Original Article

Pediatric Lung Ultrasound (PLUS) in the diagnosis of Community-Acquired Pneumonia (CAP) requiring hospitalization

Neetu Talwar, Lucky Manik, Krishan Chugh

Division of Pediatric Pulmonology, Fortis Memorial Research Institute, Gurugram, Haryana, India

ABSTRACT

Background: In childhood pneumonia, pediatric lung ultrasound (PLUS) is a very sensitive and specific diagnostic alternative to chest X-ray (CXR). However, there is a paucity of literature on this in India. We set out to compare the diagnostic accuracy of PLUS and CXR in hospitalized children with community-acquired pneumonia (CAP). **Setting and Design:** Prospective, observational study (June 2017–September 2019) at a tertiary care hospital. **Methods:** Hospitalized children of CAP (3 months–18 years) were included after taking informed, written consent. Hemodynamic instability, asthma, cystic fibrosis, congenital heart disease, immunodeficiency, and malignancy cases were excluded. CXR (frontal view) and PLUS were done within 6 h of each other and within 24 h of hospitalization. Statistical analysis was performed using SPSS software version 25. **Results:** Out of 612 consecutive, hospitalized respiratory cases, 261 were recruited. CAP was diagnosed clinically in 148 (56.7%) patients [95 boys (64.19%), mean age in years ± SD: 4.31 ± 4.41]. Abnormal PLUS was present in 141 (95.27%) and abnormal CXR in 128 (86.48%) patients. In radiologically diagnosed pneumonia, PLUS was detected in 123 [123/128 (96.09%)] children, and when CXR was normal, PLUS was abnormal in 18 [18/20 (90%)]. PLUS showed a sensitivity of 95.27% (95%CI: 90.50–98.08) and a specificity of 92.90% (95%CI: 86.53–96.89). CXR showed a sensitivity of 86.49% (95%CI: 79.9–91.55) and a specificity of 90.27% (95%CI: 83.25–95.04). **Conclusions:** PLUS is a sensitive, specific test and can be considered as the preferred investigation before CXR in children hospitalized with CAP.

KEY WORDS: Chest X-ray, community-acquired pneumonia, hospitalized, lung ultrasound

Address for correspondence: Dr. Neetu Talwar, Division of Pediatric Pulmonology, Fortis Memorial Research Institute, Sector, 44, (Opp. HUDA City Centre Metro Station), Gurugram 122002, Haryana, India.
E-mail: neetu.talwar1306@gmail.com; neetu.talwar@fortishealthcare.com

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INTRODUCTION

Community-acquired pneumonia (CAP) causes high morbidity and mortality, especially in children below the age of 5 years.[1,2] Under-five mortality due to childhood pneumonia in our country is approximately 27.5%.[3] As per World Health Organization (WHO), British Thoracic Guidelines (BTS), and most other recommendations, pneumonia is a clinical diagnosis and X-ray chest (CXR) is indicated only in severe and complicated cases.[4-8] However, CXR has several limitations such as lack of definitive, diagnostic criteria for diagnosing pneumonia and significant intra and inter-observer variations, resulting in the lack of an objective and accurate diagnosis.[9-12]

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Another significant drawback for the pediatric age group is the exposure to ionizing radiation and subsequent risk of cancer later in life.[13-15] Computed tomography (CT) scan is the gold-standard diagnostic modality for diagnosing pneumonia; however, due to higher radiation exposure, availability, cost issues, and issues related to anesthesia and sedation, its use is limited to complicated cases.[11,12,16]

Lung ultrasound for diagnosing lung diseases is a relatively new investigation, and guidelines have been published only recently.[17-20] It is rapid, easy, repeatable, and portable and is thus available at bedside or point of care.[21,22] Training is fast, and the learning curve of techniques and interpretation is easy.[23] The greatest advantage of pediatric lung ultrasound (PLUS) is that it is non-ionizing, which assumes great significance in children as compared to older age groups.[22] Thus, lung ultrasound is emerging as a promising tool in the diagnosis of pneumonia being as reliable as CXR or even better as reported.[21-23] Treatment of pneumonia in children—in many cases, without knowing the extent and pattern of disease—can lead to unnecessary use of antibiotics; thus, CXR is used. Hence, safer and radiation-free diagnostic alternatives should be considered to manage these cases. Our study aimed to compare the accuracy of PLUS and CXR in hospitalized, pediatric patients of CAP and to find out the reliability of PLUS as an alternative diagnostic test in these patients. There is limited data on this subject in children.[24]

