

# Lung Ultrasound for the Diagnosis of Pneumonia in Children: A Meta-analysis

Maria A. Pereda, MD<sup>a</sup>, Miguel A. Chavez, MD<sup>a,b</sup>, Catherine C. Hooper-Miele, MD<sup>a</sup>, Robert H. Gilman, MD, DTMH<sup>c</sup>, Mark C. Steinhoff, MD<sup>d</sup>, Laura E. Ellington, MD<sup>a</sup>, Margaret Gross, MA, MLIS<sup>e</sup>, Carrie Price, MLS<sup>e</sup>, James M. Tielsch, PhD<sup>f</sup>, William Checkley, MD, PhD<sup>a,b,c</sup>

## abstract

**BACKGROUND AND OBJECTIVE:** Pneumonia is the leading cause of death of children. Diagnostic tools include chest radiography, but guidelines do not currently recommend the use of lung ultrasound (LUS) as a diagnostic method. We conducted a meta-analysis to summarize evidence on the diagnostic accuracy of LUS for childhood pneumonia.

**METHODS:** We performed a systematic search in PubMed, Embase, the Cochrane Library, Scopus, Global Health, World Health Organization–Libraries, and Latin American and Caribbean Health Sciences Literature of studies comparing LUS diagnostic accuracy against a reference standard. We used a combination of controlled key words for age <18 years, pneumonia, and ultrasound. We identified 1475 studies and selected 15 (1%) for further review. Eight studies (765 children) were retrieved for analysis, of which 6 (75%) were conducted in the general pediatric population and 2 (25%) in neonates. Eligible studies provided information to calculate sensitivity, specificity, and positive and negative likelihood ratios. Heterogeneity was assessed by using Q and I<sup>2</sup> statistics.

**RESULTS:** Five studies (63%) reported using highly skilled sonographers. Overall methodologic quality was high, but heterogeneity was observed across studies. LUS had a sensitivity of 96% (95% confidence interval [CI]: 94%–97%) and specificity of 93% (95% CI: 90%–96%), and positive and negative likelihood ratios were 15.3 (95% CI: 6.6–35.3) and 0.06 (95% CI: 0.03–0.11), respectively. The area under the receiver operating characteristic curve was 0.98. Limitations included the following: most studies included in our analysis had a low number of patients, and the number of eligible studies was also small.

**CONCLUSIONS:** Current evidence supports LUS as an imaging alternative for the diagnosis of childhood pneumonia. Recommendations to train pediatricians on LUS for diagnosis of pneumonia may have important implications in different clinical settings.



<sup>a</sup>Division of Pulmonary and Critical Care and <sup>e</sup>Welch Medical Library, School of Medicine, and <sup>c</sup>Department of International Health, Bloomberg School of Public Health, Johns Hopkins University, Baltimore, Maryland; <sup>b</sup>Biomedical Research Unit, A.B. Prisma, Lima, Peru; <sup>d</sup>Global Child Health Center, Cincinnati Children's Hospital Medical Center, College of Medicine, University of Cincinnati, Cincinnati, Ohio; and <sup>f</sup>Department of Global Health, Milken Institute School of Public Health, George Washington University, Washington, District of Columbia

Dr Pereda conceptualized and designed the study, reviewed all abstracts and selected articles to be included in the meta-analysis, was responsible for data collection, and drafted the initial manuscript; Dr Chavez conceptualized and designed the study, reviewed all abstracts and selected articles to be included in the meta-analysis, was responsible for data collection, led the analysis, and drafted the initial manuscript; Dr Hooper-Miele participated in analysis and interpretation of results, critically revised ultrasound methods used by selected studies, and reviewed and revised the manuscript; Drs Gilman, Steinhoff, Ellington, and Tielsch participated in the analysis and interpretation of results and reviewed and revised the manuscript; Ms Gross and Ms Price conducted the literature search and reviewed and revised the manuscript; Dr Checkley conceptualized and designed the study, contributed equally to the analysis, drafted the initial manuscript, and had ultimate oversight over the study conduct, analysis plan, and writing of the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

[www.pediatrics.org/cgi/doi/10.1542/peds.2014-2833](http://www.pediatrics.org/cgi/doi/10.1542/peds.2014-2833)

DOI: 10.1542/peds.2014-2833

Accepted for publication Jan 5, 2015

Address correspondence to William Checkley, MD, PhD, Division of Pulmonary and Critical Care, School of Medicine, Johns Hopkins University, 1800 Orleans Ave, Suite 9121, Baltimore, MD 21205. E-mail: [wcheckl1@jhmi.edu](mailto:wcheckl1@jhmi.edu)

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

Copyright © 2015 by the American Academy of Pediatrics

Pneumonia is the leading cause of illness and death in children worldwide. It is estimated that pneumonia has a global annual incidence of 150 to 156 million cases<sup>1</sup> in children <5 years of age, of whom ~11 to 20 million of cases need hospitalization and 1.1 million die of this condition.<sup>2</sup> Pneumonia accounts for 18% of the total number of deaths in children <5 years worldwide, more than tuberculosis, AIDS, and malaria combined.<sup>2</sup>

Pediatric pneumonia still remains a diagnostic challenge in resource-limited settings.<sup>3</sup> Signs and symptoms of pneumonia vary depending on a child's age and the etiology of infection.<sup>4-7</sup> Moreover, presenting signs and symptoms have poor diagnostic specificity, which may further complicate the diagnosis. The American Academy of Pediatrics recommends the use of chest radiographs (CRs) cautiously for different reasons. First, ionizing radiation in young children may have potential late adverse effects.<sup>8-10</sup> Second, the lack of findings on CR does not rule out the diagnosis if there is a strong suspicion of pneumonia.<sup>3</sup> Finally, although a chest computed tomography (CT) scan has a higher level of diagnostic accuracy than CR, it is almost never used for the diagnosis of pneumonia because of higher ionizing radiation exposure, difficulty in patient cooperation, frequent need for sedation, and cost.<sup>11</sup> Other disadvantages of both techniques as a tool for the diagnosis of pneumonia, especially in resource-poor settings, include availability and lack of portability. Even when CR is available, there may be a considerable time delay between the time when a CR is ordered and a final reading is available.

