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Original Article

Diagnostic Ability of Chest Ultrasound in Selective Paediatric Pneumonia Alternative to CT scan: A single-center Comparative Observational Study

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Abstract

Introduction: Chest CT is the gold standard method of the diagnostic evaluation of patients with pneumonia. Lung sonography has been lately explored as an alternative modality to decrease radiation hazards. This study aimed to evaluate the diagnostic ability of lung ultrasonography in detecting paediatric pneumonia at presentation and follow up and comparing findings with chest CT scan.

Methods: A cross-sectional observational study was performed at a paediatric hospital from August 2019 to April 2021. We studied 106 children (ages from 45 days to 14 years) referred by the paediatrician with clinical data of pneumonia. All children underwent CT chest examination; 90 showed positive, while 16 showed no pneumonia. Ultrasonography was performed on all patients within 24 hours after CT examination.

Results: We found that lung ultrasound showed 100% specificity, 82.2 %, sensitivity in the diagnosis of paediatric pneumonia, accuracy was 84.9%, positive predictive value was 100% and negative predictive value was 50%. Their sensitivity and specificity are 100% in complicated pneumonia by parapneumonic effusion, empyema, and abscess formation.

Conclusions: Chest ultrasound is a simple technique that can be performed in everyday practice, with high specificity and sensitivity compared to a chest CT scan in diagnosis and follow up of pneumonia in the pediatric age group

Introduction

Pneumonia in children remains a condition that is challenging to diagnose accurately because the presenting signs and symptoms are nonspecific, might be subtle, and vary, depending on the patient's age, responsible pathogen, and severity of the infection.[1,2] Chest radiography (CXR) is considered the test of choice for diagnosing pneumonia in children. Nevertheless, it is not 100% sensitive nor specific, and variation exists in intra-and inter-observer agreement among radiologists.[3-6] A chest CT scan is usually considered the ideal gold stander for pneumonia patients with a non-conclusive CXR. However, it is not recommended for routine use because of its high radiation risk, high cost, and not associated improvement in outcomes.[5]

Lung ultrasonography (LUS) has been lately explored as an alternative modality to decrease radiation hazards. On lung, ultrasound pneumonia appears as a hypoechoic consolidated area of varying size and shape, with irregular borders. The echotexture can appear homogeneous or inhomogeneous.[7] Lung sliding is reduced or absent.[5] Pneumonia's most common sonographic feature is the air bronchogram, characterized by lens-shaped internal echoes within the hypodense area or echogenic lines and corresponds to air inclusions or air-filled bronchioles and bronchi. Dynamic air bronchograms can be observed. This finding rules out atelectasis.[6] Fluid bronchograms are characterized by anechoic or hypoechoic tubular structures with hyperechoic walls, without perfusion signs inside at color Doppler examination.[5-7] Pleural effusion is easily detected in the US and appears as an anechoic area in the pleural space.[8]

In paediatric patients, as in adults, lung ultrasound demonstrated a diagnostic accuracy higher or not inferior to CXR.[6,9] This study aimed to evaluate the diagnostic ability of LUS in the detection of paediatric pneumonia at presentation and follow-up and comparing findings with chest CT scan.

Methods

This was a single center, cross-sectional observational study performed at a Paediatric Hospital from October 2019 to April 2021. The study protocol was approved by the local institutional Ethics Committee (no 118/2019). We obtained express informed written consent from parents of all eligible patients accepted to participate in this study following the Declaration of Helsinki. Children with clinical signs and symptoms of pneumonia consisting of fever, cough, and shortness of breath, tachypnea, rib retraction and grunting as well as decreased air entry, fine crepitation and bronchial breathing at the auscultatory examination, in which the suspicion of pneumonia met the WHO criteria[10] (Clinically defined as age-specific tachypnea and chest indrawing) for diagnosis of pneumonia, were included in the study. We excluded children with congenital heart disease or other pulmonary background pathology, cerebellar palsy, thoracic wall malformations, thoracic trauma, obese patient, and bronchopneumonia seen at CT examination. We used a Voulson E6 GE ultrasound machine. Children underwent lung ultrasound using one of two probes, depending on the child's age and the thickness of the subcutaneous adipose tissue: a linear probe, with a frequency of 6 – 9 MHz; a convex probe (3 – 5 MHz). The ultrasound examination was performed by a senior radiologist (With more than five years of experience) in a time interval maximum 1- day post-CT study with a time of examination averaged 5 - 8 minutes. We needed no special preparation, no sedation, or fluid restrictions during the ultrasound examination.

