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Original Article

Radiology Section

Accuracy of Lung Ultrasonography versus Chest Radiography for the Diagnosis of Community Acquired Pneumonia in Children: A Cross-sectional Study

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ABSTRACT

Introduction: Pneumonia is one of the most common causes of childhood morbidity and mortality, which warrants a proper diagnosis and adequate treatment. Early diagnosis of Community Acquired Pneumonia (CAP) is essential to reduce the total burden of this disease.

Aim: To evaluate the diagnostic accuracy of Lung Ultrasound (LUS) in CAP in children as compared to Chest Radiograph (CXR).

Materials and Methods: This was a cross-sectional study involving 91 subjects with clinically suspected pneumonia, who underwent Ultrasound Examination (US) examination in the Department of Radiodiagnosis, Government Medical College, Thrissur, Kerala, India from December 2018 to December 2019. LUS was done to obtain information regarding different patterns of presentation of pneumonia. Although Computed Tomography (CT) is considered the gold standard imaging for pneumonia, it is used only for complicated pneumonia and is not routinely performed in the paediatric age group as radiation exposure will be more than that of the CXR. Hence, a CXR was taken as a reference standard in this study, and findings of LUS were compared. The data was managed using Microsoft Excel 2016 and statistical analysis was done with International Business Machines (IBM) Statistical Package for the Social Sciences (SPSS) version 27.0. The sensitivity, specificity, Positive Predictive Value (PPV), Negative Predictive Value (NPV), and accuracy were calculated.

Results: Overall, LUS had a sensitivity of 95.83%, a specificity of 93.02%, a PPV of 93.88%, a NPV of 95.24%, and an accuracy of 94.5% ($p<0.001$) as compared to CXR which had a sensitivity of 93.8%, specificity of 95.23%, the PPV of 95.80%, the NPV of 93.0% and accuracy of 95%. Substantial agreement between LUS and a CXR was found, for diagnosing specific patterns of CAP with Cohen's Kappa value of 0.74.

Conclusion: LUS offers an important contribution to the diagnosis of pneumonia in children as compared with a CXR. With its high NPV, it can replace CXR in order to exclude lung consolidation in children, thus reducing radiation exposure in this population.

Keywords: Consolidation, Patterns of pneumonia, Radiation exposure, Sensitivity

INTRODUCTION

Pneumonia is considered the leading cause of death in children worldwide [1]. World Health Organisation (WHO) states that almost one sixth of under five mortality is contributed by CAP [2]. Symptoms of paediatric pneumonia depend upon the cause of the infection and several other factors, which include the age and general health of the child. Fast breathing, increase in temperature and cough are three of the most common signs [3]. In newborns, and very young children, the cause is more likely to be viral, rather than a bacterial infection. Bacterial infections are seen more commonly in school-aged children and young adolescents [4]. Pneumonia can be of different types, Lobar pneumonia, Bronchopneumonia, or Interstitial pneumonia [5]. Lobar pneumonia affects one or more lobes of the lungs. It is known to be associated with specific bacterial infections such as *Haemophilus influenzae* type b (Hib), *Streptococcus pneumoniae*, and *Klebsiella pneumoniae* [5,6]. Bronchopneumonia affects patches throughout both lungs and is thought to be caused due to infections by Gram-negative bacteria, *Staphylococcus aureus*, and some fungi [5]. Interstitial pneumonia is typically caused due to viral infections like the influenza virus and Respiratory Syncytial Virus (RSV) [1]. Diagnosis and classification of pneumonia is mainly based on clinical findings according to the recommendations by WHO [2]. Recently, it has become highly dependent on imaging. Different imaging modalities include CXR, LUS, CT and Magnetic Resonance Imaging (MRI). In children, only severe and complicated cases warrant CXR. However, physicians now a days depend mostly on CXRs [7].

