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The reliability of POCUS in the diagnosis of community-acquired pneumonia in critically ill pediatric patients: a cross-sectional study

Shereen A. Mohamed^{1*}, Hafez M. Bazaraa¹, Sally K. Ishak¹, Mohamed H. El-Ghobashy² and Maie A. Gommaa¹

Abstract

Background Community-acquired pneumonia represents a noteworthy concern in terms of morbidity and mortality, particularly in countries with lower and middle-income levels. Accurate and timely diagnosis of pneumonia is crucial for optimal management. Chest CT is considered the gold standard imaging for diagnosis of pneumonia, but it is not always readily available and exposes children to radiation hazards, so it becomes important to find easily available and less hazardous imaging tools such as lung ultrasound to diagnose pneumonia.

A comparative investigation was carried out to assess the diagnostic capability of lung ultrasound in critically ill pediatric patients presenting with respiratory symptoms. Forty-two patients with community-acquired pneumonia from the pediatric intensive care unit were included.

Results Lung ultrasound demonstrated high sensitivity (88.1%) and specificity in diagnosing pneumonia, outperforming chest X-ray (50%) and providing comparable results to chest CT (95.2%). In addition, 45.2% of patients required mechanical ventilation, and 69.1% were diagnosed with viral pneumonia.

Conclusion The employment of lung ultrasound is deemed secure, accessible, transferable, and efficacious in the expeditious detection of community-acquired pneumonia and the subsequent monitoring of patients. Its high sensitivity and specificity make it a valuable imaging modality in pediatric pneumonia diagnosis, helping clinicians make informed decisions and improve patient outcomes.

Keywords Community-acquired pneumonia, Lung ultrasound, Critically ill children

Background

Community-acquired pneumonia (CAP) is a prevalent ailment that results in the demise of numerous children under five in developing nations like Egypt, is defined as clinical signs and symptoms of pneumonia acquired outside of a hospital setting. Every year, an estimated 151.8 million individuals are diagnosed with Community-acquired Pneumonia (CAP). A fraction of 8.7% (13.1) million cases are categorized as critically ill and necessitate hospitalization [1].

Thus, early diagnosis and management of pneumonia are crucial, which is why finding quick, easy, and available tools, e.g., chest imaging, with fewer radiation side effects as lung ultrasound for early detection and intervention instead of waiting for culture results is needed.

Point of Care Ultrasound (POCUS) is a widely recognized imaging modality in adult critical care medicine, which is low-risk and non-invasive. It has been extensively studied and has gained widespread acceptance as a reliable tool for bedside imaging, enabling an intensivist to perform the procedure and interpret the results in real



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^{*}Correspondence:

Shereen A. Mohamed

shereen.mohamed@kasralainy.edu.eg

 ¹ Pediatric Department, Faculty of Medicine, Cairo University, Cairo, Egypt
 ² Radiology Department, Faculty of Medicine, Cairo University, Cairo, Egypt

time. These properties facilitate swift clinical decisionmaking, aiming to enhance patient outcomes [2].

POCUS has emerged as an indispensable diagnostic instrument in the evaluation of various bodily systems and pathologies in the context of critically ill children. Its implementation has resulted in better physical evaluations and has had a noteworthy influence on care delivery [2].

In addition, POCUS has emerged as an emerging diagnostic tool for diagnosing adult pneumonia with remarkable sensitivity and specificity. There has been a lot of interest in using lung ultrasound (LUS) to distinguish bacterial pneumonia from viral infections in recent years [3].

Despite the increasing utilization of ultrasound as a means of diagnosing and treating severely ill pediatric patients, there remain numerous challenges that must be addressed before this approach can be universally implemented in all fields, particularly in terms of education, proficiency, and uniformity of application [4].

There exists a paucity of research elucidating the function of lung ultrasound (LUS) in the timely identification of pneumonia in pediatric patients who are gravely unwell, particularly those who present with clinical bronchiolitis and exhibit signs of potential pulmonary bacterial co-infection [3].

