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Diagnostic Accuracy of Lung Ultrasound for Detecting Pneumonia in Children: A Comparative Study with Chest Radiography

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ABSTRACT

Background: Pneumonia still tops the list of diseases that cause high rates of illness and death in children all over the world, especially in countries with low and moderate incomes. Accurate and early diagnosis plays a major role in prompt treatment; however, the chest X-ray technique that provides such diagnosis cannot be used due to radiation exposure, inaccessibility, and the long wait for reports. Lung ultrasound (LUS) has emerged as a non-radiation, fast, and at-the-bedside technique that may provide better diagnostic accuracy in pediatric pneumonia.

Objective: To evaluate the diagnostic accuracy of lung ultrasound (LUS) in identifying pneumonia among pediatric patients and to compare its performance with standard chest radiography.

Methodology: This cross-sectional diagnostic accuracy study was conducted at the Departments of Pediatrics and Radiology at Nishtar Medical University in Multan from January 2022 to March 2023. Enlistment included a group of 320 children with a clinical suspicion of pneumonia, who were aged between 6 months and 12 years. Lung ultrasonography was performed on all patients, followed by chest radiography. An experienced radiologist who was unaware of the CXR results interpreted the LUS findings. Diagnostic indices such as sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were calculated using chest radiography as the gold standard.

Results: Among 320 screened children, 120 (37.5%) had radiographically confirmed pneumonia. LUS identified pneumonia in 142 cases. Sensitivity, specificity, PPV, NPV, and overall accuracy of LUS were 95.8%, 86.0%, 80.9%, 96.9%, and 89.7%, respectively. LUS showed high performance across all age groups.

Conclusion: Lung ultrasound demonstrated excellent sensitivity and strong diagnostic accuracy for pediatric pneumonia, indicating its potential as a reliable, radiation-free alternative to chest radiography in routine clinical practice.

Keywords: Lung Ultrasound; Pediatric Pneumonia; Diagnostic Accuracy

Introduction

Pneumonia continues to be one of the most significant causes of sickness and death among children globally, especially in countries with low and middle incomes, where they usually have no access to getting diagnosed in a timely manner. Childhood pneumonia is globally estimated to be responsible for about 15% of all deaths among children under five years of age, with the most affected areas being South Asia and sub-Saharan Africa.[1] Early diagnosis of pneumonia is very important because it helps prevent complications, start the right treatment at the right time, and reduce healthcare costs. Nevertheless, clinical signs such as tachypnea, chest indrawing, and auscultatory findings are not very specific and may even overlap with other respiratory disorders, which is why imaging remains an important part of the diagnosis.[2]

Chest X-ray has been the primary imaging modality for diagnosing pneumonia in children, though it is not ideal due to its limitations. A chest X-ray is cheaper, easily accessible, and quick. However, it also has several disadvantages, including exposure to radiation, the cost of the procedure, differences in interpretation among radiologists, and delays due to busy emergency departments where the images are obtained and interpreted.[3] In addition, some types of pneumonia, particularly early or small subpleural consolidations, can be missed on X-ray, thereby prolonging the diagnosis.[4] The use of computed tomography is clearer but is not practical for children due to the high radiation amounts, cost, and the waiting for sedation in small patients.[5]

Lung ultrasound (LUS) is a non-invasive and radiation-free technique that has gained increasing popularity as a bedside diagnostic tool for assessing suspected pneumonia in children. It is small, inexpensive, repeatable, and especially useful in emergency departments, intensive care units, and low-resource settings. An increasing number of studies indicate that LUS is at least as sensitive as CXR and, in many cases, even more so for detecting consolidations and pleural abnormalities.[6,7] The sensitivity of LUS in pediatric pneumonia has been reported to exceed 90% in several meta-analyses, underscoring its strong diagnostic potential (8,9). Furthermore, rapid training of pediatricians and emergency physicians to perform LUS has broadened its use beyond radiology departments.[10]

To date, little local data on LUS versus CXR have been available in Pakistan, although international evidence has been gradually increasing. The region's healthcare systems often face limitations in imaging availability, leading to long delays in radiographic reporting, making LUS a very attractive option if it proves accurate in the local setting. There is a lack of local research, and thus no evidence-based recommendations for integrating LUS into pediatric pneumonia assessment protocols in Pakistan.