In childhood, pneumonia generally has a pattern approach based on pathologic findings and radiologic features [7]. Features of lobar pneumonia are non segmental, homogenous consolidation, predominantly involving one lobe with/without air bronchogram [7]. The imaging features of bronchopneumonia include peri bronchial thickening and ill-defined airspace opacities, and nonhomogenous patchy areas of consolidation. LUS signs of pneumonia include the presence of sonographic air bronchogram, subpleural lung consolidation, pleural line abnormalities, and pleural effusion [8]. B-lines, confluent B-lines, or small areas of subpleural consolidations may suggest interstitial pneumonia due to viral aetiology [9]. A pneumonic lung is known to exhibit a liver-like echotexture. Air and fluid bronchogram can be seen within a consolidated lung. Air bronchogram are dynamic and have echogenic foci that fluctuate with each respiratory cycle [10]. whereas fluid bronchogram is seen as anechoic tubular structures that represent fluid-filled airways [11]. Alveolar consolidations have dynamic bronchogram in contrast to atelectasis which has a static bronchogram [12]. Pneumonia in children is a major public health problem that has a considerable impact on morbidity and mortality. It has been shown that clinical signs and symptoms of lower respiratory tract infections are relatively non specific and the need to prove the diagnosis of pneumonia by imaging methods, thus seems justified. Clinicians are mostly dependent on CXRs now-a-days. But CXR exposes patients to ionising radiation, and ill children with suspected pneumonia may receive multiple CXRs, posing a small increased risk of cancer later

in life. LUS is a fast, non ionising and feasible technique and when used to address specific diagnostic questions requires minimal training for the provider, and can be performed at the point of care [13]. It can replace radiographs in order to exclude lung consolidation in children, thus reducing radiation exposure in this population. The present study aimed to find out the role of LUS in evaluating findings of pneumonia taking a CXR as the gold standard.

MATERIALS AND METHODS

This was a cross-sectional study conducted on 91 hospitalised children (0-12 years of age) with clinically suspected CAP and evaluated with CXR at Government Medical College, Thrissur, Kerala, India during the period of December 2018-December 2019. The ethics committee (Order No: B6-8772/2016/MCTCR (2)) approved this study and informed consent was obtained from the guardian for the child's participation in the study.

Inclusion criteria: Hospitalised children of age 0-12 years with clinically suspected CAP, and evaluated with CXR were included in the study.

Exclusion criteria: Patients with nosocomial infections, major cardiac or airway anomaly, previous diagnosis of chronic lung disease (cystic fibrosis, bronchiectasis), and suspected or proven asthma, those receiving antibiotic therapy for any reason or with immunodeficiency, malignancy, and haemodynamic instability were excluded from the study.

CXR findings were assessed and findings were classified as follows [14]:

1. Normal;
2. Interstitial pattern (interstitial pneumonia)-patchy interlacing linear shadows;
3. Consolidation (alveolar pneumonia)-air space opacification without significant volume loss in affected areas; air bronchogram may also be seen;
4. Mixed pattern-which shows both findings of interstitial and alveolar patterns.

Study Procedure

CXRs were considered positive for CAP, in cases of interstitial or alveolar pneumonia with or without atelectasis and effusion. Sonographic lung evaluation was performed within 24 hours of hospitalisation in all patients with GE LOGIQ S8 US device with appropriate transducers and frequencies (curvilinear probe of 3-5 MHz and linear probe of 6-15 MHz frequency) according to the age and body habitus of the child. Patients were examined as per the standard method of LUS. Each hemithorax was divided into three parts-anterior, lateral, and posterior. The anterior part extends from the parasternal to the anterior axillary line; the lateral part is defined as the area between anterior and posterior axillary lines; the posterior part is defined as the area from the posterior axillary line to the paravertebral line. Each part was subdivided into upper (clavicle to 2nd intercostal space) and lower halves (3rd intercostal space to diaphragm).

Six zone scanning protocol:

1 Anterior superior
2 Anterior inferior
3 Lateral superior
4 Lateral inferior
5 Posterior superior
6 Posterior inferior

The findings of the LUS were classified as follows [14]:

1. Normal (A-lines, lung sliding sign);
2. Interstitial pattern (more than 3 B-lines at a scan or coalescence of B-lines);
3. Consolidation (hypoechoic areas with inhomogeneous echo texture with blurred margins with or without air bronchogram or fluid bronchogram and vascularity depiction with the application of colour doppler mode);
4. Mixed pattern-which shows both findings of interstitial and alveolar patterns.