There has been recent interest in developing new tools aimed at increasing the feasibility and accuracy of pneumonia diagnosis while simultaneously decreasing exposure

to ionizing radiation. Advances in ultrasound technology have made lung ultrasound (LUS) an attractive option for the diagnosis of pneumonia. Moreover, ultrasound is safe, portable, inexpensive, and relatively easy to teach. Our group recently published a meta-analysis supporting the use of LUS for the diagnosis of pneumonia in adults<sup>12</sup>; however, evidence for the use of LUS in children is limited. In this article, we summarized information available on the diagnostic accuracy of LUS for the diagnosis of childhood pneumonia.

## METHODS

### Search Strategy

Two information specialists from Welch Medical Library developed and conducted the search strategy after input from clinical investigators in the research team. A systematic literature search was applied to PubMed (1946 to present). The search was adapted for Embase (1974 to present), the Cochrane Library (1898 to present), Scopus (1966 to present), Global Health (1973 to present), World Health Organization Global Health Regional Libraries (1980 to present), and Latin American and Caribbean Health Sciences Literature (1980 to present). We used a combination of controlled vocabulary and key words for age (<18 years), pneumonia, and ultrasound (see the Supplemental Information). We did not limit our search to studies based on publication dates or language. We did not seek to identify research abstracts from meeting proceedings or unpublished studies because these are not commonly subjected to exhaustive peer review. Results of the search were then reviewed by the research team. We also provided the 2 information specialists with 3 studies<sup>13-15</sup> as a test set to check the completeness of the search results. All titles and abstracts relevant to our study were retrieved and

searched for full texts. References from included studies and review articles were hand-searched to identify any additional relevant studies for analysis. The literature search and data analysis were performed in July 2014.

### Study Eligibility

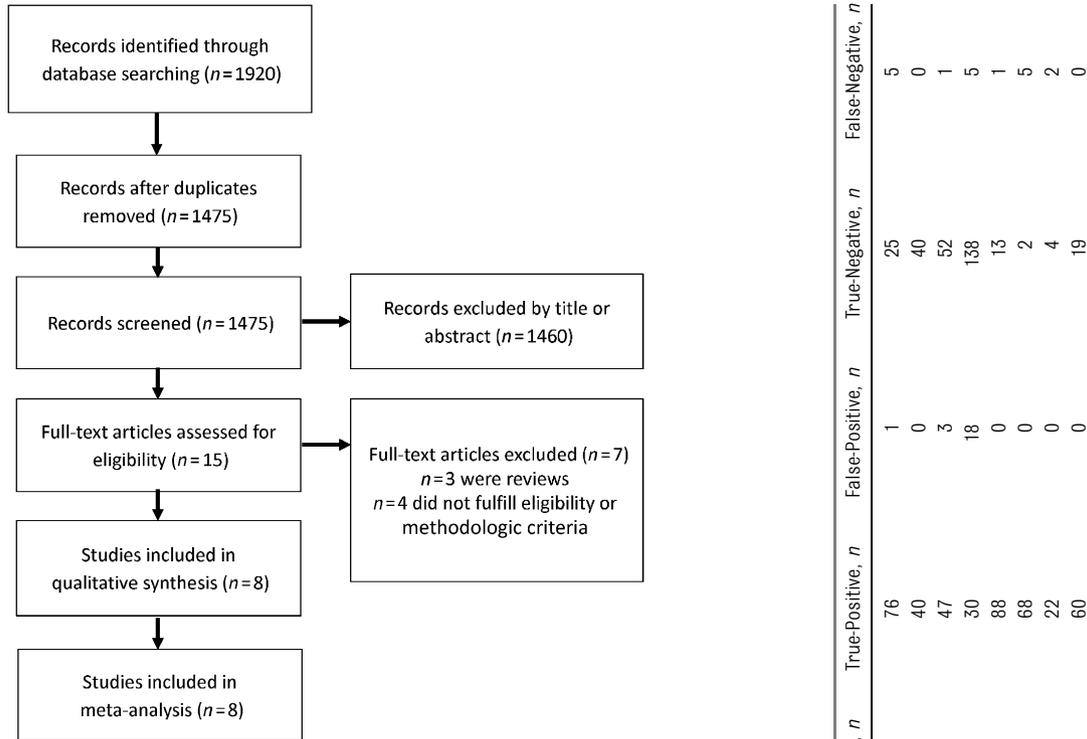
We pursued all studies with the following inclusion criteria: children with clinical suspicion (signs and symptoms) of pneumonia and/or confirmation with CR or chest CT scan. The evaluation of pneumonia was based on a combination of clinical data, laboratory results, and chest imaging by CR or chest CT scan. We included all relevant neonatal studies. We excluded studies that enrolled adults (ie, participants  $\geq 18$  years of age). Two investigators (M.A.P. and M.A.C.) independently evaluated all relevant studies for eligibility criteria. Data obtained (by M.A.P. and M.A.C.) from these studies were then compared. We defined a priori that disagreements would be resolved via consensus between 3 members of the study team (M.A.P., M.A.C., and W.C.).