MATERIALS AND METHODS

Ours was a hospital-based, prospective, observational study done at the Division of Pediatric Pulmonology at a tertiary care hospital between June 2017 and September 2019. Hospitalized children (n = 148) between the ages of 3 months–18 years with CAP were included. In all patients, CXR (frontal view) and PLUS were done within 6 h of each other and within 24 h of admission. The diagnosis was made by two experienced pediatricians (KC, NT) based on clinical features such as fever, fast breathing, cough with or without labored breathing, decreased breath sounds, and crepitations in a previously healthy child.[6-8] In infants, clinical presentation of inability to tolerate feeds, with grunting or apnea, was included.[8] Patients with suspected or proven asthma, cystic fibrosis, congenital heart disease, immunodeficiency, and hemodynamic instability were excluded from the study. Also excluded were those patients in whom CXR had been done before admission, when PLUS and CXR could not be done within 6 h of each other, or within 24 h of hospitalization.

Children with CAP were categorized according to WHO recommendations,[25] which has included only two categories of pneumonia in children, first being pneumonia with the presence of fast breathing and/or chest indrawing, which needs home therapy with oral amoxicillin, and the other being severe pneumonia, in which there is pneumonia with any general danger sign, requiring referral and injectable therapy. All our patients had fever and tachypnea for age. Chest indrawing and cough was present in 89 and 112 patients, respectively. Out of the 113 patients who did not clinically have pneumonia, 52 had bronchiolitis, 17 had foreign-body aspiration, 35 patients had viral infection with wheezing presenting for first time, three patients had urinary tract infection with sepsis, and six patients had severe dengue. The radiological findings were classified according to the guidelines by WHO, wherein primary endpoint pneumonia was defined as the presence of endpoint consolidation or pleural effusion in the lateral pleural space and was also spatially associated with a pulmonary, parenchymal infiltrate. Pneumonia was also radiologically identified in those patients with pleural effusion that obliterated enough of hemithorax to obscure an opacity.[14] Radiologists were blinded to the ultrasound findings. Results of CXR were interpreted by three trained radiologists by using the WHO scheme for the interpretation of chest radiographs.[14] PLUS was performed independently within 6 h of CXR, with the clinicosonologist being unaware of radiological findings, and it was always performed by the same expert clinicosonologist (NT) trained to perform the study protocol. Philips IU22 ultrasound machine with a high-resolution micro-convex transducer was used for LUS in all patients, with both curvilinear (3.5–5 MHz) and linear probes (high resolution; 7.5–10 MHz). Movement of the transducer was done in intercostal spaces and directed vertically, obliquely, and perpendicularly according to the standard protocol, in sitting, lateral (to scan the posterior thorax), and supine position (to scan the lateral, anterior, and posterior thorax).[24,26]

Methodical scanning of the entire thorax was done, and findings were described in the anterior, lateral, and posterior areas of each hemithorax (upper and lower). The parasternal line to the anterior axillary line defined the anterior area, the anterior axillary line to the posterior axillary line defined the lateral area, and the posterior region extended from the posterior axillary line to the para-vertebral line. Each area was further divided into upper (collar bone to second intercostal space) and lower (third intercostal space to the diaphragm)

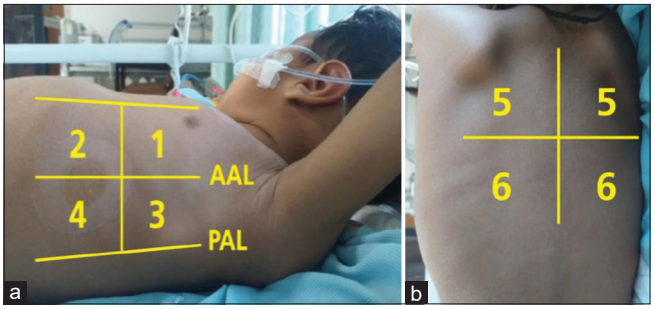

Figure 1: (a and b) Areas of thoracic region to be scanned by ultrasound: 1 and 2, anterior superior, anterior inferior; 3 and 4, lateral superior and lateral inferior; 5 and 6, posterior superior and posterior inferior; AAL, anterior axillary line; PAL, posterior axillary line

subareas.[26] Thus, each hemithorax was divided into six regions or zones as follows [Figure 1 (a and b)]:

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

Each area was the same on both sides.

