Is Lung Ultrasound Useful for Diagnosing Pneumonia in Children?

A Meta-Analysis and Systematic Review

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Background: Childhood mortality due to pneumonia is high. Chest radiography is the primary imaging modality used for the evaluation of pneumonia in children. Lung ultrasonography (LUS) is a newer, alternative diagnostic method that has been gaining popularity in recent years. We conducted a meta-analysis to summarize the diagnostic usefulness of LUS for childhood pneumonia.

Methods: All studies included in this meta-analysis were retrieved from PubMed, Elsevier's Science Direct, and Springer, and by manual searches including the use of reference lists, through March 31, 2017. Two researchers independently screened the literature, extracted the data, and evaluated risks of bias in accordance with the inclusion and exclusion criteria. For the meta-analysis, we calculated the pooled sensitivity and specificity, pooled positive likelihood ratio, negative likelihood ratio, and the diagnostic odds ratio. Summary receiver operating characteristic curve was used to assess the overall performance of LUS.

Results: Our search identified 1038 articles, and we selected 51 of these for detailed review. Eight studies containing 1013 patients met all the inclusion criteria and were included in the final meta-analysis. The pooled sensitivity and specificity for the diagnosis of pneumonia using LUS were 93.0% (95% confidence interval, 88.0%–96.0%) and 96.0% (95% confidence interval, 92.0%–98.0%), respectively. The pooled positive likelihood ratio, negative likelihood ratio, and diagnostic odds ratio were 25.8 (11.0, 60.4), 0.07 (0.05, 0.12), and 344 (104, 1140), respectively. In addition, the summary receiver operating characteristic area under the curve was calculated to be 0.98 (0.97, 0.99). A Fagan plot analysis demonstrated that when pretest probabilities were 25%, 50%, and 75%, the positive posttest probabilities were 90%, 96%, and 99%, respectively, and the negative posttest probabilities were 2%, 7%, and 18%, respectively. Four clinical signs were most frequently observed using LUS in the screening of children with pneumonia: pulmonary consolidation, positive air bronchogram, abnormal pleural line, and pleural effusion.

Conclusions: Current evidence supports LUS as a useful imaging alternative for the diagnosis of childhood pneumonia. That it is easily carried out, readily available, relatively inexpensive, and free from the hazards of radiation make it an attractive alternative to chest radiography and physical examination for the diagnosis and the follow-up of pneumonia in children.

Key Words: lung, pediatric pneumonia, ultrasonography, children

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Pneumonia is a common medical illness, with clinical outcomes ranging from mild illness with rapid and complete recovery to a fulminant clinical course with morbid complications followed by death.[1] It is a common cause of death in children.[2] Early identification and treatment for patients with pneumonia is critical for the prevention of mortality. Chest radiography (CR) is the current criterion standard for pneumonia diagnosis.[3] However, this procedure is not suitable for all children because of the high risk for long-term complications related to exposure to ionizing radiation. Current guidelines recommend that a diagnosis of pneumonia should only be made considering clinical history, respiratory rate, presence of fever, and respiratory signs and symptoms, and limits the use of CR to severe or complicated cases only.[4] Until recently, lung ultrasound (LUS) had not been recommended as a diagnostic tool according to the current guidelines.[5] Despite this, in recent years, LUS has gained a reputation in clinical practice for providing value in the diagnosis of pneumonia. The use of LUS as a diagnostic tool has evolved from the traditional assessment of pleural effusions and thoracic masses to the imaging of the pulmonary parenchyma.[6] In a recent study, Iorio et al[7] proposed LUS as initial imaging screen for children with suspected pneumonia.

Here, we assess the diagnostic value of LUS for childhood pneumonia in a meta-analysis. We expect that this study will provide additional data to facilitate an understanding of the capabilities of LUS regarding the evaluation of childhood pneumonia.

METHODS

Search Strategy

We conducted a comprehensive search for articles on the topic of LUS in the diagnosis of pneumonia in children before March 31, 2017, in the databases of PubMed (US National Library of Medicine), Elsevier's ScienceDirect, and Springer (Springer Group). Computer searches were performed using

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the Medical Subject Heading and keywords: "ultrasonography" or "lung ultrasound" and "pneumonia" or "pulmonary pneumonia" and "children" or "childhood." We also searched manually through reference lists of the included studies to identify additional studies. All included articles were published in English. Thorough literature searches were performed independently by 2 observers, each of whom first assessed the title and abstract followed by the full text. Any disagreement was resolved through discussion and consensus. All retrieved citations were exported to EndNote (version X7; Thomson Reuters) and checked for duplicates.