### Data Extraction

The following data were extracted from each study: sample size, gender proportion, mean age, LUS technique, areas of the chest that were evaluated, time lapse between CR and LUS, average time to perform LUS, operator expertise, blinding, LUS pattern definitions, and number of true-positives, true-negatives, false-positives, and false-negatives. We also contacted the author of one of the selected articles to obtain missing information for our data analysis. Furthermore, we contacted the authors of some of the selected studies<sup>13,15,16</sup> to gather additional information that was relevant to our analysis.

### Methodologic Quality Assessment

Methodologic quality was assessed by using the QUADAS-2 (Quality Assessment of Diagnostic Accuracy



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

Studies 2) criterion.<sup>17</sup> Both reviewers (M.A.P. and M.A.C.) scored the 7-item tool independently and disagreements were resolved by consensus (between M.A.P., M.A.C., and W.C.) via a face-to-face discussion about each disagreement.

### Biostatistical Methods

The primary objective was to estimate pooled measurements of diagnostic accuracy: pooled sensitivity and specificity with the use of the Mantel-Haenszel method<sup>18</sup> and pooled positive and negative likelihood ratios (LRs) by using the DerSimonian-Laird method.<sup>19</sup> We also calculated an overall area under the receiver operating characteristic curve. Heterogeneity was assessed by using the Cochran Q-statistic and the inconsistency ( $I^2$ ) test.<sup>20</sup> An  $I^2 > 20\%$  was considered as indicative of significant variation. Subgroup sensitivity analyses were also conducted by reference standard, acute care setting, age of child, and level of expertise in sonography to

determine the robustness of findings. We used Meta-DiSc 1.4 (Unit of Clinical Biostatistics team, Ramón y Cajal Hospital, Madrid, Spain; [www.hrc.es/investigacion/metadisc\\_en.htm](http://www.hrc.es/investigacion/metadisc_en.htm)) and R (R Foundation, [www.r-project.org](http://www.r-project.org)) for statistical analyses.

### RESULTS

#### Overview of Literature Search

Our search strategy identified 1475 studies of which we selected 15 (1%) for further evaluation on the basis of inclusion criteria and content (Fig 1). We excluded 3 review articles, 1 study in adults, and 3 studies that did not fit our methodologic criteria. We selected 8 studies for analysis,<sup>13-16,21-24</sup> of which 6 (75%) were conducted in the general pediatric population and 2 (25%) were conducted in neonates <28 days of age. Three studies<sup>13,15,16</sup> were conducted in emergency departments, 2 in hospital wards,<sup>21,23</sup> 1 in the pediatric intensive care unit,<sup>14</sup> and 2 in the neonatal intensive care unit.<sup>22,24</sup>

**TABLE 1** Characteristics of Studies and Patients Enrolled From Studies Retrieved for Meta-analysis

Study	Year	Origin	Design	Sample size	Age (Mean ± SD), y	Boys/Girls, n	True-Positive, n	False-Positive, n	True-Negative, n	False-Negative, n
Reali et al <sup>21</sup>	2014	Italy	Prospective	107	4 ± 3	61/46	76	1	25	5
Liu et al <sup>22</sup>	2014	China	Prospective	80	Not mentioned	43/37	40	0	40	0
Esposito et al <sup>14</sup>	2014	Italy	Prospective	103	5.6 ± 4.6	56/47	47	3	52	1
Shah et al <sup>15</sup>	2013	USA	Prospective	191	2.9 ± 6.2	106/85	30	18	138	5
Caiulo et al <sup>23</sup>	2013	Italy	Prospective	102	5 ± 3	53/49	88	0	13	1
Seif El Dien et al <sup>24</sup>	2013	Egypt	Prospective	95	0.03 ± 0.02	36/39	68	0	2	5
Iuri et al <sup>16</sup>	2009	Italy	Prospective	28	4.5 ± 4.9	17/11	22	0	4	2
Copetti and Cattarossi <sup>13</sup>	2008	Italy	Prospective	79	5.1 ± 5	37/42	60	0	19	0

## Characteristics of Selected Studies

In Table 1, we show the main characteristics of eligible studies. Overall, there were 765 children across the 8 studies. The mean age was 5 years (range: 0–17 years) and 52% were boys. One study (12%) was conducted in multiple centers<sup>15</sup> and the remaining were single-center studies (88%). Seven studies (88%) were blinded to outcomes of CR before LUS performance and interpretation.<sup>13–16,21–23</sup> Five studies were conducted in Italy,<sup>13,14,16,21,23</sup> 1 in China,<sup>22</sup> 1 in the United States,<sup>15</sup> and 1 in Egypt.<sup>24</sup> Only 3 studies (38%) followed the disease course until the consolidation was resolved.<sup>15,16,22</sup> Two studies (25%) enrolled patients with suspected neonatal pneumonia and severe disease,<sup>22,24</sup> and 6 studies (75%) enrolled children with suspected community-acquired pneumonia.<sup>13–16,21,23</sup> One study<sup>15</sup> enrolled 9 children aged  $\geq 18$  years, and the information on these participants was not included in our analysis.

Five studies (63%) reported that a highly skilled physician performed LUS,<sup>16,21–24</sup> but only 1 (12%) of the studies adequately mentioned that their physicians had performed at least 100 procedures.<sup>21</sup> One study (12%) used 15 physicians with different degrees of expertise.<sup>15</sup> Two studies (25%) trained physicians to perform the procedure.<sup>14,15</sup> One study<sup>14</sup> (12%) trained a pediatric resident with limited experience and

explained that the training approach consisted of a 3-hour lecture on LUS and 4 hours of practical, hands-on training. LUS was performed by an emergency physician in 1 study.<sup>13</sup>