We examined the patient in supine decubitus position and sitting position for the old child while the infant reviewed by both supine positions on a table or hold from parents for the irritable child and prone position. We divided each hemithorax into three areas to cover the whole lung: the anterior area delimited by parasternal and anterior axillary lines, the lateral space between the anterior and posterior axillary lines, and the rear area delimited by the paravertebral and posterior axillary lines.[11] We made a focused approach for a specific region. Each part was scanned in the longitudinal and oblique plane, medial-lateral and up-down. We examined the anterior and lateral areas of the chest while the infants were in supine decubitus. The posterior region was examined in prone decubitus in infants, while we used the sitting position to scan the rear wall in older patients. A noncontrast chest CT study was performed on 80 patients (other patients take contrast according to senior in charge opinion) using Brilliance Philips 64 slice machine. A radiologist reported the CT findings blindly to the results of the US. On lung ultrasound, consolidation, seen as "hepatization"—liver-like images or parenchymal images—with air or liquid bronchogram and anfractuous edges were considered ultrasound diagnostic parameters for pneumonia. In our study, the presence of a bronchogram inside consolidation was considered mandatory for pneumonia. The finding of dynamic air bronchogram (air bronchograms can have intrinsic dynamic centrifugal movements due to breathing) on LUS attests bronchial patency and rules out atelectasis. Detecting more than three B lines (which appear as vertical hyperechoic lines that arise from the pleural line) in one region between two ribs is considered evidence of interstitial lung syndrome. When we identified lung consolidation, we took the largest dimension longitudinal, transverse and sagittal axis and recorded the anatomical location for follow-up visits. An abscess was appreciated as a well-defined intrapulmonary rounded or oval hypoechoic lesion with variable thickness outer margins and may show internal fluid and air. Pulmonary necrosis was seen as a focal hypoechoic area within the consolidated lung, similar to CT. Lung sliding was appreciated as a horizontal movement of the pleural line in synchrony with the respiratory cycle, indicating a sliding movement of the visceral pleura against the parietal pleura. The movement disappears and cannot be detected with the LUS in a patient with pneumonia. We assessed the volume of pleural effusion in the supine position, and the transducer was aligned perpendicular to the dorsolateral chest wall measurement taken at inspiration by measuring the maximum distance between visceral and parietal pleura in millimeter multiplying by twenty. For pleural effusion diagnosis, anechoic accumulations were characteristic for uncomplicated pleural effusions or associated with septae or floating echos in complicated pleural effusions. On chest CT scan, parenchymal consolidation was defined

as air-space density with air bronchograms. The abscess was described as an intra-pulmonary cavity containing fluid and air, taking peripheral enhancement after IV contrast. Pulmonary necrosis was defined as an area of decreased density within a consolidated lung that shows no enhancement relative to the adjacent parenchyma. Pleural effusion is a free fluid density defined as loculated if the collection had a lobulated or lenticular shape with a convex border. The data was analyzed using Statistical Package for Social Sciences (SPSS) version 25. The data presented as mean, standard deviation, and ranges. Frequencies and percentages give categorical data. A Chi-square test assessed the association between U/S finding results and specific information. A level of P – value less than 0.05 was considered significant.

Results

One hundred six patients with signs, symptoms, and pneumonia-specific clinical presentation were evaluated with ages 45 days to 14 years with a mean of 6.5 years and standard deviation (SD) of ± 4.11 years. The highest proportion of study patients was > 5 years (47.2%). Regarding gender proportion, males were higher than females (66% versus 34%) with a male to female ratio of 1.94:1. Regarding residency proportion, rural was higher than urban area (51% versus 49%) while regarding immunization status, the higher proportion was partial immunization (54.7%) (Table 1).