Study Inclusion

To be included in the meta-analysis, the articles met the following criteria: (1) the study assessed the effects of LUS in diagnosing pneumonia in children; (2) the criteria for diagnosis of pneumonia were based on a combination of clinical data, laboratory results, and chest imaging by CR or chest computed tomographic scan; (3) the study provided data on true-positive (TP), false-positive (FP), false-negative (FN), and true-negative (TN) rates or reported sufficient data to derive these parameters (sensitivity, specificity, negative predictive value, and positive predictive value); and (4) the study enrolled at least 30 patients, and their ages were no more than 18 years.

Data Extraction

Two investigators independently extracted the following data from each article using standardized forms: (1) name of first author, (2) year of publication, (3) country, (4) number of patients, (5) sex distribution, (6) mean age, (7) diagnosis of pneumonia, (8) characteristic findings on LUS, (9) LUS technique, (10) level of operator expertise, (11) blinding, and (12) the TP, TN, FP, and FN rates. Disagreements were resolved by discussion between the 2 investigators.

Quality Assessment

The quality of each study was assessed using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) tool.[8] The QUADAS-2 assessment tool is composed of 10 questions that can be answered as yes, no, or unclear. This assessment of methodologic quality was performed by 2 independent reviewers who resolved disagreements by discussing the case to reach a consensus.

Statistical Analysis

The statistical analysis software "stata" (version 14.0; StataCorp, College Station, TX) was used to perform meta-analysis. Pooled estimates for sensitivity, specificity, FN, FP, TP, and TN with the corresponding 95% confidence intervals (CIs) were used to determine the accuracy of LUS for diagnosing pneumonia in children. From these data, we generated a forest plot and a summary receiver operating characteristic (sROC) curve from each study. The area under the curve (AUC) was used as a summary of the sROC curve to describe the overall accuracy as a potential summary of the sROC curve. Heterogeneity among the 8 studies was assessed by calculation of the inconsistency index (I2 or LRT_I2) and evaluation of Cochran χ^2 test (Q test or LRT_Q). LRT_I2 $\geq$ 50% and $P < 0.10$ for LRT_Q indicate substantial between-study heterogeneity. Meta-regression analysis was used to explore the source of heterogeneity. Fagan plot analysis was also performed, which assesses the relationship among an estimated pretest probability of the disease, the likelihood ratio of the diagnostic test, and the posttest probability of the disease. We assumed pretest

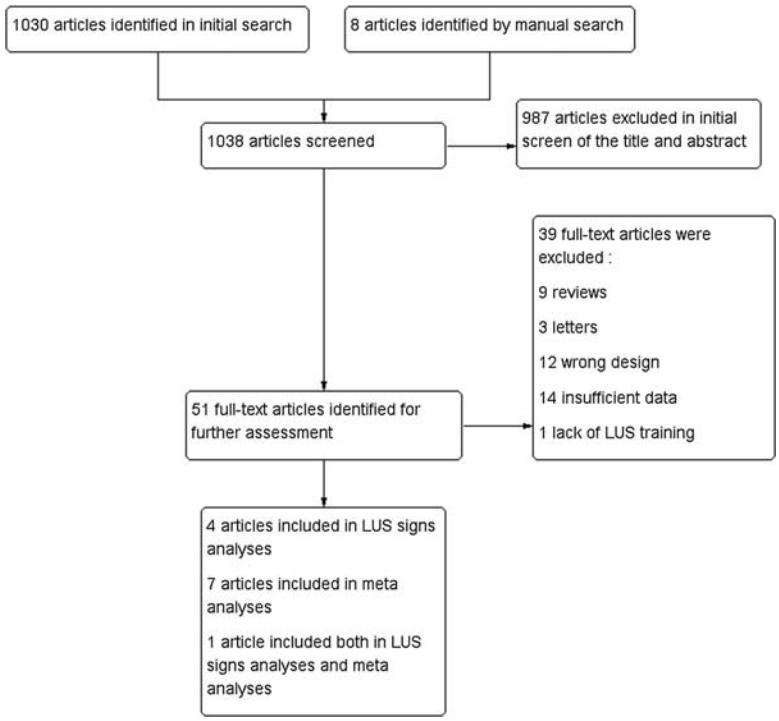

FIGURE 1. Flowchart of articles retrieved from the search of databases and reasons for exclusions.

probabilities of 25%, 50%, and 75%, and the corresponding positive and negative posttest probabilities were calculated. We used the QUADAS-2 tool to assess study quality, which comprised 4 sections: "patient selection," "index test," "reference standard," and "flow and timing." The processing of the quality assessment was conducted using RevMan 5.2 software (Nordic Cochrane Centre, Copenhagen, Denmark). Publication bias was assessed by using the Deeks funnel plot asymmetry test. A P value of less than 0.05 was considered statistically significant.