LUS was considered positive for CAP, in cases of interstitial pattern or consolidation with or without atelectasis and effusion.

STATISTICAL ANALYSIS

The data collected were coded and entered in Microsoft Office Excel 2016 spreadsheet (Microsoft Corporation). It was then rechecked and analysed using IBM SPSS Statistics 27.0. Data were expressed as Mean±Standard Deviation (SD) for quantitative parametric measures. Quantitative non parametric and qualitative data were described using both numbers and percentages. The diagnostic validity test was used to calculate the sensitivity, specificity, PPV, NPV, and diagnostic accuracy or efficacy with CXR as the gold standard. Receiver Operating Curves (ROC) was obtained to compare the diagnostic performance of LUS and radiograph. Quadratic weighted Cohen's Kappa values were calculated to know the agreement between LUS and CXR.

RESULTS

Of the 91 patients studied, 42 were boys (46.15%) and 49 were girls (53.85%) showing a male-to-female ratio of 0.85. The age of the study subjects ranged from a minimum of six months to a maximum of 12 years with the mean age of the study group being 5.3±3 years. In the present study, the majority of the patients were in the age group of 1-5 years, constituting about 50.55% (n=46) of the study population [Table/Fig-1].

Age (years)	Boys n (%)	Girls n (%)	Total n (%)
<1	3 (7.14)	1 (2.04)	4 (4.40)
1-5	20 (47.62)	29 (59.18)	49 (53.85)
5-10	16 (38.10)	13 (26.53)	29 (31.86)
≥10	3 (7.14)	6 (12.25)	9 (9.89)
Total	42 (46.15)	49 (53.85)	91 (100)

[Table/Fig-1]: Age and gender distribution of the subjects.

Among the recruited children majority (n=88; 96.7%) had cough followed by fever (n=73; 80.2%) and laboured breathing (n=65; 71.4%).

Imaging characteristics: CXR and LUS were abnormal and suggestive of pneumonia in 48 (52.7%) and 49 (53.8%) children, respectively. In radiologically proven pneumonia, LUS was positive in 46/48 (95.8%) while among radiological normal but clinically diagnosed as pneumonia, US was abnormal in 3/43 (6.9%). 40 of 91 patients did not have pneumonia, in accordance with the radiograph and US findings [Table/Fig-2].

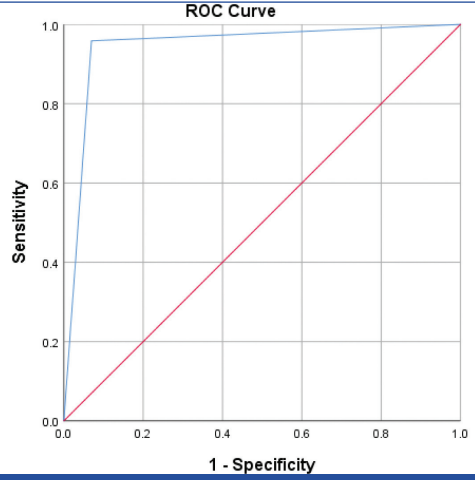
	Chest radiograph (CXR)		
LUS	Positive	Negative	Total
Positive	46	3	49
Negative	2	40	42
Total	48	43	91

[Table/Fig-2]: Contingency table for Chest Radiograph (CXR) and Lung Ultrasound (LUS) in Community-Acquired Pneumonia (CAP).

LUS shows higher sensitivity compared to radiograph to diagnose pneumonia [Table/Fig-3]. The area under the curve was obtained as 0.94 which is excellent with 95% confidence interval from the 0.88 to 0.99. The p<0.001 which was statistically significant [Table/Fig-4]. Radiograph diagnosed more interstitial patterns (n=20) and US diagnosed more alveolar patterns (n=27) [Table/Fig-5].

Variables	Chest Radiograph (CXR)	Lung Ultrasound (LUS)
Sensitivity	93.8%	95.83%
Specificity	95.23%	93.02%
Positive Predictive Value (PPV)	95.80%	93.88%
Negative predictive Value (NPV)	93.0%	95.24%
Accuracy	95%	94.50%

[Table/Fig-3]: Contingency table showing sensitivity, specificity, predictive values and accuracy of Chest Radiograph (CXR) and Lung Ultrasound (LUS) in Community-Acquired Pneumonia (CAP).