Table 1. Baseline characteristic of patients

Character	No = 106 (%)
Age	
< 2 years	8 (7.5%)
2 - 5 years	48 (45.3%)
> 5 years	50 (47.2%)
Sex	
Male	70 (66%)
Female	36 (34%)
Geographical distribution	
Rural	54 (51%)
Urban	52 (49%)
Immunization status (vaccination)	
Complete immunization	40 (37.7%)
Partial immunization	58 (54.7%)
Unimmunized	8 (7.6%)

Out of 106 patients with a suspicion of pneumonia, 90 were confirmed to have pneumonia by CT scan, among which 48 cases was complicated (LUS was similar to CT finding in this group). Non-complicated pneumonia was 42 cases in CT scan where LUS can identify only 26 cases (Figure 1).

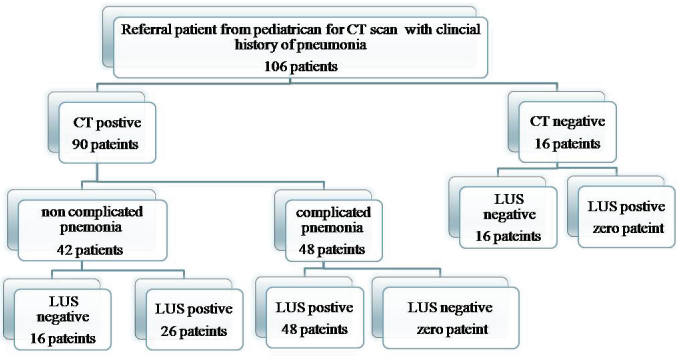

Figure 1. Flow chart presenting the relation between CT and LUS findings on admission.

Out of 74 cases with positive LUS, dynamic air bronchogram was seen in 64 (86%), followed by consolidation in 60 (81%), effusion in 42 (56.7%), an interstitial syndrome in 6 (8%), and absent lung sliding seen in 4 (5%) (Figure 2).

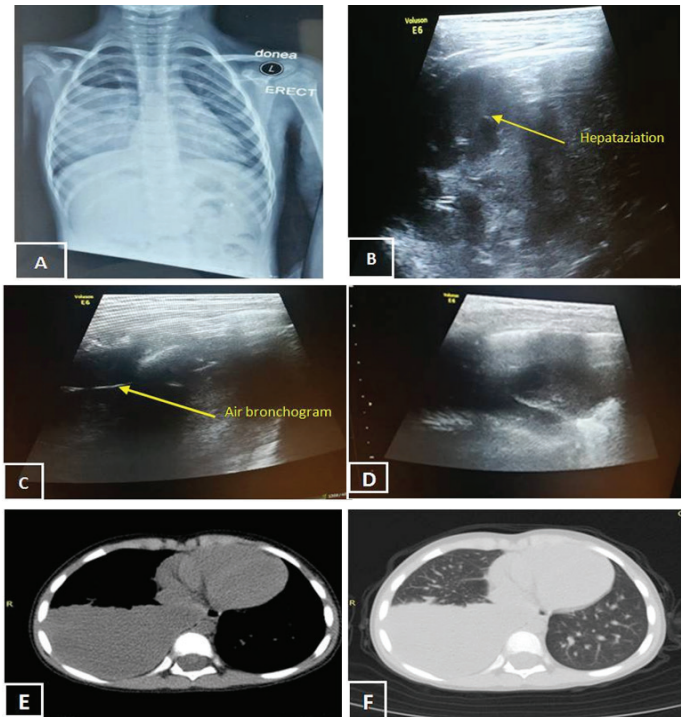

Figure 2 (A-F). Nine years old child presented with fever and signs of pneumonia (tachycardia and guarding). (A) chest x ray. (B, C and D) longitudinal and transverse plane at lower anterior and lower lateral of right lung LUS image show hepatization and air bronchogram (yellow arrow). (E and F) mediastinal and lung window CT non contrast study shows collapsed consolidation of right lower lobe.

The most common site seen by CT - scan was the right lower lobe (18.9%), while by LUS, the highest proportion of study patients showed negative results (30.2%). Among those with positive results, 15.1% were in the right lower lobe. It was positive for pleural effusion in 39.6% of cases

by CT-scan and U/S examinations. About cavity, CT-scan diagnosed abscess in 11.3% of cases; while by LUS, it was diagnosed in 9.4% of patients (Figure 3).