Additional Analyses on Studies Found With LUS-Specific Clinical Signs

We identified 5 articles that specifically provided signs for the diagnosis of pneumonia in children using LUS (Fig. 1). Most of these articles could not be included in our meta-analysis because of inappropriate reference standards according to our selection criteria. To better understand LUS for the diagnosis of pneumonia, we performed a separate, independent review of these articles.

RESULTS

Study Characteristics

Our literature search identified 1038 articles in total. We excluded 987 of these articles because of a lack of relevance, based on information in the abstracts. The full texts of the remaining 51 articles were obtained for further evaluation. Considering all inclusion criteria in the study selection process (Fig. 1), 8 articles were selected for meta-analysis and underwent quality assessment using QUADAS-2 (Fig. 2). These 8 studies were performed in the United States, Italy, Spain, Poland, Belgium, and Taiwan and included 1013 patients with ages ranging from newborn to 18 years. The general characteristics of each of the studies are shown in Table 1. Three of the studies were performed in emergency departments[5,10,13] and 5 were performed in pediatric wards.[7,11,12,14,15] Six of the studies[5,10,12–15] were prospective and 2 were retrospective studies.[7,11]

Quality Assessment of the Studies

Figure 2 illustrates the methodological quality of the included studies based on QUADAS-2 assessment, with the results reflecting bias risk and applicability. All studies used an acceptable reference standard independent of the index test. All studies' interpretation of the reference standard was blinded to the results of the physical examinations. The training time of the LUS operators differed among the included studies. Some operators had only a few days of training,[14] whereas some were experienced experts.[7,11,15] The inconsistency index (I^2) for the overall meta-analysis was 0 (95% CI, 0–100) and the Q test statistic was 0.161 ($P = 0.461$), indicating that very little heterogeneity existed among these 8 studies. However, heterogeneity in the sensitivity of LUS ($I^2 = 54.81\%$) and the specificity of LUS ($I^2 = 71.84\%$) were evident. In addition, publication bias was detected by using the Deeks funnel plot asymmetry test ($P = 0.04$; Fig. 3). There was some asymmetry in the funnel plot of the included trials suggesting possible publication bias. According to statistic results, the mixed-model correlation was 1.00 and the proportion of heterogeneity likely due to threshold effect was 1.00, suggesting that the causes of variations existed other than threshold effect. We performed subgroup analysis.

Summary Estimates of Sensitivity and Specificity

Figures 4 and 5 show the pooled sensitivity, specificity, and the sROC curve that describe the efficacy of LUS for the diagnosis of pneumonia. Overall pooled sensitivity and specificity were 93.0% (95% CI, 88.0%–96.0%) and 96.0% (95% CI 92.0%–98.0%), respectively. The overall pooled positive likelihood ratio (PLR), negative likelihood ratio (NLR), and diagnostic odds ratio (DOR) were 25.8 (11.0, 60.4), 0.07 (0.05, 0.12), and 344 (104, 1140), respectively. In addition, the sROC AUC was 0.98 (0.97, 0.99).

Subgroup Analysis

Our results indicated that heterogeneity from nonthreshold effects was present in the sensitivity and specificity among the 8 included studies. To investigate the source of this heterogeneity, we used a meta-regression analysis to evaluate various covariates from these studies, including the "type of medical ward," "experience of the operator," and "type of ultrasound (US) system." We first compared the performance of LUS for diagnosis of pneumonia between different medical wards. In studies conducted in emergency departments (n = 3), the pooled sensitivity was 87.0% (95% CI, 82.0%–92.0%) and the pooled specificity was 93.0% (95% CI, 89.0%–96.0%). In studies conducted in pediatric wards (n = 5), the pooled sensitivity was 95.0% (95% CI, 93.0%–98.0%) and the pooled specificity was 98.0% (95% CI, 96.0%–100.0%). Next, we compared the performance of LUS for diagnosis of pneumonia between different operators based on their level of experience. In studies that used an operator with limited experience (n = 5), the pooled sensitivity was 93.0% (95% CI, 88.0%–97.0%) and the pooled specificity was 95.0% (95% CI, 90.0%–100.0%). In studies that used an expert LUS operator (n = 3), the pooled sensitivity was 93.0% (95% CI, 88.0%–97.0%) and the pooled specificity was 97.0% (95% CI, 94.0%–100.0%). Finally, we compared the performance of LUS for diagnosis of pneumonia between different ultrasound systems. In studies conducted with European ultrasound systems (n = 6), the pooled sensitivity was 92.0% (95% CI,

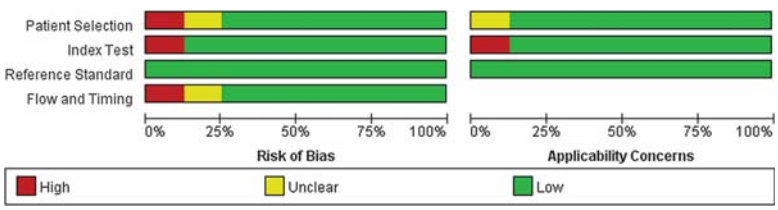

FIGURE 2. Graph reviews authors' judgements about each domain presented as percentages across included studies in meta-analysis.