Zones 1–4 were evaluated in a supine or upright position preferably. Zones 5 and 6 were assessed in the upright posture, and in case this was not possible, the evaluation was done in a lateral decubitus position. For scanning zone 5, the patient's arms were raised or shoulders shrugged to move away from the scapulae.[26]

In each lung zone, a 3-s clip was recorded for longitudinal and transverse/oblique intercostal view. On each side, a longitudinal still image of costophrenic sulcus was taken to evaluate for pleural effusion, and an upright position was used whenever possible.[26]

More images were obtained using a linear transducer and curved array or sector transducer on detection of an abnormality. In areas of suspected lung consolidation, clips and color Doppler images were recorded using an additional recording of pulsed Doppler waveforms done on identifying vessels. In case pneumothorax was suspected, an M-mode tracing using the linear transducer was performed, and the edge of the normally aerated lung was searched. Thus, a minimum of 24 clips and two still images were obtained for each examination. Images were labeled appropriately for the correct side (right or left), orientation and zone. Lung ultrasound study duration of approximately 15 min was kept.[26]

The pleural line was identified as a regular echogenic line moving continuously during respiration, called the "lung sliding sign." "A lines" and "B lines" were identified. B lines are indicative of fluid-rich subpleural interlobular septae surrounded by air.

The findings were then categorized as being normal, patchy, or lobar consolidation, pleural effusion, or interstitial disease. "Normal" findings were defined as the presence of normal lung sliding, the presence of A lines, and the absence of other findings. "Interstitial disease" was defined when three or more B lines per imaging field were present. "Patchy or lobar consolidation" region was visible as an echo-poor, non-aerated lung or an area with tissue-like appearance, depending upon the amount of air loss and predominance of fluid, with or without air bronchograms.[23,27] Air bronchograms were defined as punctate or branching echogenicities seen within the consolidated areas. These were either static, which did not show motion within the bronchi, or dynamic, which moved within the bronchi.[26] In an area of consolidation, the vascular flow was seen by using color Doppler imaging, and pulsed Doppler waveforms were obtained. If vascular flow was present, it was defined as an area of consolidation.[23] Fluid bronchograms was defined as an anechoic tubular structure, with hyperechoic walls, without color-Doppler signal.

Pneumonia was diagnosed sonologically as an area of consolidation of different sizes, shapes, and with poorly defined borders, air or fluid bronchograms, with or without the presence of pleural effusion.[23,24,26,27] Pleural effusion was identified as an anechoic or hypoechoic area between the parietal and visceral pleura or the presence of fluid at the thickest part of the pleural space, with a depth greater than 3 mm measured perpendicular to the pleural surface, with or without floating debris.[23,26] There was discordance in the diagnosis of CAP by PLUS and CXR in 23 patients. Thus, CT scan of chest was done in these patients by using Philips Brillance iCT 256 Slice (Amsterdam, Netherlands).

Written informed consent was taken before recruitment. The institution's ethics committee approved the study protocol.

Statistical analyses

The primary objective of the study was to assess the accuracy of point-of-care PLUS in the diagnosis of CAP in children. With reference to the previous studies, the accuracy of PLUS ranged between 60% and 90%. Therefore, assuming $P = 80\%$ as the accuracy with a 10% margin of error, the minimum required sample size at 5% level of significance was 62 patients.

The data were recorded in preformed questionnaires that included anthropometry, demographic, clinical, and diagnostic variables, and statistical analyses were then done by using SPSS software version 25. Continuous variables were presented as mean ± SD. Categorical variables were expressed as frequencies and percentages. Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated with clinical diagnosis as the gold standard.