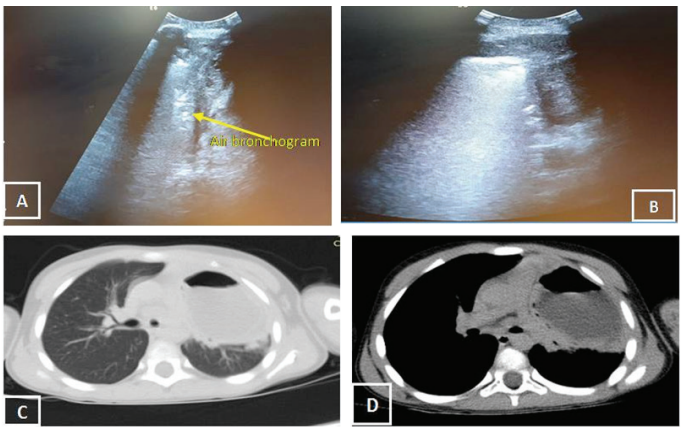

Figure 3 (A-D). Six years old child complain of fever and cough on examination tachypnea with positive auscultation finding. (A and B) longitudinal and transverse plane LUS image show abscess as a amorphous collection of fluid and air bronchogram (yellow arrow) at left upper lobe. (C and D) contrast enhanced CT scan mediastinal and lung window show enhancing wall left upper lobe cavity contain fossa of gas.

By CT - scan, empyema was diagnosed in 5.7%, while by LUS, it was diagnosed in 3.8% of patients (Table 2) (Figure 4).

Table 2. Localization and detection of certain findings by CT-scan versus LUS examinations

Finding	By CT scan N = 106 (%)	By LUS N = 106 (%)
Location of pneumonia		
Negative	16 (15.1)	32 (30.2)
Lingula	14 (13.2)	8 (7.5)
LLL	12 (11.3)	10 (9.4)
LUL	16 (15.1)	14 (13.2)
RLL	20 (18.9)	16 (15.1)
RUL	14 (13.2)	14 (13.2)
RML	14 (13.2)	12 (11.3)
Pleural effusion		
Positive	42 (39.6)	42 (39.6)
Negative	64 (60.4)	64 (60.4)
Cavity		
Abscess	12 (11.3)	10 (9.4)
Negative	94 (88.7)	96 (90.6)
Empyema		
Positive	6 (5.7)	4 (3.8)
Negative	100 (94.3)	102 (96.2)

LLL; Left lower lobe, LUL; left upper lobe, RLL; right lower lobe, RUL; right upper lobe, RML; right middle lobe.

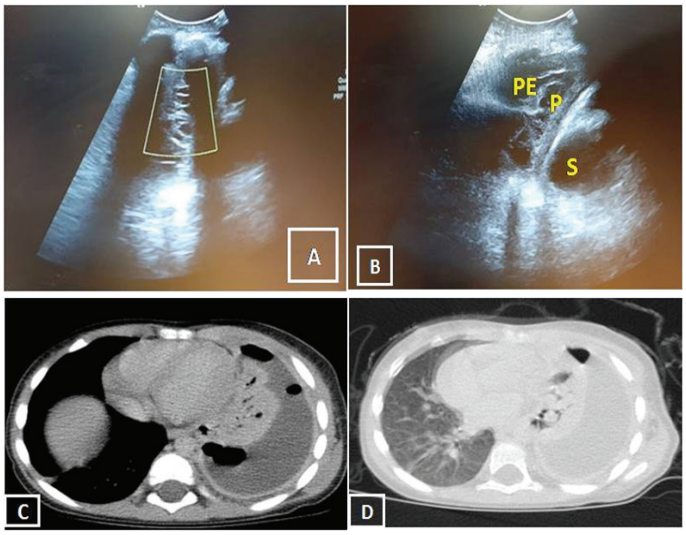

Figure 4 (A-D). Five years old child presented with fever and SOB, on examination tachycardia, grunting and rib retraction. (A and B) LUS upper anterior and lower anterior of the left lung longitudinal and oblique plane show thick septation with pleural fluid at left lung base corresponding with complicated empyema. (C and D) CT with contrast mediastinal and lung window show enhancing pleural edge with split pleura sign and air bronchogram seen at lingula and gas locula. S (spleen), PE (pleural effusion), P (pleura).