## Methodologic Heterogeneity

The quality of most of the studies included in this meta-analysis was high (Table 2). Seven studies (88%) enrolled patients who would have had a CR as part of usual clinical practice.<sup>13–16,21,23,24</sup> Only 1 (12%) study included controls who did not have CRs.<sup>22</sup> All studies described their selection criteria with sufficient detail and conducted LUS immediately after chest imaging was obtained. One (12%) study used the same radiologist to read both the CR and LUS.<sup>24</sup> Seven (88%) studies assessed LUS results independently and were blinded to CR results.<sup>13–16,21–23</sup> LUS techniques were described in sufficient detail in each of these studies. LUS sonographers were not blinded to clinical data. Furthermore, 5 (63%) studies used clinical criteria and CR as a diagnosis standard<sup>13,21–24</sup> and 3 included laboratory results as additional diagnostic tools<sup>21,22,24</sup> (Table 3). Chest CT scan was not used as a gold standard in any of the studies; however, 3 studies (38%) used chest CT scan for clinical purposes.<sup>13,21,24</sup> In 1 (13%) study, chest CT scan was used to confirm the diagnosis of pneumonia in 4 children who had discrepancies between the CR and LUS results.<sup>13</sup> In these

4 children, CR did not reveal evidence of pneumonia, whereas LUS and chest CT findings were both consistent with a diagnosis of pneumonia.

All of the studies used a linear probe (Table 4), with frequencies ranging from 6 to 12 MHz.<sup>13–16,21–24</sup> In addition, a convex probe with frequencies ranging from 2 to 6.6 MHz was used in conjunction with the linear probe in 3 of the 8 studies.<sup>13,14,16</sup> LUS methods were consistent between 5 of the studies that used the approach described by Copetti and Cattarossi in 2008.<sup>13–15,21,23</sup> Two studies mentioned the length of time to perform LUS and noted the examination took a maximum of 10 minutes.<sup>15,21</sup>

## Overall Meta-analysis

The overall pooled sensitivity and specificity (Fig 2) for the diagnosis of pneumonia were 96% (95% confidence interval [CI]: 94%–97%) and 93% (95% CI: 90%–95.7%), respectively. Positive and negative LRs (Fig 2) were 15.3 (95% CI: 6.6–35.3; Cochran Q-statistic = 14.6;  $P = .04$ ) and 0.06 (95% CI: 0.03–0.11; Cochran Q-statistic = 14.3;  $P = .05$ ), respectively. All  $I^2$  values were  $>0.45$ . The area under the receiver operating characteristic curve was 0.98 (95% CI: 0.96–1; Fig 3).

## Subgroup Analyses

All 8 studies used CR as a diagnostic tool for pneumonia; however, 5 studies used both CR and clinical criteria as

**TABLE 2** QUADAS-2 Risk of Bias Assessment

Study	Risk of Bias				Applicability Concerns		
	Patient Selection	Index Test	Reference Standard	Flow and Timing	Patient Selection	Index Test	Reference Standard
Reali et al <sup>21</sup>	L	L	L	L	L	L	L
Liu et al <sup>22</sup>	H	L	L	U	L	L	L
Esposito et al <sup>14</sup>	H	L	L	L	L	L	L
Shah et al <sup>15</sup>	L	L	L	L	L	L	L
Caiulo et al <sup>23</sup>	L	L	L	L	L	L	L
Seif El Dien et al <sup>24</sup>	H	H	L	H	L	L	L
Iuri et al <sup>16</sup>	L	L	L	L	L	L	L
Copetti and Cattarossi <sup>13</sup>	L	L	L	L	L	L	L

QUADAS-2, Quality Assessment of Diagnostic Accuracy Studies 2. L, low; H, high; U, unclear.

**TABLE 3** Chest Imaging and Diagnostic Criteria of Selected Studies

Study	Imaging	Pneumonia Diagnosis	Patient Type	Inclusion Criteria	LUS Operator	Diagnosis Criteria	Blinding
Reali et al <sup>21</sup>	CR	Clinical diagnosis + CR + blood results	Hospitalized	Pneumonia signs and symptoms	Pulmonologists and trained residents	Consolidation	Yes
Liu et al <sup>22</sup>	CR	Clinical diagnosis + CR + blood results	Critically ill	Pneumonia signs and symptoms, laboratory results	Experienced physician	Alveolar and interstitial	Yes
Esposito et al <sup>14</sup>	CR	CR	Hospitalized	Pneumonia signs and symptoms	Trained pediatric resident	Alveolar and interstitial	Yes
Shah et al <sup>15</sup>	CR	CR	Presented to emergency department	Clinical suspicion of community-acquired pneumonia requiring CR	Fifteen pediatric emergency physicians with different degrees of expertise	Alveolar and interstitial	Yes
Caiulo et al <sup>23</sup>	CR	Clinical diagnosis + CR	Hospitalized	Pneumonia signs and symptoms	Experienced physician	Alveolar and interstitial	Yes
Seif El Dien et al <sup>24</sup>	CR	Clinical diagnosis + CR + blood results	Critically ill	Pneumonia signs and symptoms	Experienced physician	Consolidation	No
Luri et al <sup>16</sup>	CR	CR	Presented to emergency department	Pneumonia signs and symptoms	Experienced physician	Consolidation	Yes
Copetti and Cattarossi <sup>13</sup>	CR	Clinical diagnosis + CR	Presented to emergency department	Pneumonia signs and symptoms	Emergency physician	Consolidation	Yes

