Original Article

Lung Ultrasonography Versus Chest X-Ray In The Diagnosis Of Pneumonic Consolidation In Hospitalized Children: A Preliminary Single-Center Study

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Abstract

Background Pneumonia is a leading cause of mortality among children, particularly below the age of 5 years, with a large burden on the healthcare system. Therefore, rapid, early diagnosis is important using an easy, non-invasive method with minimal radiation exposure. Until now the most used imaging investigation in children with suspected pneumonia is chest X-ray (CXR). **Aim** To identify the sensitivity, specificity, and accuracy of point-of-care lung ultrasonography (POCUS) in the diagnosis of pneumonic consolidation in hospitalized children compared to CXR as a reference standard. **Methods** We enrolled children aged from 1 month to 18 years, with clinically diagnosed pneumonia, who were admitted to Mansoura University Children's Hospital, Egypt during the period from August 2020 to August 2021. CXR and lung ultrasound (LUS) were done for each patient, within 24 hours of each other. The presence of consolidation in both imaging modalities was compared using sensitivity, specificity, and diagnostic accuracy. The agreement between LUS and CXR was evaluated using Cohen's kappa test. **Results** A total of 82 children with clinically diagnosed pneumonia were evaluated. From those 46 patients were included. The study revealed a sensitivity of 97.4% for the detection of pneumonic consolidations by LUS and an accuracy of 87%. The agreement between LUS and CXR for consolidation was statistically significant ($p < 0.05$), with fair strength of agreement. **Conclusion** Lung ultrasound is a fast, non-invasive, simple method for the evaluation of children with pneumonia. It is as reliable as CXR in the detection of consolidation and can be easily performed at the patient's bedside.

Keywords: chest X-ray, consolidation, lung ultrasonography, pediatric, pneumonia, point-of-care lung ultrasonography.

INTRODUCTION

Pneumonia is one of the most common causes of childhood infections requiring hospitalization and is responsible for 14% of all deaths of children under 5 years old ***(World Health Organization, 2022)***. Although the majority of deaths attributed to pneumonia in children are mostly in developing countries, the burden of the disease is substantial, and there are significant healthcare-associated costs related to pneumonia globally ***(Rudan et al., 2013)***.

Chest X-ray (CXR) is currently the standard radiological investigation for suspected pneumonia in children, with the hazards of radiation exposure. Lung ultrasound (LUS) was neglected for many years based on the fact that ultrasound waves are reflected by air and bone, which is why LUS was not considered possible ***(Fauci, 2015)***. However, an increasing number of studies have changed that concept, demonstrating that LUS can be useful in the pulmonary evaluation of critically ill patients ***(Anantham and Ernst, 2010; Koenig et al., 2011; Reissig et al., 2011)***. LUS has emerged as an alternative to overcome the limitations of CXR in the diagnosis of pneumonia in both adults and children, being non-invasive, feasible, safe, and can be performed at the patient's bedside ***(Volpicelli et al., 2012; Pereda et al., 2015; Osman et al., 2020; Carrard et al., 2022)***. Point-of-care ultrasound (POCUS) refers to an ultrasound performed at the bedside and interpreted directly by the treating clinician ***(Dietrich et al., 2017)***. LUS might save costs for health systems and reduce the length of stay in emergency departments when compared with CXR ***(Harel-Sterling et al., 2019)***. Recent studies show that LUS is comparable to chest computerized tomography in its diagnostic accuracy ***(Danish et al., 2019; Alrefaey et al., 2020; Wang et al., 2021)***

Materials and Methods

Aim of work

This study aimed to identify the sensitivity, specificity, and accuracy of point-of-care lung ultrasonography in the diagnosis of pneumonic consolidation in hospitalized children compared to chest x-ray as a reference standard for pneumonia diagnosis.

Study design and participants

We conducted a preliminary prospective longitudinal descriptive study, in Mansoura University Children's Hospital (MUCH), from August 2020 to August 2021.

Infants and children (aged between 1 month and 18 years), with clinically diagnosed pneumonia were included in this study.

