detecting COVID-19 pneumonia in the emergency setting. It was found that LUS had a moderate sensitivity and poor specificity. These results suggest that it should not be used independently to diagnose COVID-19, but could perform a triage process for patients with COVID-19 pneumonia (or other causes of pneumonia). Scanning a fewer number of lung regions can worsen the diagnostic accuracy. The LCT diagnostic performance was superior to the LUS in studies that compared the two modalities on the same patients.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Rothan H, Byrareddy S. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun. 2020;109:102433.
2. Manivel V, Lesnewski A, Shamim S, Carbonatto G, Govindan T. CLUE: COVID-19 lung ultrasound in emergency department. Emerg Med Australas. 2020;32(4):694-696.
3. Sureka B, Garg P, Saxena S, Garg M, Misra S. Role of radiology in RT-PCR negative COVID-19 pneumonia: review and recommendations. J Fam Med Primary Care. 2021;10(5):e1814.
4. Arevalo-Rodriguez I, Buitrago-Garcia D, Simancas-Racines D, et al. False-negative results of initial RT-PCR assays for COVID-19: a systematic review. PLOS One. 2020;15(12):1-19.
5. Ai T, Yang Z, Hou H, et al. Correlation of chest CT and RT-PCR testing for coronavirus disease 2019 (COVID-19) in China: a report of 1014 cases. Radiology. 2020;296(2):E32-E40.
6. Vetrugno L, Baciarello M, Bignami E, et al. The “pandemic” increase in lung ultrasound use in response to Covid-19: can we complement computed tomography findings? A narrative review. Ultrasound J. 2020;12(1):1-11.
7. Smith M, Hayward S, Innes S, Miller A. Point-of-care lung ultrasound in patients with COVID-19—a narrative review. Anaesthesia. 2020;75(8):1096-1104.
8. Tung-Chen Y, Marti de Gracia M, Diez-Tascon A, et al. Correlation between chest computed tomography and lung ultrasonography in patients with coronavirus disease 2019 (COVID-19). Ultrasound Med Biol. 2020;46(11):2918-2926.
9. Kameda T, Mizuma Y, Taniguchi H, Fujita M, Taniguchi N. Point-of-care lung ultrasound for the assessment of pneumonia: a narrative review in the COVID-19 era. J Med Ultrason. 2021;48(1):31-43.
10. Boero E, Schreiber A, Rovida L, Vetrugno L, Biaivs M. The role of lung ultrasonography in COVID-19 disease management. J Am College Emerg Physicians Open. 2020;1(6):1357-1363.
11. Gandhi D, Jain N, Khanna K, Li S, Patel L, Gupta N. Current role of imaging in COVID-19 infection with recent recommendations of point of care ultrasound in the contagion: a narrative review. Ann Trans Med. 2020;8(17):1094.
12. Jackson K, Butler R, Aujayeb A. Lung ultrasound in the COVID-19 pandemic. Postgrad Med J. 2020;97(1143):34-39.
13. Schmid K, Feuerstein D, Lang C, et al. Lung ultrasound in the emergency department—a valuable tool in the management of patients presenting with respiratory symptoms during the SARS-CoV-2 pandemic. BMC Emerg Med. 2020;20(1):1-7.
14. Pivetta, E., Goffi, A., Tizzani, M., Locatelli, S., Porrino, G., Losano, I., Leone, D., Calzolari, G., Vesana, M., Steri, F., Ardito, A., Capuano, M., Gelardi, M., Silvestri, G., Dutto, S., Avolio, M., Cavallo, R., Bartalucci, A., Paglieri, C., Morello, F., Riccardini, F., Sacchi, C., Sozzi, M., Totaro, S., Visconti, P., Risi, F., Basile, F., Bariccochi, D., Beuk, A., Beux, V., Bima, P., Cara, I., Chichizola, L., Dellavalle, F., Grosso, F., Labarile, G., Oddi, M., Ottino, M., Pia, L., Scategni, V. and Surra, A. Lung ultrasonography for the diagnosis of SARS-CoV-2 pneumonia in the emergency department. Ann Emerg Med 2021; 77(4), 385–394.
15. Piscaglia F, Stefanini F, Cantisani V, et al. Benefits, Open questions and Challenges of the use of Ultrasound in the COVID-19 pandemic era. The views of a panel of worldwide international experts. Ultraschall in der Medizin - Eur J Ultrasound. 2020;41(3):228-236.

16. Moher D, Liberati A, Tetzlaff J, Altman D. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Int J Surg. 2010;8(5):336-341.

17. Colombi D, Petrini M, Maffi G, et al. Comparison of admission chest computed tomography and lung ultrasound performance for diagnosis of COVID-19 pneumonia in populations with different disease prevalence. Eur J Radiol. 2020;133:e109344.