the reference standard to identify pneumonia,<sup>13,21-24</sup> whereas 3 studies used CR alone as the reference standard.<sup>14-16</sup> In subgroup analysis, we estimated the sensitivity and specificity only using the CR results in all 8 studies as a reference standard and found that LUS had a sensitivity of 96% (94%–98%) and a specificity of 84% (80%–88%) for the diagnosis of pneumonia. In the 6 studies (75%) that enrolled children excluding neonates,<sup>13-16,21,23</sup> LUS had a sensitivity of 96% (93%–98%) and a specificity of 92% (88%–95%); and in the 2 studies that were limited to only neonates, LUS had a sensitivity of 96% (90%–98.5%) and a specificity of 100% (92%–100%).<sup>22,24</sup> Three studies were conducted in emergency departments and had a combined sensitivity of 94% (88%–98%) and specificity of 90% (85%–94%).<sup>13,15,16</sup> Studies conducted in hospital settings other than in an emergency department had a combined sensitivity of 96% (94%–98%) and a specificity of 97% (93%–99%).<sup>14,21-24</sup> In the 4 studies that reported having an experienced physician or radiologist perform LUS, we found a sensitivity of 97% (93%–99%) and a specificity of 99% (94%–100%).<sup>16,22-24</sup> In studies that used emergency department physicians, general practitioners, residents, or health care professionals otherwise not specified, LUS had a pooled sensitivity of 95% (95% CI: 91%–97%) and a specificity of 91% (87%–95%).<sup>13-15,21</sup>

## DISCUSSION

In our meta-analysis comparing the use of LUS against a reference standard for the diagnosis of childhood pneumonia, we found overall high sensitivity and specificity. In subgroup analysis<sup>13-16,21-24</sup> when the reference standard was limited to findings based on CR alone, we

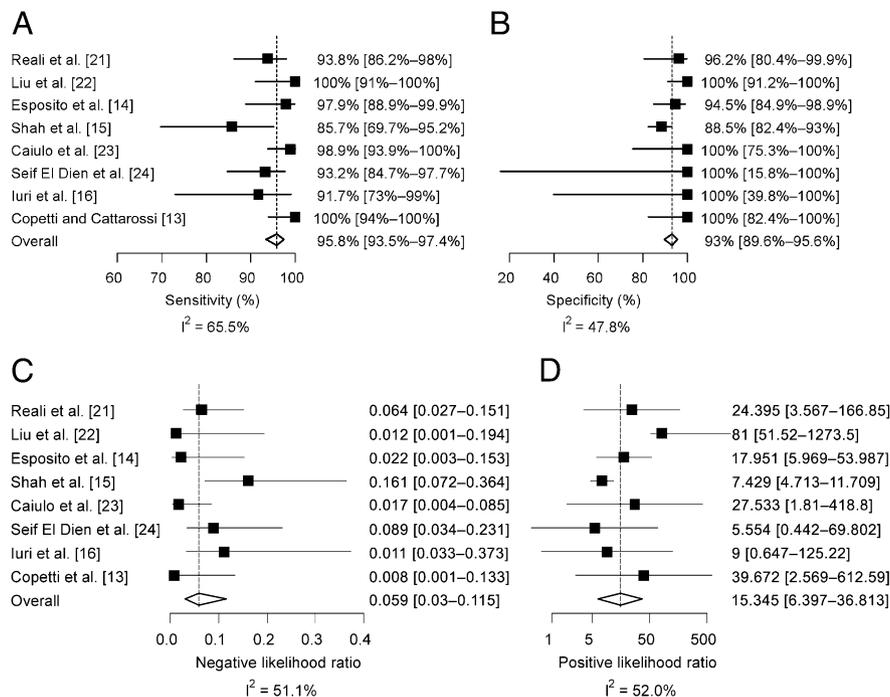
**TABLE 4** Ultrasound Characteristics and Procedure for Assessing the Lung

Study	Ultrasound	Time of Procedure	Area Examined
Reali et al <sup>21</sup>	Esaote MyLab 25 (Esaote Medical Systems, Florence, Italy); linear probe 7.5–10 MHz	Mean of 10 min	Anterior, lateral, and posterior; longitudinal, oblique, and parallel scans
Liu et al <sup>22</sup>	GE Voluson E8/6 (General Electric Healthcare, Little Chalfont, United Kingdom); linear probe 9–12 MHz	Not mentioned	Chest divided in 3 areas by anterior and posterior axillary lines; parallel to rib scans
Esposito et al <sup>14</sup>	Esaote MyLab 25 Gold (Esaote Medical Systems, Florence, Italy); linear probe 7.5–12 MHz and convex probe 2.5–6.6 MHz	Not mentioned	Anterior, lateral, and posterior; perpendicular, oblique, and parallel scans
Shah et al <sup>15</sup>	Sonosite Micromaxx (Sonosite, Bothell, USA), Sonosite, and Siemens GS60 (Siemens Healthcare, Malvern, USA); linear probe 7.5–10 MHz	7 ± 2 min	6-zone lung ultrasound imaging protocol similar to Copetti and Cattarossi <sup>13</sup>
Caiulo et al <sup>23</sup>	Toshiba Nemio (Toshiba Medical Systems Corp., Tochigi, Japan), KONTRON Meical Agile (KONTRON Medical, Saint Germaine en Laye Cedex, France); linear probe 6–12 MHz	Not mentioned	Anterior, lateral, and posterior; longitudinal, oblique, and parallel scans; similar to Copetti and Cattarossi <sup>13</sup>
Seif El Dien et al <sup>24</sup>	Toshiba Nemio XG SSA-580A (Toshiba Medical Systems Corp., Tochigi, Japan); linear probe 7 MHz	Not mentioned	Lung regions that were explored by auscultation; transverse, longitudinal, and inclined transverse or inclined longitudinal
Iuri et al <sup>16</sup>	Philips ATL HDI 5000 (Philips Ultrasound, Bothell, USA); linear probe 5–12 MHz and convex probe 2–5 MHz	Not mentioned	Entire anterior and posterior chest wall; longitudinal and axial scans
Copetti and Cattarossi <sup>13</sup>	Esaote MeGas CVX (Esaote Medical Systems, Florence, Italy); linear probe 7.5–10 MHz and convex probe 3.5–5 MHz	Not mentioned	Anterior, lateral, and posterior; perpendicular, oblique, and parallel scans

found that the sensitivity of LUS was similar to that when both clinical criteria and CR were used to define childhood pneumonia, but specificity decreased to 84%, likely reflecting that CR alone is inadequate for the