Pneumonia was defined according to the clinical criteria of CDC: the presence of either elevation in the body temperature more than 38°C, decreased or increased number of white blood cells (≤4000 WBCs/mm3 or >12,000 WBCs,/mm3) with at least two of the following: the presence of abnormal breath sounds as crepitations or bronchial breathing; the presence of purulent sputum or increase in the amount of respiratory secretions, or suction requirements; age-specific tachypnea (respiratory rate >60 breaths per minute in patients <2 months old; >50 breaths per minute in patients 2-12 months old; >30 breaths per minute in children >1 year-old, > 25 breaths per minute in older children and adults), cough that is new or has worsened; or deterioration in gas exchange evidenced as desaturation, increase in the oxygen or ventilator requirements ***(Centers for Disease Control and Prevention (CDC), 2023)***. Chest X-ray was done, however, the patients were included only based on the clinical criteria, as the operator was blinded to the result of the X-ray.

Exclusion criteria

Patients with viral bronchiolitis, asthma exacerbations, chronic lung disease, chest wall deformities or thoracotomy, and failure to obtain consent from caregivers were excluded from the study.

Radiological evaluation

Plain chest X-ray in the antero-posterior view was done to all patients using a commercially available portable X-ray machine. It was repeated as clinically indicated.

Ultrasound examination of the chest was performed in all patients by a single trained pediatrician under the supervision of a pediatric radiologist. The operator was blinded to the result of CXR at the time of performing POCUS. The CXR and LUS were performed within 24 hours of each other ***(Iorio et al., 2015; Lissaman et al., 2019; Osman et al., 2020)***. LUS was performed using an ultrasound device (Mindray DP-20, China) with a linear probe. It was performed once at the diagnosis of pneumonia.

Lung parenchyma was divided into 12 regions, six areas on each hemithorax, by dividing each hemithorax into anterior, lateral, and posterior regions: each region was further divided in upper and lower quadrants. All these areas were divided considering the thorax's normal anatomical landmarks: from sternum to anterior axillary line (anterior areas: 1 and 2), from anterior to posterior axillary line (lateral areas: 3 and 4) and from posterior axillary line to spine (posterior areas: 5 and 6) (Figure 1). Ultrasound examination was conducted with a longitudinal approach (probe perpendicular to the ribs) ***(Lichtenstein, 2007)***.

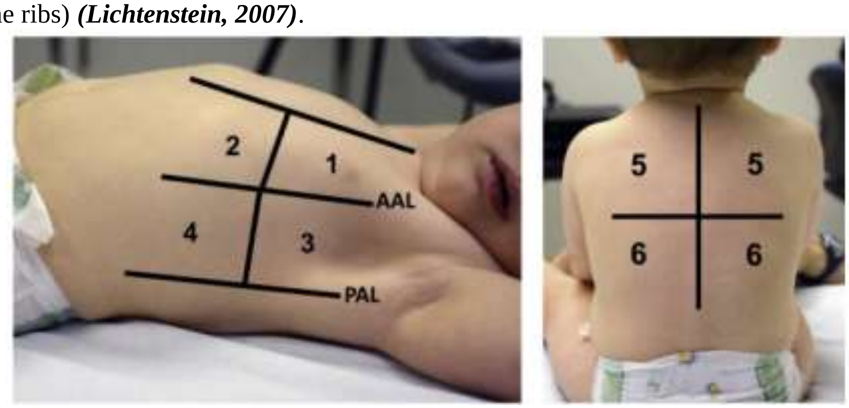

Figure (1) Areas of thoracic region to be scanned by ultrasound ***(Ambroggio et al., 2016)***

Ethical considerations
The study was approved by Institutional Research Board of Faculty of Medicine, Mansoura University (code number: MD. 20.06.336). Written informed consent was taken from legal guardians of all patients before enrollment in the study. All measures were taken to keep data confidentiality of patients. All study participants were free to leave the study at any time without penalty.