TABLE 1. Characteristics of Studies Evaluating the LUS

Study	Year	Origin	Design	Sample Size	Mean Age (Range)	M/F	TP	FP	FN	TN	Ultrasound System	Blind	Patient Origin	LUS Operator Experience	Pneumonia Diagnosis
Reali et al[9]	2014	Italy	Prospective	107	4 y (0–16 y)	61/46	76	1	5	25	Mylab 25; Esaote, Genoa, Italy, and a linear probe (7.5–10 MHz)	Yes	Pediatric ward	A background of at least 100 procedures performed	Physical and CR
Samsona et al[5]	2016	Spain	Prospective	200	29.5 mo (6 mo–12 y)	116/84	74	6	11	109	6-zone LUS imaging protocol	Yes	Emergency department	Experienced pediatric radiologist	Physical and CR
Shah et al[10]	2013	American	Prospective	200	3 y (1–8 y)	112/88	31	18	5	146	7.5–10 MHz linear array transducer and MicroMax; Sonosite and GS60; Siemens	Yes	Emergency department	Sonologists with less experience (≤25 ultrasonography examinations)	Physical and CR
Caiulo et al[11]	2014	Taiwan	Retrospective	102	73.2 mo (25.6–120.8 mo)	91/72	88	0	1	13	5 MHz convex probe, Sono57500; Philips, Bothell, WA	Yes	Pediatric ward	An expert pediatric sonographer	Physical and CR
Urbankowskal et al[12]	2015	Poland	Prospective	106	52.5 mo (1–213 mo)	No	71	0	5	30	Linear probes, 3–7 and 5–9 MHz, respectively (ProSound a6 ALOKA, Japan)	Yes	Pediatric ward	The same pediatric sonographer	Physical and CR
Claes et al[13]	2016	Belgium	Prospective	143	3 y 5 mo (8 d–14 y)	77/66	55	5	8	90	Philips iU-22 machine with a linear probe (L 12–5 MHz)	Yes	Emergency department	Basic ultrasound knowledge	Physical and CR
Iorio et al[7]	2015	Italy	Retrospective	52	3.5 y (2–12.5 y)	39/67	28	1	1	22	Linear probes 3–7 and 5–9 MHz, respectively, and ProSound a6 ALOKA, Japan	Yes	Pediatric ward	The same expert operator	Physical and CR
Esposito et al[14]	2014	Italy	Prospective	103	5.6 y (1–10 y)	56/47	47	1	3	52	MyLab25 Gold (Esaote, Genoa, Italy) with a convex 2.5–6.6 MHz probe and a linear 7.5–12 MHz probe (MicroMax Systems)	Yes	Pediatric ward	Limited experience in ultrasound	Physical and CR

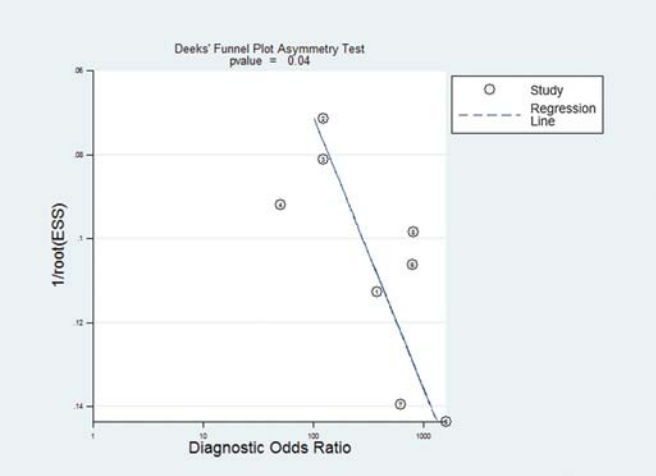

FIGURE 3. The funnel plot analyses. The analyses showed no potential publication bias for analyses of LUS. ESS, effective sample size.