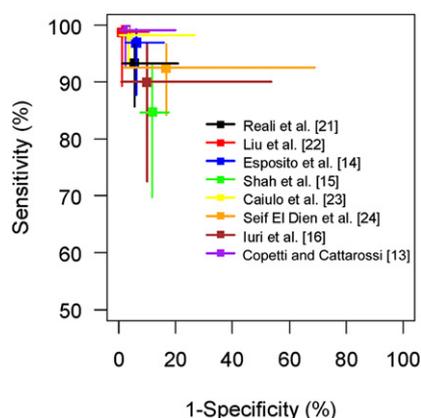
diagnosis of pneumonia. Nonetheless, both of these results suggest that LUS appears to be a reliable imaging alternative in children who present with suspected pneumonia.

Findings from another meta-analysis<sup>25</sup> that included both adults and children found a similar degree of pooled diagnostic accuracy (sensitivity of 97% and specificity of 94%). However, the inclusion of



**FIGURE 2**

Forest plots showing the diagnostic accuracy of lung ultrasound for the diagnosis of pneumonia. A, sensitivity; B, specificity; C, negative likelihood ratio (LR); and D, positive LR. Inconsistency ( $I^2$ ) describes the percentage of total variation across studies due to heterogeneity.



**FIGURE 3**

Summary receiver operating characteristic curve for the use of LUS for the diagnosis of childhood pneumonia. Values for sensitivity and (1-specificity) for each study are represented with a square; 95% CIs for sensitivity and (1-specificity) are shown with vertical and horizontal lines, respectively.

both children and adult studies in the same analysis introduced marked heterogeneity and may not provide the most accurate results given differences between the populations studied. In a separate meta-analysis by our group in which we evaluated the use of LUS in adults,<sup>12</sup> we found a slightly lower sensitivity (94%) but higher specificity (96%) compared with our results in children. Quality of examination results may vary depending on body habitus and thorax size; however, the range in values of body habitus and thorax size is smaller in children than in adults. Specifically, the smaller thoracic diameter and lung volume of children and neonates permit better visualization with LUS.<sup>26,29</sup> Similarly, the spectrum of disease found in children may differ from that seen in the adult population, necessitating different standards in both diagnosis and treatment.<sup>3,27</sup>

To identify pneumonia by LUS, a consolidation needs to reach the pleura and be within an intercostal window.<sup>28</sup> In children, the former is offset by the relative small lung size,<sup>26</sup> as mentioned previously, and may explain the relative high

sensitivity found in our results. Conversely, when features typical of pneumonia are identified on LUS, it may be a result of noninfiltrative processes including atelectasis.<sup>28,29</sup> Atelectasis, present in common respiratory diseases such as bronchiolitis or asthma,<sup>7,27</sup> can present as a small consolidation and be misinterpreted as pneumonia by ultrasound. Similarly, a smaller consolidation may not be detectable by CR, which could lead to a false-negative reading by CR. This issue was addressed by Shah et al,<sup>15</sup> who found a sensitivity of 86% and a specificity of 89% when using CR as the reference standard, with a high level of discordance between CR and LUS when consolidation size was  $\leq 1$  cm. When including only consolidation size  $> 1$  cm, specificity was 97%. Similar findings were presented by Esposito et al<sup>14</sup> and likely explain the decrease in pooled specificity when we used diagnosis based on CR alone as the reference standard. Furthermore, a recent study found that LUS was more sensitive in detecting pneumonia than CR in adults with pleuritic pain.<sup>30</sup> LUS may have increased diagnostic accuracy in neonates. Specifically, we found better sensitivity and specificity estimates in neonates than in older children. In both studies, strong clinical suspicion for pneumonia combined with the critical care status of neonates may have led to a selection bias and an overinflated sensitivity. Neonates with other common respiratory conditions (eg, atelectasis, pulmonary hemorrhage, meconium aspiration, and acute respiratory distress syndrome) were not included in the study. The higher sensitivity and specificity of LUS for the diagnosis of pneumonia in neonates may also be influenced by methodologic differences and selective sample examined. For example, in 1 of the studies that enrolled neonates, the physician

performing LUS was not blinded to CR results<sup>24</sup>; and the other study<sup>22</sup> included only neonates with severe signs and symptoms of pneumonia, which may improve the detection of consolidation and hence diagnostic accuracy of LUS. Finally, the diagnostic accuracy in children aged  $\geq 1$  month may be affected by variations in body habitus and calcification of ribs, which are dependent on age.

As expected, subgroup analysis of studies that used highly skilled physicians had a higher specificity to diagnose pneumonia with LUS; however, the sensitivity and specificity remained high in nonexpert trained physicians. In the study conducted by Esposito et al,<sup>14</sup> a pediatric resident with only 7 hours of training in LUS obtained a high sensitivity (98%) and specificity (95%). Also, Bedetti et al<sup>31</sup> demonstrated that beginners were able to detect pulmonary interstitial syndrome after 30 minutes of training. And the International Liaison Committee on Lung Ultrasound considered LUS as a basic sonographic technique that is easy to learn.<sup>32</sup> Nevertheless, more studies are needed to validate the accuracy of LUS in novice users and to outline the training necessary to obtain satisfactory results.