Statistical analysis

Data were analyzed using IBM-SPSS software Version 26 ***(IBM Corp., 2019)***.
Qualitative data were expressed as number (N) and percent (%). *Quantitative data* were initially tested for normality using Shapiro-Wilk test with data being normally distributed if $p>0.05$. Quantitative data were expressed as median (interquartile range) as data was not normally distributed ± presence of significant outliers.
Cohen's Kappa *(Cohen, 1960; McHugh, 2012)*
Cohen's kappa (κ) was used to measure inter-modality agreement (table 1).

Table (1) Interpretation of Cohen's kappa (k)

Value of k	Strength of agreement
< 0.20	Poor
0.21-0.40	Fair
0.41-0.60	Moderate
0.61-0.80	Good
0.81-1.00	Very good

(McHugh, 2012)

Results

A total of 82 children with clinically diagnosed pneumonia were evaluated. Thirty-six patients were excluded (5 patients with chronic lung disease, 6 patients with failure to obtain parental consent, 4 uncooperative patients, 9 patients with viral bronchiolitis, 12 patients with acute asthma exacerbations) (figure 2)

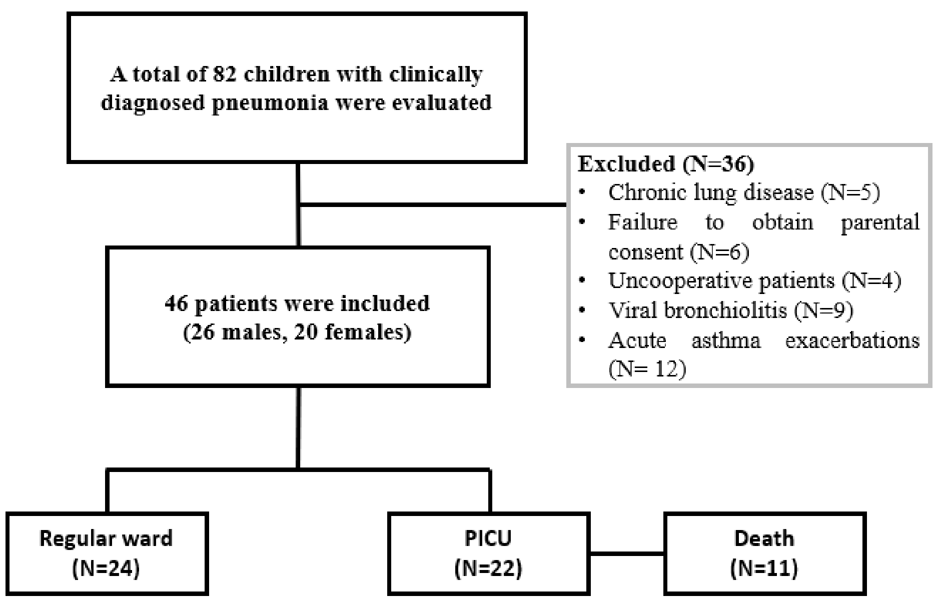

Figure (2) Flow chart for the study participants

The study included 46 consecutive patients diagnosed with pneumonia, 26 males (56.5%) and 20 females (54.3%) with a median age of 7 months (IQR 3-12 month) and median body mass index 13 kg/m^2. Two cases were transferred to another facility due to unavailability of ICU beds (missing in the analysis of length of hospital stay and mortality). Thirty-four enrolled patients had co-morbidity. The percent of a co-morbidity in non-survivors was 81.8% **(Table 2).**

The median time to perform LUS was 7 minutes. It was difficult to calculate the time needed to obtain CXR **(Table 3).**

The median duration of hospital admission attributable to pneumonia was 10 days. Forty-seven percent of the children had severe pneumonia requiring admission to the pediatric intensive care unit (PICU) and mechanical ventilation (MV). The median duration of MV and PICU stay were 5.5 and 15 days, respectively. Mortality rate among cases was 25% **(Table 4).**

The results of the current study revealed a sensitivity of 97.4% for the detection of pneumonic consolidations by LUS compared to CXR and an accuracy of 87% **(Table 5).**