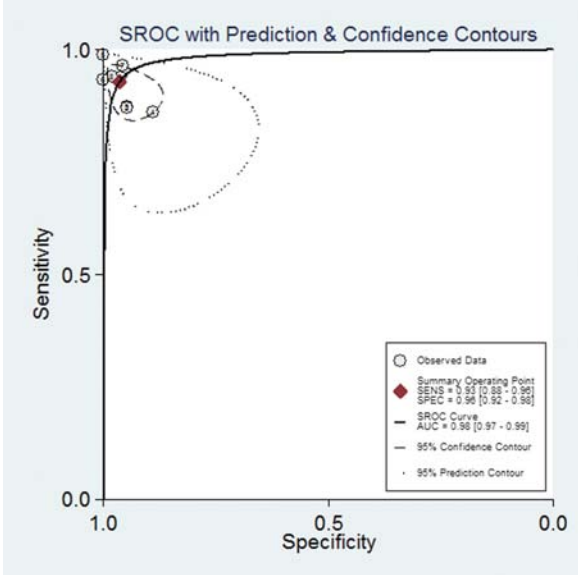

FIGURE 5. Summary receiver operating characteristic curves for estimating the testing accuracy of LUS.

88.0%–96.0%) and the pooled specificity was 96.0% (95% CI, 92.0%–99.0%). In studies conducted with Asian ultrasound systems (n = 2), the pooled sensitivity was 95.0% (95% CI, 89.0%–100%) and the pooled specificity was 98.0% (95% CI, 95.0%–100.0%).

The detailed data for the meta-regression analysis are presented in Figure 6. From the results, for sensitivity, the covariate of "type of medical ward," "experience of the operator," and "type of ultrasound (US) system" is statistically significant ($P < 0.05$). For specific, the covariate of "type of ultrasound (US) system" is statistically significant ($P < 0.05$). Thus, the results of this meta-regression analysis suggested that the covariate of the "type of medical ward," "experience of the operator," and "type of ultrasound (US) system" might be the potential source of heterogeneity in sensitivity and the covariate of "type of ultrasound (US) system" might be the potential source of heterogeneity in specificity of our diagnostic meta-analysis.

LUS Signs of Childhood Pneumonia

Clinical signs of childhood pneumonia that can be detected with LUS are shown in Table 2. We found that 4 of these signs are most often seen on LUS in pneumonia patients: pulmonary

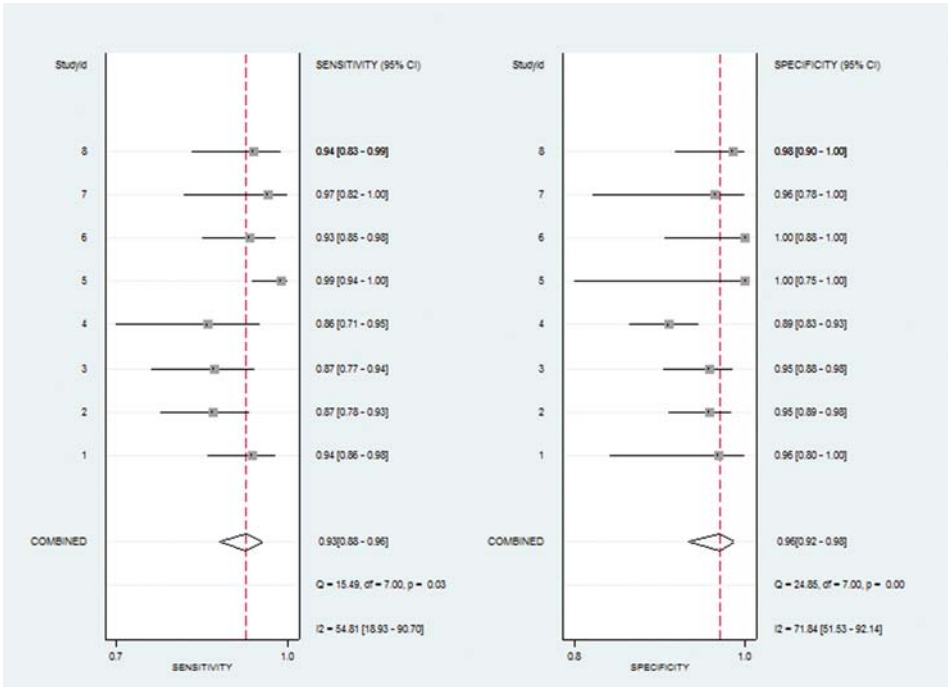

FIGURE 4. Forest plots of sensitivity and specificity for each study.