Thus, the current study aimed to determine the diagnostic accuracy of lung ultrasound in detecting pneumonia in children with chest radiography as the standard reference. The study aims to generate local evidence to support clinical decision-making and the development of diagnostic guidelines for pediatric pneumonia in Pakistan.

Objective

To evaluate the diagnostic accuracy of lung ultrasound (LUS) in identifying pneumonia among pediatric patients and to compare its performance with standard chest radiography.

Methodology

This diagnostic accuracy study, conducted cross-sectionally, took place at Nishtar Medical University and Hospital, Multan, where the departments of pediatrics and radiology are located, and lasted from January 2022 until March 2023. The primary objective was to compare the diagnostic performance of lung ultrasound (LUS) with chest radiography (CXR) in children with pneumonia, with CXR serving as the reference standard.

A sample of 320 children who presented to the emergency department and pediatric outpatient clinics with a clinical suspicion of pneumonia was enrolled consecutively using a non-probability consecutive sampling method. The first step for all qualifying children was a clinical examination, followed by a lung ultrasound and chest radiography.

The participants in the research were kids aged 6 months to 12 years with clinical signs suggesting a lower respiratory tract infection. So, these inclusion criteria required that participants' symptoms include fever (defined as a temperature of 38°C or greater) plus cough, and either hard breathing, as shown by accelerated respiration per World Health Organization age-group guidelines, or drawing in the lower part of the chest, or chest pain. Moreover, the incorporation of the subject was based on the clinician on duty's ability to assert a clinical doubt about pneumonia strong enough to necessitate radiographic imaging for diagnostic confirmation.

To obtain a more uniform group and reduce the risk of confounding factors, several important exclusion criteria were applied. Known pre-existing structural or chronic respiratory conditions in children were among the reasons for exclusion; this included congenital lung malformations, cystic fibrosis, and bronchiectasis. Children suffering from severe cardiac disease or heart failure were also not allowed to participate, as well as those who had been mechanically ventilated before imaging, since this could heavily influence lung interpretations. In cases where subsequent ultrasound or radiographic studies were considered technically inadequate or compromised,

the images were non-diagnostic, and additional exclusions were made. Finally, informed consent from a parent or guardian was required for the study, and any refusal to participate was considered grounds for exclusion.

Detailed clinical examination was performed on all enrolled children. Vital signs, including temperature, respiratory rate, and oxygen saturation, were measured during this procedure, and systematic chest auscultation was performed to identify key findings, such as crackles, decreased breath sounds, or bronchial breathing. Also, a complete examination of the respiratory distress was performed. At the same time, relevant demographic and historical information, such as the child's age, gender, weight, duration of symptoms, and antibiotic history, was recorded methodically on a structured proforma.

Lung ultrasound was performed within 1 hour of clinical assessment by a trained pediatric radiologist with at least 3 years' experience in pediatric ultrasonography. A high-frequency linear probe (7–12 MHz) was used for superficial structures, while a low-frequency convex probe (3–5 MHz) was employed for deeper lung evaluation as needed.

Scanning was performed in anterior, lateral, and posterior thoracic zones following standardized 12-zone lung scanning protocols. Each hemithorax was examined with the child in a supine, semi-recumbent, or sitting position, depending on comfort.

If any of the one or more very characteristic sonographic criteria were present, the diagnosis of pneumonia via lung ultrasound (LUS) was performed. The very criteria involved subpleural consolidations with tissue-like echotexture, dynamic or static air bronchograms, and abnormalities in the pleural line characterized by disruption of continuity. The additional diagnostic findings included focal or confluent B-lines adjacent to the consolidation areas and any pleural effusion. Each LUS examination was assigned a binary code indicating whether pneumonia was present. The radiologist who performed and authenticated the lung ultrasound was unaware of the concurrent chest X-ray results to prevent any influence on the assessment.