The agreement between LUS and CXR for consolidation was statistically significant ($p < 0.05$), with fair strength of agreement **(Table 6).**

Table (2) The baseline characteristics of the studied cases

Characteristic	**Statistic**
Male Female	26/46 (56.5%) 20/46 (54.3%)
Age (months)	7 (3-12)
Body Mass Index (kg/m^2)	13 (11.32-15.32)
Weight (Kg)	5.5 (3.9-9.1)
Height/ Length (cm)	65 (55-75.75)
Presence of Chronic Illness Prior to Admission	34/46 (73.9%)
Presence of Chronic Illness Prior to Admission *in non-Survivors*	9/11 (81.8%)

Notes: Data are expressed as frequency (%) and median (IQR), IQR=interquartile range.

Table (3) Duration of ultrasound examination

Characteristic	**Statistic**
Duration of US examination (minutes)	7 (5-8)

Notes: US= Ultrasound
Data are expressed median (IQR), IQR=interquartile range.

Table (4) Outcome of the studied cases

Characteristic	**Statistic**
LOS attributed to pneumonia in survived cases (Days)	10 (6-16)
Need for PICU	22/46 (47.8%)
Need for MV	22/46 (47.8%)
Duration of PICU Stay in survived cases (Days)	15 (5.75-22.75)
Duration of MV in survived cases (Days)	5.5 (2.5-14.75)
Mortality rate	11/44 (25%)

Notes: MV= Mechanical Ventilation, PICU= Pediatric Intensive Care Unit, LOS= Length of hospital stay.
Data are expressed as frequency (%) and median (IQR), IQR=interquartile range.

Table (5) Diagnostic performance of LUS vs CXR

Finding	Sensitivity	Specificity	PPV	NPV	Accuracy
Consolidation in the US	97.4	28.6	88.4	66.7	87

Notes: US= ultrasound, PPV= positive predictive value, NPV= negative predictive value

Table (6) Agreement between US and X-ray (Cohen's kappa)

Finding	Kappa	SE	95% CI	P value	Strength
Consolidation in the US	0.34	0.2	-0.05 – 0.73	0.01	Fair

Notes: US= ultrasound, SE = standard error, CI = confidence interval.

Discussion

Lung ultrasonography has gained attention in the past few years in the diagnosis of pediatric pneumonia. For many years, the application of LUS remained strictly confined to adult critical care units ***(Musolino et al., 2021)***. Several studies have recently been conducted to evaluate the reliability of LUS in children. According to their findings, LUS can detect lung consolidation and other ultrasound features of pneumonia in children with similar accuracy and reliability as CXR. Furthermore, LUS had the advantages of no radiation exposure and savings in cost and time, both in the diagnosis and follow-up ***(Shah et al., 2013; Liu et al., 2014; Reali et al., 2014; Boursiani et al., 2017; Balk et al., 2018; Biagi et al., 2018; de Souza et al., 2019; Lissaman et al., 2019)***.

We conducted a prospective longitudinal descriptive study over one year to evaluate the diagnostic performance of POCUS in the detection of pneumonic consolidations in hospitalized children compared to CXR as a reference standard.

The study included 46 consecutive patients who fulfilled the inclusion criteria. All the patients had both LUS and CXR imaging done within 24 hours of each other.

Thirty-four patients had co-morbidities (73.9%). The presence of co-morbidities was higher among non-survivors (81.8%) compared to survivors. They included cardiovascular, neurological, genetic, hepatic, renal, immunodeficiency, and nutritional co-morbidities. The presence of a chronic illness in a patient was presumed to be a risk factor for the higher mortality rate. A study done in children with pneumonia described the presence of co-morbidities in 99% of their enrolled patients reporting that non-survivors had 94% co-morbidities ***(Nurhayati et al., 2021)***. Moreover, Zhang et at. Observed that comorbid condition is a well-recognized risk factor for death due to pneumonia ***(Zhang et al., 2018)***.