Patients with complicated pneumonia could have more than one pleural effusion, abscess, and empyema. Six patients have empyema on CT associated with pleural effusion; two are missed by ultrasound. Twelve cases have cavitary lesions by CT scan, six associated with pleural effusion, two cavities missed by ultrasound examination. The study results revealed high sensitivity and specificity of 100% for LUS to detect complicated pneumonia, compared to CT (Table 3).

Table 3. Sensitivity, specificity and accuracy of LUS in comparison to CT

	Sensitivity	Specificity	Accuracy	PPV	NPV
LUS pneumonia	82.2%	100%	84.9%	100%	50%
LUS Complicated pneumonia	100%	100%	100%	100%	100%
LUS Non-complicated pneumonia	61.9%	100%	72%	100%	50%

LUS, lung ultrasound, PPV; positive predictive value, NPV; negative predictive value

Table 4. Distribution of study patients by follow up

Variable	No. (%)
Pneumonia (n = 62)	
Complete remission	44 (71)
Stationary	6 (9.7)
Progressive	8 (12.8)
Regressive	4 (6.5)
Pleural effusion (n = 36)	
Complete Remission	30 (83.3)
Stationary	6 (16.7)

Table 5. Association between LUS finding results and patients characteristics.

Variable	LUS Finding		Total (%)	P- Value
	Pneumonia (%) N = 74	No(%) N = 16+by CT	N = 90	
Age (Year)				
< 2	0 (0.0)	8 (100.0)	8 (8.9)	0.001
2 - 5	36 (90.0)	4 (10.0)	40 (44.4)	
> 5	38 (90.5)	4 (9.5)	42 (46.7)	
Gender				
Male	48 (80.0)	12 (20.0)	60 (66.7)	0.581
Female	26 (86.7)	(13.3) 4	30 (33.3)	
Residency				
Urban	34 (15.62)	4 (3.38)	38	0.27
Rural	40 (21.38)	12 (4.62)	52	
Immunization status (Vaccination)				
Complete	28 (13.98)	6 (3.02)	34	0.46
Partial	44 (21.38)	8 (4.62)	52	
No immunization	2 (1.64)	2 (0.36)	4	
Tachypnea				
Yes	48 (77.4)	14 (22.6)	62 (68.9)	0.21
No	26 (92.9)	(7.1) 2	28 (31.1)	
Rib Retraction				
Yes	22 (68.8)	(31.2) 10	32 (35.6)	0.079
No	52 (89.7)	6 (10.3)	58 (64.4)	
Grunting				
Yes	34 (85.0)	6 (15.0)	40 (44.4)	0.663
No	40 (80.0)	10 (20.0)	50 (55.6)	
Auscultatory finding				
Yes	58 (80.6)	14 (19.4)	72 (80.0)	0.559
No	16 (88.9)	(11.1) 2	(20.0) 18	

The distribution of study patients by follow-up is shown in (Table 4). In this study, six cases of consolidative lesion missed follow-up; three of them had pleural effusion. During the follow-up, 71% of cases of pneumonia and 83.3% of effusion cases were entirely resolved.

In this study, all patients with pneumonia aged < 2 years were not diagnosed by LUS with a significant association between LUS finding results and age (P = 0.001). There were no significant associations (P ≥ 0.05) between LUS finding results and all other characteristics (Table 5).

Discussion

The total number of study patients enrolled in the current study was 106. All of them were children who presented with signs and symptoms of pneumonia. Regarding general data of patient distribution, the current study shows results that are slightly different from other studies.[12-15] Different sample sizes, history of coexisting chronic respiratory diseases, such as asthma, socioeconomic status, and geographical factors, can determine the observed differences. In the current study, out of 90 patients with pneumonia, 48 (53.3%) patients had complicated pneumonia with pleural effusion, empyema, or abscess formation were confirmed equally by LUS and CT. While in uncomplicated cases, LUS identified 26 (28.8%) cases and missed 16 (17.7%).