Chest radiographs (posteroanterior or anteroposterior views, depending on the patient's condition) were obtained using digital X-ray equipment available in the radiology department. Images were interpreted by a pediatric radiologist with at least 5 years of experience, who was blinded to the LUS findings.

Pneumonia on chest X-ray (CXR) was radiographically defined by the presence of alveolar consolidation, a lobar or segmental opacity, an air bronchogram, or patchy infiltrates consistent with the diagnosis. In this study, the chest X-ray served as the established reference standard against which the findings of the lung ultrasound were compared.

A specially designed proforma for this research investigation was used to systematically record all clinical, laboratory, and imaging data collected. For the analysis of diagnostic accuracy, cases were stratified into four categories based on agreement between lung ultrasound (LUS) and the reference standard, chest X-ray (CXR). The categories were: True Positive (LUS positive and CXR positive), True Negative (LUS negative and CXR negative), False Positive (LUS positive but negative CXR), and False Negative (LUS negative but CXR positive).

Statistical analysis was performed using SPSS version 25.0 (IBM Corp., USA). Quantitative variables, including age and illness duration, are presented as mean ± standard deviation (SD). Categorical variables, such as gender and imaging findings, are expressed as frequencies and percentages.

The diagnostic performance of lung ultrasound (LUS) was evaluated against the reference standard of chest X-ray (CXR). Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy were calculated based on a 2 × 2 contingency table. To further investigate the utility of LUS across developmental stages, a subgroup analysis was conducted by age category: 6 months to 2 years, 2 to 6 years, and>6 years. For all analyses, a p-value of less than 0.05 was considered statistically significant.

The study protocol was reviewed and approved by the Institutional Review Board of Nishtar Medical University, Multan. Written informed consent was obtained from parents or legal guardians before enrollment. Privacy and confidentiality were maintained throughout the study.

Results

A total of 320 children presenting with clinical suspicion of pneumonia were screened during the study period. Of these, 120 (37.5%) were confirmed to have pneumonia based on chest radiography, which served as the reference standard. The mean age of the study population was 6.3 ± 2.6 years, ranging from 6 months to 12 years. Males constituted a slightly higher proportion (59.4%, n=190) compared to females (40.6%, n=130).

Distribution of study cases by age showed that, 91 (28.4%) children were aged 6 months–2 years, 112 (35.0%) belonged to the 2–6-year group, and 117 (36.6%) were older than 6 years. The majority of participants (118 patients; 36.9%) weighed >25 kg, followed by 110 (34.4%) in the 16–25 kg category and 92 (28.7%) in the 7–15 kg category. Most children (255; 79.7%) had no history of antibiotic intake in the week prior to presentation (Table 1).

Lung ultrasound identified pneumonia in 142 children (44.4%), whereas chest radiography identified 120 cases (37.5%) (Table 2).

Among the 120 radiographically confirmed cases, lung ultrasound correctly detected 115, while 27 children without radiographic evidence were also found to be LUS-positive. Conversely, LUS missed 5 cases that were positive on X-ray (Table 3). Based on these findings, lung

Table 1. Demographic Profile of the Study Population (n=320)

Variable	Category	Frequency n (%)
Age Groups	6 months–2 years	91 (28.4)
	2–6 years	112 (35.0)
	>6 years	117 (36.6)
Weight Groups	7–15 kg	92 (28.7)
	16–25 kg	110 (34.4)
	>25 kg	118 (36.9)
Antibiotic Use (last 7 days)	Yes	65 (20.3)
	No	255 (79.7)

ultrasound demonstrated a sensitivity of 95.8%, specificity of 86.0%, positive predictive value (PPV) of 80.9%, negative predictive value (NPV) of 96.9%, and an overall diagnostic accuracy of 89.7% in comparison to chest radiography (Table 4).

Stratified analysis revealed that LUS sensitivity remained consistently high across all age groups. In children aged 6 months to 2 years, sensitivity and specificity were 97.3% and 70.0%, respectively. For the 2–6-year age group, LUS showed 95.2% sensitivity and 92.3% specificity, while in children older than 6 years, sensitivity reached 94.4% with a specificity of 94.7%. Diagnostic accuracy improved progressively with increasing age (Table 5).