RESULTS

Out of 261 recruited children, CAP was clinically diagnosed in 148 patients (56.70%) [Figure 2]. The mean age + SD in years was 4.31 ± 4.41, and the median age in years was 2.58 (minimum–maximum age = 0.5–16.8); 95 (64.19%) were boys. The mean weight (in kg) ± SD of the children was 18.27 ± 14.32. The patients from a rural background were 102 (68.92%),[28] and the mean duration of hospital stay (number of days) ± SD was 5.11 + 4.17. All the children diagnosed as CAP had fever and fast breathing as per age, with cough and labored breathing being present in 112 (75.67%) and 89 (60.13%), respectively. Out of 148

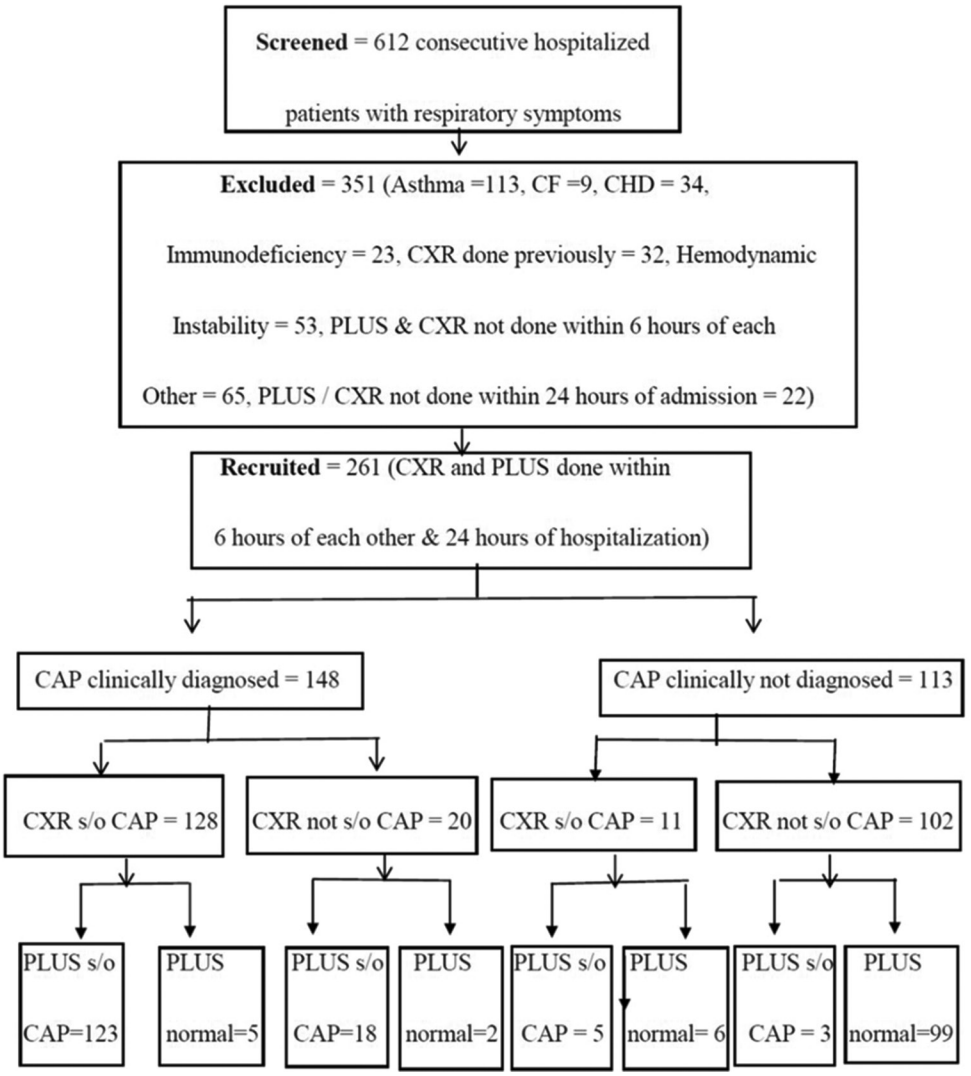

Figure 2: Consort flow diagram of the study. CXR - x-ray chest PA view; PLUS - pediatric lung ultrasound; CAP - community-acquired pneumonia; CHD - congenital heart disease; CF - cystic fibrosis