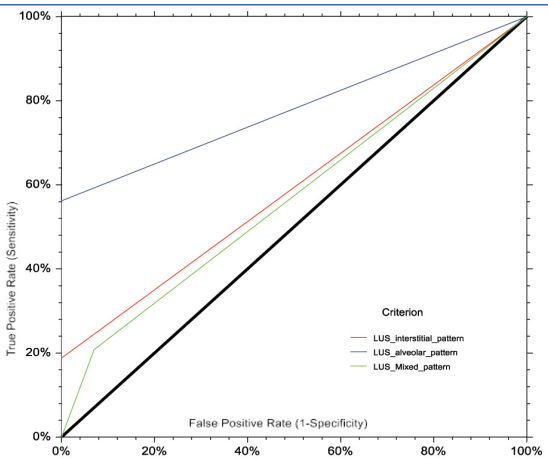


[Table/Fig-4]: Receiver Operating Curves (ROC) curve showing diagnostic accuracy of Lung Ultrasound (LUS).

Specific patterns	Chest Radiograph (CXR)	Lung Ultrasound (LUS)
Normal	43	42
Interstitial pattern	20	9
Alveolar pattern	17	27
Mixed pattern	11	13

[Table/Fig-5]: Frequency distribution of specific patterns in Community-Acquired Pneumonia (CAP) by Chest Radiograph (CXR) and Lung Ultrasound (LUS).

The area under the curve for interstitial pattern was obtained as 0.71 which is fair with 95% confidence interval from the 0.47 to 0.78. The area under the curve for alveolar pattern was obtained as 0.8 which is good with 95% confidence interval from the 0.61 to 0.88. The area under the curve for mixed pattern was obtained as 0.72 which is fair with 95% confidence interval from the 0.54 to 0.91[Table/Fig-6].



[Table/Fig-6]: Comparison of Receiver Operating Curves (ROC) curves for different patterns of pneumonia by Lung Ultrasound (LUS).

LUS shows optimal sensitivity and specificity for diagnosis of alveolar pattern [Table/Fig-7]. Quadratic Weighted Cohen's Kappa=0.74 which shows a substantial agreement between LUS and CXR for diagnosing specific types of pneumonia (Standard Error=0.068, 95% CI=0.61-0.88) [Table/Fig-8].

Specific patterns	Sensitivity of lung ultrasound (LUS)	Specificity of lung ultrasound (LUS)
Interstitial pattern	30%	95.77%
Alveolar pattern	70.59%	79.73%
Mixed pattern	54.54%	91.25%

[Table/Fig-7]: Sensitivity and specificity of Lung Ultrasound (LUS) for specific patterns in CAP.

Specific patterns	Lung ultrasound (LUS)				
Chest radiograph (CXR)	Normal	Interstitial	Alveolar	Mixed	Total
Normal	40*			3	43
Interstitial	2	6*	10	2	20
Alveolar		3	12*	2	17
Mixed			5	6*	11
Total	42	9	27	13	91

[Table/Fig-8]: Diagnosis of specific patterns of Community-Acquired Pneumonia (CAP) by chest radiograph (CXR) and Lung Ultrasound (LUS).
*Concordant results

DISCUSSION

Of the 91 patients studied, majority were under 5 years of age with a female predominance. This was in concordance with the studies by Boursani C et al., (age range, 6 months-12 years; median age, 4.5 years) and Esposito S et al., (mean age 5.6±4.6 years) [14,15]. This was also comparable to other similar studies which showed a female majority [13,14]. The predominant presenting symptom among the patients studied was cough (96.7%). Tirdia P et al., with a study sample (n=139) also had a similar distribution with cough (95%) as the most common presenting symptom [16]. However, in Yadav KK et al., study population, fever (86%) was the frequent presentation as compared to cough (63%) [17].