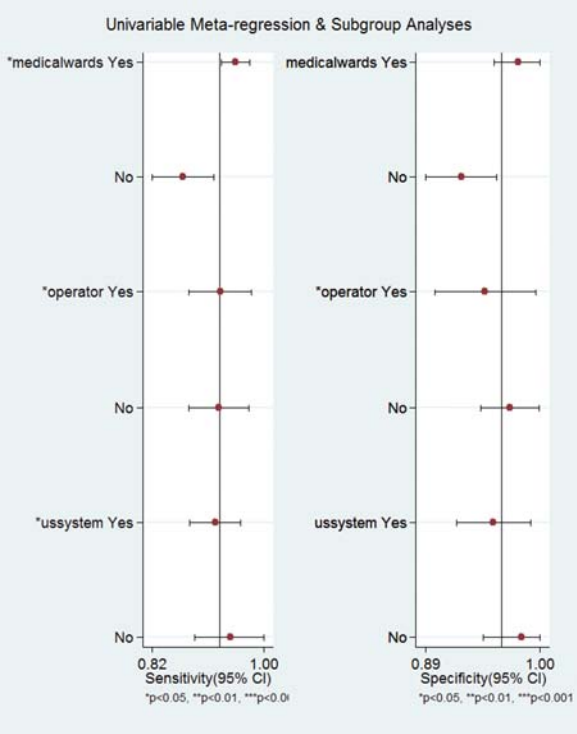

FIGURE 6. Subgroup analysis based on the covariate of "type of medical ward," "experience of the operator," and "type of ultrasound (US) system."

consolidation, positive air bronchogram, abnormal pleural line, and pleural effusion. From the results in Table 2, we can conclude that positive air bronchogram and lung consolidation are the most often detected signs on LUS.

Fagan Plot Analysis

The Fagan plot demonstrated that when the pretest probabilities were 25%, 50%, and 75%, the positive posttest probabilities were 90%, 96%, and 99%, and the negative posttest probabilities were 2%, 7%, and 18%, respectively (Fig. 7).

DISCUSSION

The diagnosis of pneumonia is primarily based on physical examination along with radiologic and laboratory evaluation.[4] Although LUS has shown high sensitivity and specificity in detecting several pleuropulmonary diseases in adults,[19] its role in the diagnosis of childhood pneumonia has not yet been widely recognized. Lung ultrasound is rapid, portable, repeatable, and nonionizing in nature. The latter is of critical importance for infants, who carry a higher risk for developing cancer from exposure to radiation than do people of other ages. Interest in LUS for use in diagnosis and follow-up of pediatric pneumonia has increased in the last few years. The use of LUS even for follow-up avoids multiple, repeated exposures to radiation. However, despite the obvious benefits and increasing interest, this technique still has not been widely accepted as a routine imaging tool for everyday clinical use.

In this meta-analysis, we assessed the performance of LUS in the diagnosis of pediatric pneumonia. A thorough, systematic literature search and screening process resulted in 8 studies that satisfied all of the inclusion criteria. In our meta-analysis, we have more recent studies and studies that were almost published between 2012 and 2017. Our meta-analysis evaluated pneumonia based on clinical signs and symptoms and used CR as the reference standard. Several studies have reported that LUS has good sensitivity and specificity.[18] Others, however, have raised concerns regarding the limitations of LUS, such as the fact that small and localized parenchymal lesions do not reach the pleura and thus remain potentially undetectable by ultrasound.[20] The results of our meta-analysis indicate that LUS has high diagnostic power for the detection of childhood pneumonia (93.0% sensitivity and 96.0% specificity). Based on these values, we can calculate the DOR, which is a single indicator of test accuracy. The DOR is the ratio of the PLR relative to the NLR; thus, the higher the DOR is, the greater the accuracy of the method for the diagnosis of pneumonia. In our review and meta-analysis, the mean DOR was 344 (104, 1140), which demonstrates a significantly high level of overall accuracy. Although the DOR can be a useful measure of diagnostic test performance, LRs are more clinically meaningful. The pooled PLR and NLR were 25.8 (11.0, 60.4) and 0.07 (0.05, 0.12), respectively. Finally, the sROC AUC was 0.98, indicating a high level of overall diagnostic accuracy.

We found that heterogeneity from nonthreshold effects was present in the sensitivity and specificity among the 8 studies ($I^2 > 50\%$). Subgroup analysis revealed that the diagnostic sensitivity of LUS among subgroups based on the "type of medical ward," "experience of the operator," and "type of ultrasound (US) system" was statistically significant ($P < 0.05$), and the diagnostic specificity of LUS among subgroups based on the "type of ultrasound (US) system" was statistically significant ($P < 0.05$). Results of a meta-regression analysis revealed that the covariate of the "type of medical ward,"

TABLE 2. Pooled Studies About LUS Signs of Childhood Pneumonia

Feature	Ho et al[16] (n = 163)	Guerra et al[17] (n = 222)	Cortellaro et al[18] (n = 120)	Urbankowska et al[12] (n = 106)	Boursiani et al[15] (n = 69)
Established diagnosis of pneumonia	163 (100%)	222 (100%)	81 (67.5%)	76 (71.7%)	66 (95.7%)
LUS positive	159/163 (97.5%)	207/222 (93.2%)	80/81 (98.8%)	71/76 (93.4%)	62/66 (93.9%)
Pneumonia consolidation	95 (59.7%)	139 (67.2 %)	73 (91%)	17 (23.50%)	37 (56.1%)
B-line pattern	81 (50.9%)	10 (4.8%)	7 (9%)	NA	36 (54.5%)
Air bronchogram	149 (93.7%)	75 (36.2 %)	71 (97%)	54 (76.50%)	9 (13.0%)
Pleural effusion	43 (27.0%)	76/207 (36.7 %)	31 (42%)	39 (54.30%)	3 (4.5%)

N, number of patients enrolled; NA, not available.