Discussion

Lung ultrasound (LUS) has demonstrated exceptional diagnostic performance in detecting pneumonia in children, as shown in this study, with 95.8% sensitivity and 96.9% negative predictive value compared with chest X-ray. The implication of these results is that LUS is increasingly recognized globally as an appropriate imaging technique for pediatric pneumonia, especially where reducing radiation exposure and fast bedside assessment are paramount.

The diagnostic capacity revealed by our findings is nearly identical to that demonstrated in the past literature. Pereda et al. conducted a meta-analysis that remains the best to date, reporting pooled sensitivity and specificity for LUS in pediatric pneumonia of 96% and 93%, respectively.[11] Along these lines, Balk et al. reported sensitivity of 95.5% and specificity of 92.3% in their systematic review, which included more than 1500 children.[7] These numbers align with the performance indicators of our research, thereby corroborating LUS's strength as a diagnostic tool.

In particular, LUS identified more pneumonia cases in our investigation (44.4%) than CXR (37.5%). The ability to detect these cases more accurately has been noted in previous research. Conlon et al. noted that LUS often detects small subpleural consolidations that are not visible on X-ray, thereby enabling earlier diagnosis.[12] Urbankowski et al. also provided evidence supporting LUS's capacity to detect developing inflammatory pulmonary infiltrates before they are visible on fluoroscopies, which, in turn, points to its sensitivity to early disease alterations.[13] This characteristic is particularly helpful in EDs and pediatric areas with high patient turnover, where rapid clinical interventions are vital.

Table 2. Frequency of Pneumonia Diagnosed on LUS and Chest X-Ray

Diagnostic Modality	Pneumonia Present n (%)	Pneumonia Absent n (%)
Lung Ultrasound	142 (44.4)	178 (55.6)
Chest X-ray (Gold Standard)	120 (37.5)	200 (62.5)

Table 3. Diagnostic Accuracy of Lung Ultrasound Compared with Chest Radiography

	Chest X-ray +	Chest X-ray –	Total
LUS +	115	27	142
LUS –	5	173	178
Total	120	200	320

Age-stratified performance in our dataset showed a slight decline in specificity among younger children, while sensitivity remained consistently high across age groups. Yan et al. also reported similar findings, noting that artifacts from hyperinflation, rapid breathing, and smaller thoracic dimensions made interpretation difficult in infants and toddlers.[14] Still, detection sensitivity remained excellent throughout, further confirming LUS's usefulness as the first screening tool for all ages.

The very high negative predictive value indicates that LUS can rule out pneumonia with high certainty when findings are normal. This benefit was likewise reported by Sansone et al., who found that adding LUS to pediatric emergency evaluations significantly reduced the number of chest radiographs needed while maintaining diagnostic accuracy.[15] In a developing country like Pakistan, where limiting unnecessary radiation exposure to kids and saving costs are important, LUS could eventually become an indispensable part of routine respiratory evaluations.

In addition, lung ultrasound (LUS) was recognized as a tool for continuous evaluation. Inpatient follow-ups that involve monitoring the size of consolations and pleural effusions by ultrasound are recommended, especially in resource-poor settings, as demonstrated by Lissaman et al.[16] Our experimental design did not include a follow-up, yet this application is of great importance for local practice.

One thing that has not been resolved yet is dependence on the operator. A sonographer's skill level can affect diagnostic accuracy. On the other hand, some research has shown that, after a short period of training, clinicians become highly competent. According to Raimondi et al., even pediatric emergency physicians can be trained to perform trustworthy lung scans after only a few hours of training.[17] Given the increasing adoption of POCUS worldwide, it might be a good idea to incorporate LUS skills into pediatric and radiology residency programs in Pakistan to increase diagnostic capacity.

In our discussions, we can consider the LUS-positive but radiograph-negative cases observed in our findings as an indication that radiography failed to detect early pneumonic changes, although false positives due to atelectasis or viral infections are also possible. Musolino et al. noted these limitations in their work and advised correlating with the clinical presentation.[18] Nevertheless, the strong overall diagnostic performance has given strong support to the use of LUS in diagnostics.