18. Whiting PF, Rutjes AW, Westwood ME, et al. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. Ann Intern Med. 2011;155(8):529-536.

19. Byron W, Dahabreh I, Trikalinos T, Lau J, Trow P, Schmid C. Closing the gap between methodologists and end-users: R as a computational back-end. J Stat Softw. 2012;49(5):1-15.

20. Via G, Storti E, Gulati G, Neri L, Mojoli F, Braschi A. Lung ultrasound in the ICU: from diagnostic instrument to respiratory monitoring tool. Minerva Anestesiol. 2012;78(11):1282-1296.

21. Lichtenstein D. Lung ultrasound in the critically ill. Ann Intensive Care. 2014;4(1):1-12.

22. San I, Begoz B, Usul E, et al. Role of lung ultrasonography in the diagnosis of COVID-19 patients admitted to the emergency department. Notfall Rettungsmedizin. 2021;24:15-20.

23. Favot M, Malik A, Rowland J, Haber B, Ehrman R, Harrison N. Point-of-care lung ultrasound for detecting severe presentations of coronavirus disease 2019 in the emergency department: a retrospective analysis. Crit Care Explor. 2020;2:8.

24. Gibbons R, Magee M, Goett H, et al. Lung ultrasound vs. chest X-ray for the radiographic diagnosis of COVID-19 pneumonia in a high-prevalence population. J Emerg Med. 2021;60(5):615-625.

25. Lieweld A, Kok B, Schuit F, et al. Diagnosing COVID-19 pneumonia in a pandemic setting: lung ultrasound versus CT (LUVCT)—a multi-centre, prospective, observational study. ERJ Open Res. 2020;6(4).

26. Sorfini C, Femia M, Nattino G, et al. The role of lung ultrasound as a frontline diagnostic tool in the era of COVID-19 outbreak. Intern Emerg Med. 2020;16(3):749-756.

27. Zanforlin A, Strapazzon G, Falk M, et al. Lung ultrasound in the emergency department for early identification of COVID-19 pneumonia. Respiration. 2020;100(2):154-153.

28. Tung-Chen Y, Algora-Martín A, Llamas-Fuentes R, et al. Point-of-care ultrasonography in the initial characterization of patients with COVID-19. Med Clin. 2021;156(10):477-484.

29. Bar S, Lecourtois A, Diouf M, et al. The association of lung ultrasound images with COVID-19 infection in an emergency room cohort. Anaesthesia. 2020;75(12):1620-1625.

30. Narinx N, Smisms An, Symons R, Frans J, Demeyere A, Gillis M. Feasibility of using point-of-care lung ultrasound for early triage of COVID-19 patients in the emergency room. Emerg Radiol. 2020;27(6):663-670.

31. Bosso G, Allegorico E, Pagano A, et al. Lung ultrasound as diagnostic tool for SARS-CoV-2 infection. Intern Emerg Med. 2020;16(2):471-476.

32. Pare J, Camelo I, Mayo K, et al. Point-of-care lung ultrasound is more sensitive than chest radiograph for evaluation of COVID-19. West J Emerg Med. 2020;21(4):771-778.

33. Brenner D, Liu G, Omron R, Tang O, Garibaldi B, Fong T. Diagnostic accuracy of lung ultrasound for SARS-CoV-2: a retrospective cohort study. Ultrasound J. 2021;13(1):1-11.

34. Watson J, Whiting P, Brush J. Interpreting a covid-19 test result. BMJ. 2020;369:m1808.

35. Fischer J, Bachmann L, Jaeschke R. A readers’ guide to the interpretation of diagnostic test properties: clinical example of sepsis. Intensive Care Med. 2003;29(7):1043-1051.

36. Vetvsheva N, Reshetnikov R, Leonov D, Kulberg N, Mokienko O. Diagnostic value of lung ultrasound in COVID-19: systematic review and meta-analysis. Digital Diagn. 2020;1(1):13-26.

37. Karam M, Althuwaikh S, Alazemi M, et al. Chest CT versus RT-PCR for the detection of COVID-19: systematic review and meta-analysis of comparative studies. JRSM Open. 2021;12(5):1-10.

38. Yassa M, Yirmibes C, Cavusoglu G, et al. Outcomes of universal SARS-CoV-2 testing program in pregnant women admitted to hospital and the adjuvant role of lung ultrasound in screening: a prospective cohort study. J Matern Fetal Neonatal Med. 2020;33(22):3820-3826.

39. Buonsenso D, Pata D, Chiaretti A. COVID-19 outbreak: less stethoscope, more ultrasound. Lancet Respir Med. 2020;8(5):e27.

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