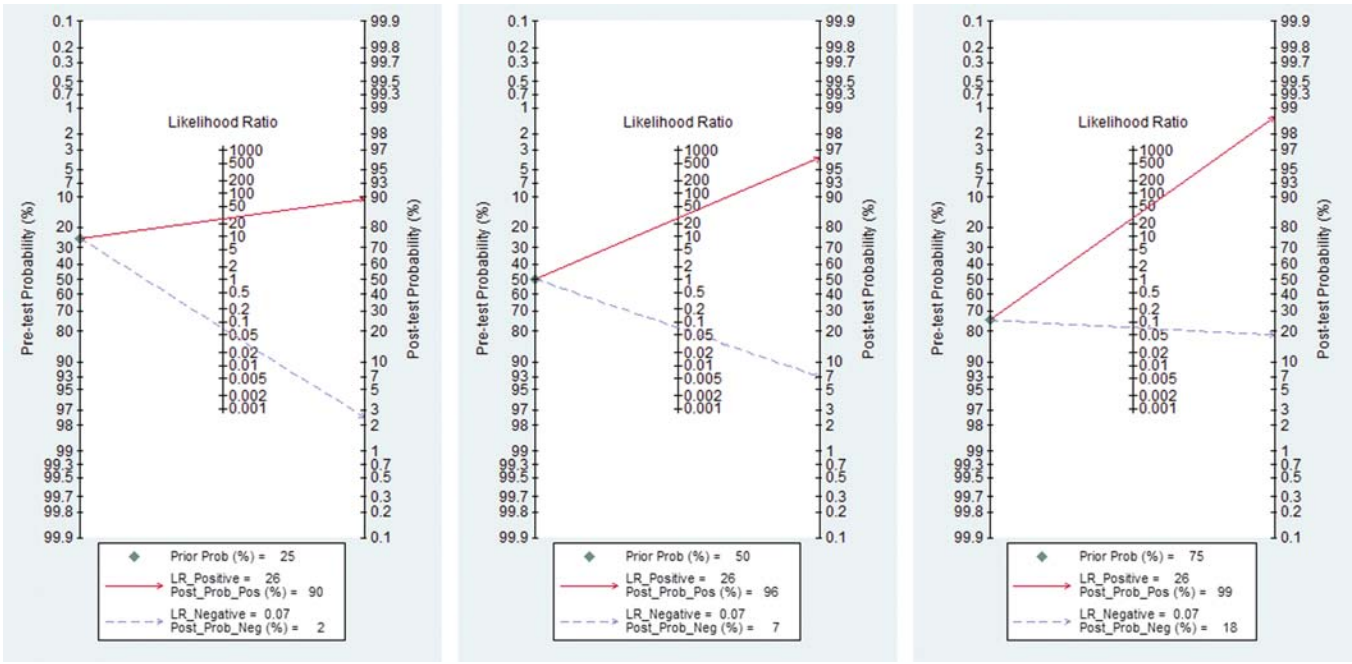

FIGURE 7. Fagan plot analyses to evaluate the clinical utility of LUS.

"experience of the operator," and "type of ultrasound (US) system" might be the potential source of heterogeneity in sensitivity, and the covariate of "type of ultrasound (US) system" might be the potential source of heterogeneity in specificity of our diagnostic meta-analysis.