There are some limitations to our analysis. First, most studies included in our analysis did not have large numbers of children. In addition, the total number of studies was also small and there was significant heterogeneity between studies. Second, not all studies compared LUS results with a clinical diagnosis and, in some studies, the final diagnosis was based solely on CR findings without the influence of clinical data,<sup>14-16</sup> thus likely contributing to the heterogeneity of results reported in our study. Most studies excluded children who had a history of congenital heart

disease or chronic lung disease or who were hemodynamically unstable.<sup>14,15,21,22,24</sup> Three studies used a nonstandard technique to perform LUS,<sup>16,22,24</sup> which may help explain the heterogeneity in our analyses. Most of the studies were performed in a single center, and most of the studies were conducted in settings in high-income countries or with adequate resources. Despite all of these limitations, this meta-analysis included 765 participants and found useful results that provide evidence for the importance of future cost-benefit analysis with the utilization of this diagnostic technique and

support for potential training programs geared to teach physicians this diagnostic tool. Furthermore, these results could have an even more powerful impact on intervention trials in poor-resource settings. The only diagnostic guideline in place in such settings is the World Health Organization case management algorithm for pneumonia. If LUS technology can provide improved diagnostic capacity in areas where CR technology is difficult to implement, there is potential for increased diagnostic accuracy and decreased inappropriate use of antibiotics.

## CONCLUSIONS

Despite significant heterogeneity across studies, LUS performed well for the diagnosis of pneumonia in children. Although the sensitivity and specificity are best in the hands of expert users, our study provides evidence of good diagnostic accuracy even in the hands of nonexperts. Recommendations to train general pediatricians on LUS for the diagnosis of childhood pneumonia may have an important impact in different clinical settings, especially in resource-poor countries and small primary care clinics where CRs may not be commonly available.

---

**FINANCIAL DISCLOSURE:** The authors have indicated they have no financial relationships relevant to this article to disclose.

**FUNDING:** Miguel Chavez and Catherine C Hooper-Miele were both supported by the Fogarty International Center (5R25TW009340), United States National Institutes of Health. William Checkley was supported by a Pathway to Independence Award (R00HL096955) from the National Heart, Lung and Blood Institute, United States National Institutes of Health.

**POTENTIAL CONFLICT OF INTEREST:** The authors have indicated they have no potential conflicts of interest to disclose.

---

## REFERENCES

1. Rudan I, Tomaskovic L, Boschi-Pinto C, Campbell H; WHO Child Health Epidemiology Reference Group. Global estimate of the incidence of clinical pneumonia among children under five years of age. *Bull World Health Organ.* 2004;82(12):895–903
2. World Health Organization. Pneumonia. Fact Sheet No. 331. Available at: [www.who.int/mediacentre/factsheets/fs331/en/](http://www.who.int/mediacentre/factsheets/fs331/en/). Accessed August 1, 2014
3. Gereige RS, Laufer PM. Pneumonia [published correction appears in *Pediatr Rev.* 2014;35(1):29]. *Pediatr Rev.* 2013; 34(10):438–456
4. Prayle A, Atkinson M, Smyth A. Pneumonia in the developed world. *Paediatr Respir Rev.* 2011;12(1):60–69
5. Schlaudecker EP, Frenck RW Jr. Adolescent pneumonia. *Adolesc Med State Art Rev.* 2010;21(2):202–219, vii–viii
6. Ebell MH. Clinical diagnosis of pneumonia in children. *Am Fam Physician.* 2010;82(2):192–193
7. Shah S, Sharieff GQ. Pediatric respiratory infections. *Emerg Med Clin North Am.* 2007;25(4):961–979, vi
8. Mazrani W, McHugh K, Marsden PJ. The radiation burden of radiological investigations. *Arch Dis Child.* 2007; 92(12):1127–1131
9. Frush DP, Donnelly LF, Rosen NS. Computed tomography and radiation risks: what pediatric health care providers should know. *Pediatrics.* 2003;112(4):951–957
10. Hall EJ. Lessons we have learned from our children: cancer risks from diagnostic radiology. *Pediatr Radiol.* 2002;32(10):700–706
11. Syrjälä H, Broas M, Suramo I, Ojala A, Lähde S. High-resolution computed tomography for the diagnosis of community-acquired pneumonia. *Clin Infect Dis.* 1998;27(2):358–363
12. Chavez MA, Shams N, Ellington LE, et al. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res.* 2014;15(1):50
13. Copetti R, Cattarossi L. Ultrasound diagnosis of pneumonia in children. *Radiol Med (Torino).* 2008;113(2): 190–198
14. Esposito S, Papa SS, Borzani I, et al. Performance of lung ultrasonography in children with community-acquired pneumonia. *Ital J Pediatr.* 2014;40:37
15. Shah VP, Tunik MG, Tsung JW. Prospective evaluation of point-of-care ultrasonography for the diagnosis of pneumonia in children and young adults. *JAMA Pediatr.* 2013;167(2): 119–125
16. Iuri D, De Candia A, Bazzocchi M. Evaluation of the lung in children with suspected pneumonia: usefulness of ultrasonography. *Radiol Med (Torino).* 2009;114(2):321–330
17. Whiting PF, Rutjes AW, Westwood ME, et al; QUADAS-2 Group. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med.* 2011;155(8):529–536
18. Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. *J Natl Cancer Inst.* 1959;22(4):719–748
19. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials.* 1986; 7(3):177–188

20. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327(7414):557–560
21. Reali F, Sferrazza Papa GF, Carlucci P, et al. Can lung ultrasound replace chest radiography for the diagnosis of pneumonia in hospitalized children? *Respiration*. 2014;88(2):112–115
22. Liu J, Liu F, Liu Y, Wang HW, Feng ZC. Lung ultrasonography for the diagnosis of severe neonatal pneumonia. *Chest*. 2014;146(2):383–388
23. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound characteristics of community-acquired pneumonia in hospitalized children. *Pediatr Pulmonol*. 2013;48(3):280–287
24. Seif El Dien HM, Abd Ellatif DAK. The value of bedside lung ultrasonography in diagnosis of neonatal pneumonia. *Egypt J Radiol Nuc Med*. 2013;44(2):339–347
25. Hu Q-J, Shen Y-C, Jia L-Q, et al. Diagnostic performance of lung ultrasound in the diagnosis of pneumonia: a bivariate meta-analysis. *Int J Clin Exp Med*. 2014;7(1):115–121
26. Reissig A, Copetti R. Lung ultrasound in community-acquired pneumonia and in interstitial lung diseases. *Respiration*. 2014;87(3):179–189
27. Browne LR, Gorelick MH. Asthma and pneumonia. *Pediatr Clin North Am*. 2010;57(6):1347–1356
28. Lichtenstein DA, Mauriat P. Lung ultrasound in the critically ill neonate. *Curr Pediatr Rev*. 2012;8(3):217–223
29. Reissig A, Gramegna A, Aliberti S. The role of lung ultrasound in the diagnosis and follow-up of community-acquired pneumonia. *Eur J Intern Med*. 2012;23(5):391–397
30. Volpicelli G, Cardinale L, Berchiolla P, Mussa A, Bar F, Frascisco MF. A comparison of different diagnostic tests in the bedside evaluation of pleuritic pain in the ED. *Am J Emerg Med*. 2012;30(2):317–324
31. Bedetti G, Gargani L, Corbisiero A, Frassi F, Poggianti E, Mottola G. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc Ultrasound*. 2006;4:34
32. Volpicelli G, Elbarbary M, Blaivas M, et al; International Liaison Committee on Lung Ultrasound (ILC-LUS) for the International Consensus Conference on Lung Ultrasound (ICC-LUS). International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med*. 2012;38(4):577–591

**BAGGING THE PEAKS:** *The other day I was interviewed for a local news broadcast. While waiting for the cameraperson to get adjusted, the reporter asked me about a picture of a local mountain I had on my office wall. I told her it was a favorite hike of mine. She then asked if I was a “46er,” which is the local term for someone who has climbed the 46 high peaks of the Adirondacks. All of these 46 peaks are higher than 4,000 feet. If you climb them all you are entitled to a special patch. While hikers west of the Mississippi might not consider a 4,000 foot mountain much of a mountain at all, compared to many states that lack high terrain, hiking a four thousand foot peak would be quite an accomplishment.*

*As reported on CNN (Travel: January 16, 2015), many hikers like to “bag” the highest peak in every state. In some, this can be done in a few minutes without breaking a sweat. For example, in Delaware the highest point is Ebright Azimuth, at 442 feet above sea level. A sign beside a road in suburban Wilmington, Delaware marks the spot. The summit of Britton Hill, the state of Florida’s highest point, is 345 feet above sea level. True peak baggers, those committed to climbing the highest peak in each state, can knock this off in just a few minutes compared to the weeks of preparation it takes to plan and hike Alaska’s 20,237 foot-tall Mount Denali (aka Mount McKinley), the highest peak in North America. While I am intrigued by the thought of climbing the tallest peak in each state, I think I will stay more local. I told the reporter that I was not yet a 46er, but I had plans to be one soon.*

*Noted by WVR, MD*

## Lung Ultrasound for the Diagnosis of Pneumonia in Children: A Meta-analysis

Maria A. Pereda, Miguel A. Chavez, Catherine C. Hooper-Miele, Robert H. Gilman,  
Mark C. Steinhoff, Laura E. Ellington, Margaret Gross, Carrie Price, James M.  
Tielsch and William Checkley

*Pediatrics*; originally published online March 16, 2015;

DOI: 10.1542/peds.2014-2833

<b>Updated Information &amp; Services</b>	including high resolution figures, can be found at: <a href="/content/early/2015/03/11/peds.2014-2833">/content/early/2015/03/11/peds.2014-2833</a>
<b>Supplementary Material</b>	Supplementary material can be found at: <a href="/content/suppl/2015/03/11/peds.2014-2833.DCSupplemental.html">/content/suppl/2015/03/11/peds.2014-2833.DCSupplemental.html</a>
<b>Citations</b>	This article has been cited by 2 HighWire-hosted articles: <a href="/content/early/2015/03/11/peds.2014-2833#related-urls">/content/early/2015/03/11/peds.2014-2833#related-urls</a>
<b>Subspecialty Collections</b>	This article, along with others on similar topics, appears in the following collection(s): <b>Honor Roll of Giving</b> <a href="/cgi/collection/honor_roll_of_giving">/cgi/collection/honor_roll_of_giving</a>
<b>Permissions &amp; Licensing</b>	Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at: <a href="/site/misc/Permissions.xhtml">/site/misc/Permissions.xhtml</a>
<b>Reprints</b>	Information about ordering reprints can be found online: <a href="/site/misc/reprints.xhtml">/site/misc/reprints.xhtml</a>

PEDIATRICS is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. PEDIATRICS is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 2015 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 0031-4005. Online ISSN: 1098-4275.

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™



# PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

## **Lung Ultrasound for the Diagnosis of Pneumonia in Children: A Meta-analysis**

Maria A. Pereda, Miguel A. Chavez, Catherine C. Hooper-Miele, Robert H. Gilman,  
Mark C. Steinhoff, Laura E. Ellington, Margaret Gross, Carrie Price, James M.  
Tielsch and William Checkley

*Pediatrics*; originally published online March 16, 2015;

DOI: 10.1542/peds.2014-2833

The online version of this article, along with updated information and services, is  
located on the World Wide Web at:

[/content/early/2015/03/11/peds.2014-2833](http://content.early/2015/03/11/peds.2014-2833)

PEDIATRICS is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. PEDIATRICS is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 2015 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 0031-4005. Online ISSN: 1098-4275.

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™