Table 1: CXR findings of patients admitted with community-acquired pneumonia

CXR Findings	*n* (%)
Normal	20 (13.51)
Endpoint consolidation	72 (48.64)
Non-end point infiltrates	56 (37.83)
Pleural effusion	29 (19.59)

Table 2: Pediatric lung ultrasound (PLUS) findings in hospitalized children of community-acquired pneumonia

No	PLUS findings	*n* (%)
1	Normal	7 (4.73)
2	Patchy/lobar consolidation	104 (70.27)
3	Interstitial pattern	37 (25)
4	Pleural effusion	38 (25.68)

children, 56 (37.83%) were categorized as pneumonia and 92 (62.16%) as severe pneumonia as per Revised WHO classification.[5] Detailed findings of PLUS and CXR in children with CAP are listed in Tables 1 and 2.

Out of 148 patients of pneumonia, radiological detection was made in 128 (86.48%) patients. An agreement study between radiologists for reporting of CXR showed good agreement (kappa = 0.8). Diagnosis by PLUS was made in 141 (95.27%) patients. In these clinically and radiologically diagnosed patients, lung ultrasound (LUS) was suggestive of pneumonia in 123 (123/128; 96.09%). CXR could not detect pneumonia in 20 (13.51%) clinically diagnosed patients, out of which PLUS could detect pneumonia in 18 (90%) patients, which was confirmed on CT chest [Figure 3]. Out of these 18 patients, nine patients had sub-centimetric areas of consolidations on CT scan (zone 1 on the right side in two patients, zone 5 on the left side in five patients, and zone 3 on the left side in two patients). Five patients had lesions in the lateral segment of the left upper lobe (zone 1 on the left side in three patients and zone 3 on the left side in two patients), and four had involvement in posterior segment of right lower lobe (zone 2 on the right side in one patient and zone 6 on the right side in three patients). Details of one

discordant patient with normal CXR is shown in Figure 4. Five patients without findings of pneumonia on PLUS were positive on CXR, who were also confirmed on CT chest. In two of these patients, there was an area of opacity in the right upper lobe on CXR (area of consolidation in the anterior segment of the right upper lobe on CT chest). Two patients showed left upper zone opacity and on CT chest showed involvement of posterior segments of left upper lobe. Details of one discordant patient with normal PLUS is shown in Figure 5.

In 113 patients without a clinical diagnosis of pneumonia, chest X-ray was normal in 102 patients (specificity: 90.27%) [Figure 2]. PLUS was normal in 105 patients (specificity: 92.90%). Table 3 shows the sensitivity, specificity, positive and negative likelihood ratios, and positive and negative predictive values of CXR and PLUS.

The difference in the diagnosis of CAP by PLUS and chest radiology showed the Chi-square statistic of 6.88, with a *P* value of 0.008 as significant. There was excellent concordance between CXR and PLUS for diagnosis of pleural effusion as shown in Table 4. Linear weighted Cohen's kappa was 0.83 (SE = 0.05, 95%CI = 0.72–0.94).

DISCUSSION

In patients with CAP, whenever there is a diagnostic dilemma, suspicion of complication, inadequate response to treatment, or progression of disease, chest X-ray is the most common and preferred diagnostic test. However, this test has many limitations, of which the most important is the risk of radiation and future risk of cancer, which assumes tremendous significance in the pediatric age group due to rapid cell division and a higher life expectancy. In addition, inter and intraobserver variation is another significant drawback. This prompted the researchers to look at ultrasound as an alternative.