There are several possible explanations for this heterogeneity. First, patients in the meta-analysis included hospitalized patients, emergency department patients, and bedside patients, and thus, the severity of illness in the patients differed (most of the patients were mildly ill but some were critically ill). Second, physicians performing the ultrasound examination varied and included trained residents, pulmonologists, emergency physicians, and experienced physicians. It is possible that the accuracy of LUS in diagnosis of pneumonia is dependent on the skills of the operators. The training time of the operators was highly varied, ranging from several hours of training to several years of clinical practice. Inadequate training and/or incomplete thorax investigation may cause misdiagnoses. Monti et al[21] showed that clinicians with 10 to 30 minutes of ultrasonography training can rapidly (within 2–5 minutes) and accurately identify pulmonary pathology using ultrasonography. For example, in a study by Zhan et al,[22] all LUS examinations were performed by the same pediatric resident who had only basic ultrasound knowledge after a 3-day point-of-care emergency ultrasound course, and with minimal practical ultrasound experience. This study reported that LUS had a sensitivity of 40% (95% CI, 30%–51%), a specificity of 91% (95% CI, 83%–96%), a PLR of 4.71 (95% CI, 2.21–10.04), and an NLR of 0.65 (95% CI, 0.54–0.79) for the diagnosis of pneumonia. Thus, in this study, LUS had good specificity but poor sensitivity, and it was excluded from our meta-analysis. The lack of LUS training or presence of skilled supervision likely explains some of the heterogeneity observed in the pooled sensitivity. Third, different ultrasound systems are different in the detection of lesions. Therefore, different ultrasound systems might contribute to the heterogeneity of our meta-analysis.

In addition to the heterogeneity among the studies, we must consider the effect of the publication bias that was detected in our meta-analysis by using the Deeks funnel plot asymmetry test. It is possible that the small number of included studies, combined with low numbers of patients within some studies, resulted not only in the large CIs but also in the assessment for publication bias.

One LUS limitation is the airiness of the lungs, which does not allow for exposure under physiological conditions. However, in pathological situations, airiness of the lung is reduced. This results in artifacts and subpleural lesions. Observation of the various configurations of lung subpleural lesions in LUS allows for the differential diagnosis of lung diseases.[23] Adequate interpretation and recognition of certain signs is crucial to diagnosing pathological processes.[24] In our separate analysis of LUS signs for the diagnosis of pneumonia, we found 4 major abnormalities that are the most frequently observed: pulmonary consolidation, positive air bronchogram, abnormal pleural line, and pleural effusion. Pneumonia is sonographically identified as a subpleural, nonhomogeneous, hypoechogenic area, and/or a marked liver-like area, with irregular margins and arborized air bronchograms within. As can be seen from the results of Table 2, positive air bronchogram and lung consolidation are the most often detected signs on LUS. The presence of these signs diagnoses pneumonia with a positive predictive value of 97 %.[25] The ultrasonographic appearance of pneumonia does not differ between children and adults. Caiulo et al[11] compared the use of different combinations of LUS signs and found that combining 4 of them led to the highest accuracy for diagnosing pneumonia.

Several other meta-analyses have summarized data regarding LUS and childhood pneumonia.[26] The analysis by Pereda et al[27] found that LUS had a sensitivity of 96% (95% CI, 94%–97%), a specificity of 93% (95% CI, 90%–96%), a PLR of 15.3 (95% CI, 6.6–35.3), and an NLR of 0.06 (95% CI, 0.03–0.11). Our findings are similar to these results; in addition, our analysis adds additional objective data to support the application of LUS for the diagnosis of childhood pneumonia.

The overall result of our meta-analysis suggests that LUS has significant power in diagnosing childhood pneumonia. However, it is also essential to know how the diagnostic test utility varies with the perceived risk. For this reason, Fagan plot analysis was performed and determined that with pretest probabilities of 25%, 50%, and 75%, the posttest probabilities of a correct diagnosis are 90%, 96%, and 99%. This analysis provides further support for the high value of LUS for diagnosing childhood pneumonia.

It is important to note that our study has several limitations. First, there is a lack of a formal validity testing procedure and a lack of quality assessment criteria for studies; however, to address this, we combined the relevant published guidelines with currently widely used tools. We did not analyze the inherent heterogeneity present within each study or the impact this had on the pooled diagnostic performance of LUS. Second, our meta-analysis was relatively small, because our screen identified only 8 studies that met all of the inclusion criteria. This may be because LUS is still a relatively new technique and large-scale studies will be required to validate the clinical use of LUS as a diagnostic tool for childhood pneumonia. Third, there was heterogeneity among studies and the publication bias was asymmetry, which was discussed previously. Fourth, most of our included studies were single-center studies and our results were generated from different etiological groups within the same analysis. Therefore, in future studies, we encourage researchers to be more rigorous in patient selection. Fifth, the patient's position being examined may have influenced the performance of LUS diagnosis.

CONCLUSIONS

In conclusion, LUS is a highly valuable imaging technique that complements CR and physical examination in the diagnosis and follow-up monitoring of pediatric pneumonia. Of critical importance, this method does not expose patients to ionizing radiation. Our meta-analysis demonstrates that the sensitivity and specificity of LUS in the diagnosis of pneumonia are excellent. It is important to note, however, that this conclusion is based solely on a small number of studies that met our specific inclusion criteria. Large-scale, well-designed, and multicenter studies are needed to validate this conclusion and further evaluate the performance of LUS in the diagnosis of pediatric pneumonia.

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