In this study, compared to CXRs, LUS demonstrated good diagnostic performance with 95.83% sensitivity, and 93.02% specificity. Of particular importance is the very high NPV of LUS (95.24%), which indicates that LUS is a good technique to exclude pneumonia and could be a useful tool for triage in emergency rooms. A study by Caiulo VA et al., also shows similar findings among 89 hospitalised children, of which 92% had abnormal CXR while 98.8% had LUS suggestive of CAP [18]. Shah VP et al., reported only 66.6% of children with suspected CAP had abnormal CXR and 90.7% had an abnormal US [5]. LUS did not miss any case of pneumonia in a randomised controlled trial comparing LUS with CXR in 191 children done by Jones BP et al., [19]. In a study done by Yadav K et al, higher number of lung consolidation was observed by US than CXR [17].

In this study, the CXRs of three patients which showed no obvious lesions were found to have pneumonia patches on LUS. CXR failed to detect these lesions due to: 1) their small size (<1 cm) or at the early stage of disease; and 2) if the lesions are beyond the heart or mediastinum; 3) the subpleural locations. Iorio G et al., reported findings similar to present study with false negative radiograph cases identified on LUS were either located in the retro cardiac or diaphragmatic areas or were tested immediately after onset of illness [20]. Two patients were negative for pneumonia on LUS but showed a positive pneumonia patch on CXR. The reasons why LUS did not detect the pneumonia patch may be because lesions were not large enough to extend to the pleura, or the lesions were in areas difficult for the US beam to reach like supraclavicular and the retro-scapular regions. Urbankowska E et al., also reported similar false negative results in 5 patients who had perihilar consolidation in CXR [21]. In another study by Reali F et al., two patients had paracardiac consolidations, two others were in the scapular area and 1 was in the medial lobe which gave similar results as in our study [22]. Urbankowska E et al., suggested that LUS may be considered as the first imaging test in children with suspicion of CAP and it can

also be used for follow-up, to know the resolution of pneumonic lesions [21].

Comparison of Diagnosis of Specific Patterns

Regarding the diagnostic accuracy of different patterns of lesions in CAP, LUS showed only 30% sensitivity for interstitial pattern compared to radiograph which diagnosed more interstitial patterns, whereas for alveolar pattern LUS showed a moderately good sensitivity and specificity with 70.5% and 79.7%, respectively. Study by Principi N et al., also reported similar findings with lower sensitivity of LUS for interstitial CAP and considers this to be associated with differences in definitions like the number of B-lines, coalescence or the distance among them [23]. It is likely unimportant in clinical practice because interstitial CAP commonly due to viral aetiology which does not warrant treatment with antibiotics.

Agreement analysis showed substantial overall agreement between LUS and radiograph in terms of pneumonia patterns (Cohen's kappa coefficient of 0.74). There was fair agreement between the two methods in the diagnosis of interstitial and mixed disease (p-value=0.017). However, there were statistically significant differences in the diagnosis of alveolar disease (p-value <0.001), because US classified more cases as alveolar CAP.

This may have important implications when it comes to prescribing antibiotics. Few cases which were defined alveolar pattern by LUS were diagnosed as non alveolar pattern by radiograph. According to the available recommendations, most cases of alveolar CAP are due to a typical bacterial infection requiring antibiotic therapy, whereas interstitial CAP is mainly thought to be due to viruses, that may not require antibiotics or atypical bacteria that require different antibiotics. This discordant result would have been due to the different limits for the CXR detection of lung consolidation.

Limitation(s)

First, CXR is not a perfect gold standard. It requires strict technical criteria, especially in children, and the interobserver variability in interpretation is more. Incorrect positioning and insufficient lung expansion on inspiration have a great influence on the quality of the radiograph and certain areas of the lung, such as the bases, superposed to the diaphragm, are more difficult to interpret. In the present study, a lateral CXR was not performed because it is never performed routinely in order to limit radiation exposure as much as possible. Although this study highlights new possibilities in the diagnostic approach to paediatric CAP, all patients studied were hospitalised, and evaluation on children managed in the outpatient setting was not done.

CONCLUSION(S)

The LUS is a promising tool that offers portability and diagnostic accuracy at the point of care in resource-limited settings. It plays a significant role in the detection of CAP which is not inferior to CXR and helps to better characterise and manage patients. Moreover, with prospective follow-up, one may better understand the evolution of US findings over time and determine whether early diagnosis using US may translate into clinically meaningful outcomes.

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