In our study, pneumonia was detected radiologically in 128 (86.49%) patients, whereas PLUS was suggestive of CAP in 141 (95.27%) cases. These figures show that PLUS can detect a significantly higher number of cases of pneumonia as compared to CXR ($P = 0.008$). Similar findings have been recorded by some other workers. In a study by Coppetti and Cattarossi, lung ultrasound could diagnose pneumonia in 60/79 (75.94%), while X-ray chest was positive in 53/60 (88%) children.[24] Shah *et al*.[29] reported a lower detection rate of pneumonia in 66.6%

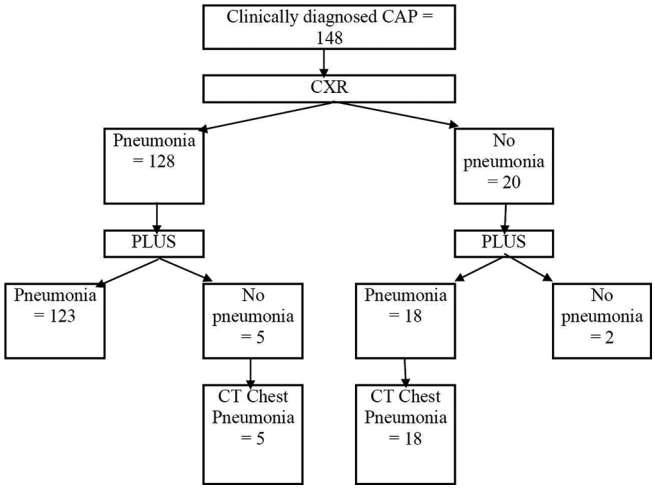

Figure 3: Details of Discordant Patients. CXR – chest r ray; PLUS – pediatric lung ultrasound; CAP – community acquired pneumonia

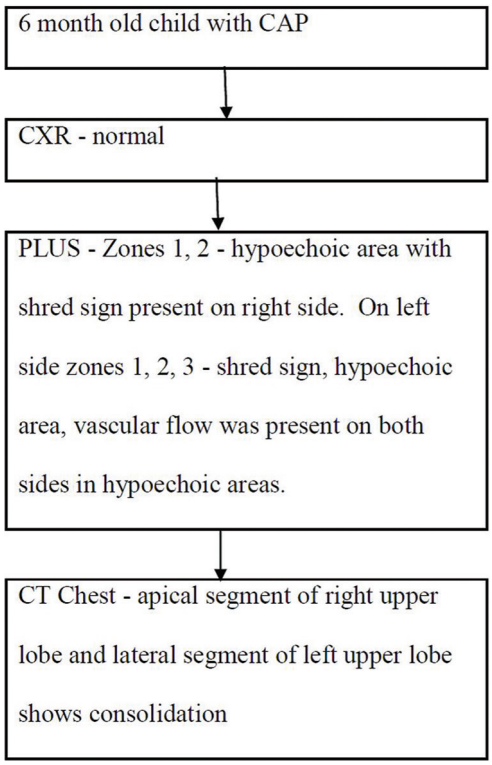

Figure 4: Child with discordant findings on CXR, PLUS, CT Chest. CXR – chest x ray; PLUS – pediatric lung ultrasound

Table 3: Diagnostic accuracy of PLUS and CXR in the detection of community-acquired pneumonia (95% confidence intervel)

	Sensitivity % (95% CI)	Specificity% (95% CI)	LR+ (95% CI)	LR- (95% CI)	PPV (95% CI)	NPV (95% CI)
PLUS	95.27% (90.50-98.08)	92.90% (86.53-96.89)	13.46 (6.89-26.27)	0.05 (0.02-0.11)	94.63% (90.03-97.18)	93.75% (87.90-96.87)
CXR	86.49% (79.9-91.55)	90.27% (83.25-95.04)	8. 88 (5.05-15.63)	0. 15 (0.1-0.23)	92% (86.86-95.34)	83.61% (77.16-88.51)

LR+, positive likelihood ratio; LR−, negative likelihood ratio; PPV, positive predictive value; NPV, negative predictive value; CI, confidence interval; CXR, chest radiography; PLUS, Pediatric lung ultrasound

Table 4: Concordance between chest X-ray (CXR) and pediatric lung ultrasound (PLUS) for the diagnosis of pleural effusion in hospitalized patients of CAP

CXR	PLUS		
	Absent	Present	Total
Absent	110	9	119
Present	0	29	29
Total	110	38	148

PLUS, Pediatric lung ultrasound; CXR, X-ray chest (PA view); CAP, Community-acquired pneumonia

by radiology as compared to 90.7% by lung ultrasound. Similar findings were reported by Iorio *et al*.[30]