Two cases were transferred to another facility due to unavailability of ICU beds. Cases admitted to MUCH and completed their follow up (N=44), with a median duration of 10 days of admission into the hospital. Forty-seven percent of children required ICU admission and mechanical ventilation (MV). The duration of MV and PICU stay were median 5.5 and 15 days, respectively. Mortality rate among cases was 25%.

Because consolidations are more likely than other findings to represent parenchymal inflammatory damage, we have chosen to evaluate pneumonic consolidations for diagnosis of pneumonia in this study.

The LUS sensitivity compared to CXR in this study to detect consolidations was 97.4%, with a positive predictive value 88.4%. Lichtenstein reported the sensitivity and specificity of LUS was 90% and 98% for alveolar consolidation ***(Lichtenstein, 2009)***. LUS has shown to be a useful tool for diagnosis of pulmonary consolidations in children ***(Barillari et al., 2011; Shah et al., 2013; Liu et al., 2014; Reali et al., 2014; Boursiani et al., 2017; Balk et al., 2018; Biagi et al., 2018; de Souza et al., 2019; Lissaman et al., 2019)***.

A systematic review done in adult hospitalized patients with acute respiratory failure, comparing LUS to CT-detected radiographic consolidation reported that the sensitivity of LUS ranged from 91% to 100%, while the specificity ranged from 78% to 100%. Two of the reviewed studies evaluated both LUS and CXR in same patients where the sensitivity of ultrasound was significantly higher than CXR ***(Hew et al., 2015)***. Another study in adult patients evaluating the accuracy of LUS for the diagnosis of consolidations in comparison with chest CT reported that LUS sensitivity and specificity were 82.8% and 95.5% for consolidations, respectively ***(Nazerian et al., 2015)***. Moreover, a systematic meta-analysis demonstrated the high sensitivity of LUS compared with CXR (92% and 53%, respectively), with specificities (91% and 78%, respectively) in the diagnosis of consolidation compared to chest CT ***(Hansell et al., 2021)***.

The agreement between LUS and CXR in consolidation detection was statistically significant ($p < 0.05$), with fair strength of agreement. The agreement between LUS and CXR in the detection of consolidation has been previously reported in children. It was found that agreement was almost perfect for consolidation with a statistically significant p-value ***(Ciuca et al., 2021)***. Another study done in Egyptian children under 5 years of age, showed a statistically significant agreement with good strength between LUS and CXR in detection of pneumonia reporting their findings in terms of consolidation detection ***(Karkar et al., 2021)***.

To our knowledge, only one study reported no agreement for consolidations ***(Smargiassi et al., 2019)***. This study was done on different cohort (adults with post-thoracic surgery), with a smaller sample size (24 patients) and for a shorter duration (2 months).

The aforementioned findings validate the efficacy of LUS and confirm that it is nearly as sensitive as CXR in the diagnosis of pneumonia. As a result, LUS is a useful imaging tool for the diagnosis of pediatric pneumonia. These results are supported by other studies ***(Pereda et al., 2015; Claes et al., 2017; Hegazy et al., 2020; Malla et al., 2021; Shams et al., 2021)***.

There are some limitations for this study. A single center study, with a relatively small sample size, hence additional extended large-scale studies are required to substantiate the findings of the current study. It is also acknowledged as a limitation the fact that the results were interpreted by a single pediatrician.

Consolidation was taken as the hallmark for pneumonia diagnosis, further studies should consider other sonographic findings related to pneumonia. Chest tomography should be considered when the results of LUS and CXR are not concordant.

Conclusion

Pneumonia is a major cause of morbidity and mortality in the pediatric population. The rapid diagnosis of pediatric pneumonia, with easy, feasible method with minimal side effects is mandatory.
In this study, LUS detected the presence of consolidations among children with pneumonia with high sensitivity and accuracy comparable to CXR as a reference standard. Thus, we suggest that POCUS can be used as the first line for the diagnosis of pneumonia in pediatric age group when available.

List Of Abbreviations

CXR; chest x-ray
LUS; Lung ultrasound
MUCH; Mansoura University Children's Hospital
MV: mechanical ventilation.
PICU: pediatric intensive care unit
POCUS: point-of-care lung ultrasonography

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