In comparison to other studies, Saraya et al[12] included 56 pediatric patients diagnosed with pneumonia found a different result, as 26 patients (46.4%) were positive by both LUS and CT while 19 cases (34%) were negative by both modalities. Ten patients (17.8%) showed negative results with ultrasound, while CT showed patchy pneumonia not reaching a septal surface in seven patients (12.5%) and bronchiolitis in the other three patients (5.3%). One case (1.8%) was diagnosed as suspected pneumonia by ultrasound showing few B lines, yet CT revealed clear lung fields. Furthermore, 17 patients (30.3%) showed associated pleural effusion as a complication on both US and CT, with no cases showing pulmonary abscess or lung necrosis on either modality. Differently, according to CT findings in Hajalioghli et al,[14] 98 children with pneumonia were included and the diagnosis of pneumonia was confirmed in 84 children (85.7%), among whom complications (pleural effusion) were observed in 26 (31%). Pleural thickening with floating fibrin strands and echogenic debris inside effusions were reported in 16 (61.5%) and 18 (69.2%) cases, respectively. There was no case of pulmonary abscess or lung necrosis. On the other hand, LUS detected all exudative para-pneumonic effusions correctly. Discrepancies in the studies mentioned above are multifactorial. They can be attributed to the sample size included in each study, type of respiratory problem studied, type of device used in each study, the operator's experience, duration, and severity of the disease. Other issues are size and location of consolidation

that cannot be seen by chest ultrasound. According to the study done by Hajalioghli et al,[14] the presence of air bronchograms is a vital sign that can easily be detected by LUS and help differentiate pneumonia from atelectasis with high sensitivity and specificity. This dynamic sign in LUS is advantageous over CXR and even CT images. In the current study, dynamic air bronchograms were present in 64 patients (86%) out of 74 patients, while interstitial syndrome was seen in (8%) consolidation (81%), and these were similar to Bitar et al.[6]

In the current study and according to the above results, LUS showed, in comparison to CT, a sensitivity, specificity, and accuracy for diagnosis of community-acquired pneumonia of 82.2%, 100%, and 84.9% respectively. The positive predictive value was 100%, and the negative predictive value was 50%. While in complicated pneumonia, the sensitivity, specificity, and accuracy were 100% for each. In non-complicated pneumonia, the sensitivity, specificity, and accuracy were 61.9%, 100%, and 72.4%. These results show a relative discrepancy with reports published by other authors such as Saraya et al[12] which found a sensitivity of 72.2%, specificity 95 %, and accuracy of 80.3%. Pereda et al[19] published a summary of eight studies in 2015 where LUS had a sensitivity of 96%, specificity of 93%, and positive and negative likelihood ratios were 15.3 and 0.06, respectively. Hu-Q et al[20] found a summary estimate of 97% for sensitivity and 94% for specificity, and the AUC was 0.99, indicating a high level of overall accuracy. Reissig et al[21] revealed that LUS had a sensitivity of 93.4% and a specificity of 97.7%. As mentioned earlier, the discordant results observed in the studies can have been attributed to the number of participants included in each study, technical factors of each device used, and the anatomical location of pneumonic lesions.

In the present study, 71% of cases of pneumonia and 83.3% of effusion cases were entirely resolved. This finding was comparable to the study by Saraya et al,[12] which showed almost complete resolution of the pneumonic hepatization in 53.8%. In comparison, associated pleural effusion was resolved in 94.1% of treated cases. In the current study, all patients with pneumonia aged < 2 years were not diagnosed by LUS with a significant association between LUS finding results and age (P = 0.001). We attributed this to the small number of patients aged less than two years (8 cases) included in our study; all have non-complicated central pneumonia not reaching the pleural surface. There were no significant associations ($P \geq 0.05$) between LUS finding results and all other characteristics, including sex, residency, immunization status, and clinical presentation. A few limitations that exist for this study must be acknowledged. The number of patients is still limited for broader applicability, and a more extensive, multicenter study would provide more generalizable results. Another limitation is that we did not assess the diagnostic ability of lung ultrasound for lung necrosis due to a lack of cases.

Conclusions

Chest ultrasound is a simple tool that can be performed in everyday practice, with high specificity and sensitivity compared to chest CT scan in diagnosis and follow-up of complicated pneumonia in the pediatric age group. Therefore, ultrasound needs to be encouraged not just as a valid diagnostic alternative but as a necessary ethical choice.

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