In radiologically and clinically diagnosed patients of CAP (128), PLUS was abnormal in 123 (123/128, 96.09%) cases. When CXR was normal (20), PLUS could identify pneumonia in 18 (18/20, 90% cases), which were confirmed by CT chest [Figure 3]. In a significant randomized controlled trial, Jones *et al*.[31] reported that PLUS did not miss any case of CAP. The possible reasons can be that CXR has its diagnostic limitations in cases of sub-centimetric consolidations, subpleural and retrocardiac lesions, juxta-diaphragmatic region, and radiolucency in the early stages of a pneumonic process.[29,30]

In our study, PLUS could not detect pneumonia in five radiologically diagnosed cases. The chest X-ray findings in these patients were confirmed to be positive following a subsequent evaluation and confirmation by CT chest [Figure 3]. The possible reasons for not detecting by PLUS can be due to the supra-clavicular and the retro-scapular locations of the lesions.[30]

Lung ultrasound has come a long way as an important diagnostic modality for CAP, initially in adults and now in children, with standard guidelines having been established.[23,24,30,32,33] Our study showed PLUS to have a sensitivity of 95.27% (95%CI: 90.50–98.08), which was quite higher than CXR, which showed a sensitivity of 86.49% (95%CI: 79.9–91.55) ($P = 0.03$). The specificity of PLUS was 92.90% (95%CI: 86.53–96.89) in diagnosing CAP, and that of CXR was 90.27% (95%CI: 83.25–95.04) ($P = 0.45$). A prospective study by Susanna Esposito *et al*.[34] reported the sensitivity, specificity, and positive and negative predictive values of LUS in comparison with CXR to be 97.9%, 94.5%, 94.0%, and 98.1%, respectively. Other studies too have shown sensitivity of PLUS ranging from 86% to 97.9% and specificity from 94.5% to 100%.[29] Some of the differences may be due to the use of different classifications of radiological findings and using CXR in lateral view along with the PA view. In addition, interpretation of X-ray chest depends on the quality of radiographic film and skill and expertise of readers, leading to varying degrees of concordance between clinicians and radiologists as well as between radiologists.[13]

Both CXR and PLUS were performed within 6 h of each other as findings can worsen or improve very quickly. In our

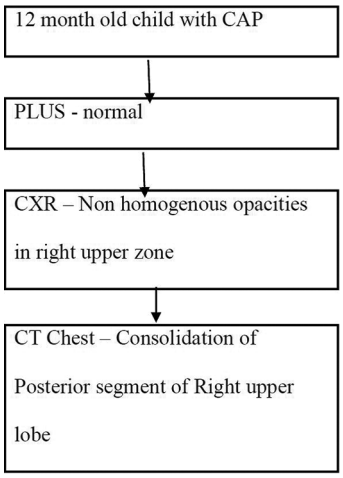

Figure 5: Second case with discordant findings on CXR, PLUS and CT Chest; CXR – chest x ray, PLUS – pediatric lung ultrasound

study pneumonia was diagnosed sonologically as an area of consolidation, air or fluid bronchograms, with or without the presence of pleural effusion. Air bronchograms caused due to the presence of trapped air in the airway were present in 93.5%, and fluid bronchograms were found in 36.7%. The higher percentage of the latter finding was probably because post-obstructive pneumonia is frequent in children. Similar data have been reported in other studies.[23] In the diagnosis of pleural effusion, there was an excellent concordance between CXR and PLUS, as shown in Table 4. Similar findings have been reported in other studies as well.[26]

Limitation of the study

Our study had a few limitations. We did not do CT chest in all our patients and did not take it as the gold-standard test to diagnose pneumonia due to the risk of radiation exposure and cost. Repeat LUS as a follow-up to detect the improvement or deterioration was not done. In addition, our study was limited to children admitted in the pediatric ward and PICU at point of care to the exclusion of outpatient patients.

CONCLUSION

Lung ultrasound is a very sensitive and specific test and can be considered as the preferred investigation before chest radiology in children hospitalized with suspected CAP whenever expertise and facilities are available. In addition, chest X-ray can be reserved for indicated cases only, leading to a significant reduction in radiation exposure.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest
There are no conflicts of interest.

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