To conclude, our results add to the ongoing increase in posts, indicating that LUS is an extremely sensitive, rapid,

Table 4. Sensitivity, specificity, PPV, NPV and diagnostic accuracy of LUS

Statistic	Value	95% CI
Sensitivity	95.83%	90.54% to 98.63%
Specificity	86.50%	80.97% to 90.91%
Positive Likelihood Ratio	7.1	4.99 to 10.10
Negative Likelihood Ratio	0.05	0.02 to 0.11
Disease prevalence (*)	37.50%	32.18% to 43.06%
Positive Predictive Value (*)	80.99%	74.96% to 85.84%
Negative Predictive Value (*)	97.19%	93.61% to 98.79%
Accuracy (*)	90.00%	86.18% to 93.06%

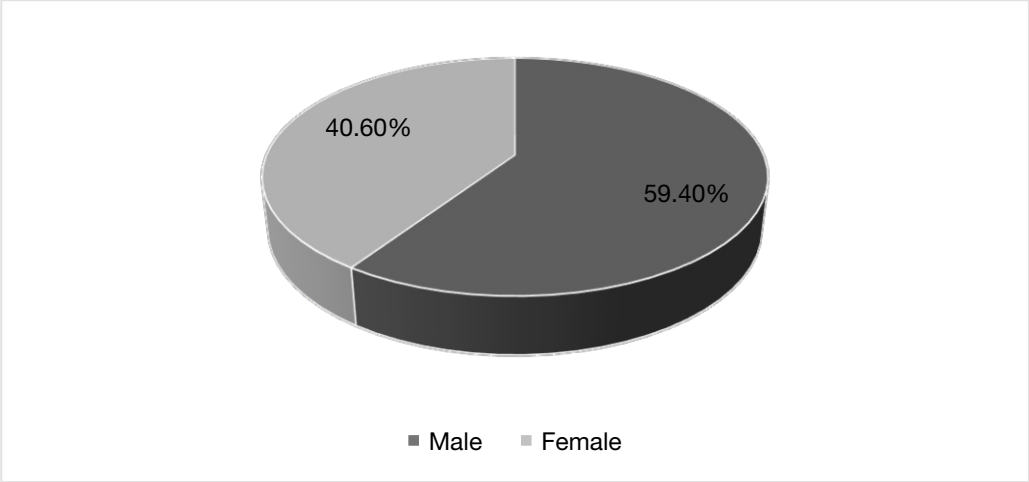

Figure 1. Gender-based distribution of study cases

radiation-free, and cost-effective imaging tool for diagnosing pediatric pneumonia. Supplying LUS to clinical routes might improve diagnostic efficacy and reduce reliance on conventional radiography, especially in high-volume pediatric regions of Pakistan.

Conclusion

This research establishes that lung ultrasound is an extremely sensitive, dependable, and clinically useful tool for diagnosing pneumonia in pediatrics. LUS is considered an excellent diagnostic technique compared to chest radiography, especially for ruling out pneumonia, given its high negative predictive value. It is convenient, quick to use at the bedside, and has no radiation exposure; thus, it is especially suitable for emergency departments, pediatric wards, and resource-poor healthcare areas.

LUS, with its high accuracy and practical advantages, can be effectively integrated into the routine assessment of children with suspected pneumonia and used as a first-line imaging tool. The introduction of standardized training programs for pediatric and emergency clinicians could further enhance their usefulness and facilitate their widespread adoption. In conclusion, the results of this research provide a strong argument for the inclusion of lung ultrasound as a secondary, and in many cases more desirable, alternative to chest X-ray in the diagnostic evaluation of pediatric patients.

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Table 5. Age-Stratified Diagnostic Accuracy of LUS

Age Group	LUS + / CXR +	LUS – / CXR +	LUS + / CXR –	LUS – / CXR –	Sensitivity	Specificity	PPV	NPV	Accuracy
6 mo–2 yrs	36	1	6	48	97.3%	70.0%	85.7%	98.0%	92.3%
2–6 yrs	41	2	3	66	95.2%	92.3%	93.2%	95.7%	93.8%
>6 yrs	38	2	8	59	94.4%	94.7%	82.6%	96.7%	94.5%

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