Aim of work

The reliability of lung ultrasound at the point of care for early detection and subsequent monitoring of community-obtained pneumonia in critically ill children is being examined.

Methods

This cross-sectional study was conducted on pediatric critically ill patients admitted with community-acquired pneumonia from January 2022 to January 2023 and recruited from the pediatric intensive care unit (PICU) of the university hospital.

Inclusion criteria

The study included critically ill patients admitted to PICU with CAP and one or more system failures, e.g., severe respiratory, cardiovascular (CVS), or neurological derangement and/or multi-inflammatory syndrome. The study group age ranges from 1 month to 15 years old with both sexes included.

Exclusion criteria

Patients whose age was less than 1 month old (neonates) and patients with chronic lung disease, like cystic fibrosis and chronic interstitial lung disease were excluded. Also, patients with congenital respiratory malformation were excluded. Patients who had previous hospital admission or any antibiotics during their current illness were excluded.

All cases were concerned with initial assessment including age, gender, cause of PICU admission and duration of PICU stay, initial clinical assessment for determination of failing system, and measurement of vital signs, e.g., blood pressure index of normal for age (patient systolic or diastolic blood pressure divided by 50th percentile value for age and sex), heart rate, the respiratory rate calculated as a percentage from maximum standard value for age and sex [5].

The assessment also included initial oxygen support required including mechanical ventilation, baseline imaging techniques, e.g., chest X-ray, bedside lung ultrasound, and chest CT (CCT) when needed, and laboratory assessment, e.g., CBC (complete blood count), CRP (C-reactive protein), chemistry profile. In addition to cultures including blood, ETA (endotracheal aspirate) culture, urine, and stool cultures if infection and/ or sepsis was suspected.

Pneumonia was diagnosed using standard criteria that included clinical assessment (a juvenile displaying symptoms of coughing, respiratory distress, and a notably accelerated respiration of 50 or more breaths per minute (in the age range of 2 to 12 months) or 40 or more breaths per minute (for those aged 12 to 59 months), coupled with or without inward chest movements.

Our gold standard for pneumonia diagnosis is ETA culture and /or polymerase chain reaction (PCR) (ETA Bio Fire).

All pneumonia patients were evaluated using CPIS (clinical pulmonary infection score) (Table 1) at the time of admission and follow-up on day 2, day 7, and weekly if prolonged PICU stay.

Repeated bedside lung ultrasound examination was done within 24 h of admission, and every 3 days to check pneumonia occurrence/ improvement. Were performed with a 10-MHz linear probe of Mindray mobile trolley UMT-200 ultrasound machine made in China scanning through a standardized survey applying a six-zone scanning protocol on each edge. The technique of 12-zone scanning involves evaluating the anterior, lateral, and posterior regions of the lungs on both sides of the body. This is achieved through a scanning process that covers the apex to the base of the lungs in longitudinal and transverse directions (Fig. 1) [7].

The thoracic cavity comprises three distinct zones, namely anterior [1, 2, 5, 6], posterior [8–11], and lateral [3, 4, 7, 12] pulmonary fields. The transducer scans all regions longitudinally and transversely, encompassing both the cranial-caudal and medial-lateral planes.

Table 1 CPIS Score [6]

Patient temperature ≥ 36.5 °C and ≤ 38.4 °C (0 points) \geq 38.5 °C and \leq 38.9 °C (1 point) \geq 39 °C (2 points) ≤ 36 °C (2 points) WBC \geq 4000/mm-3 and \leq 11,000/mm^{-3} (0 points) <4000/mm-3 or $>11,000/mm^{-3}$ (1 point) $<4000/mm-3 \text{ or} > 11,000/mm^{-3} \text{ with} \ge 50 \text{ bands} (2 \text{ points})$ Tracheal secretions Absent (0 points) Present, non-purulent (1 point) Present, purulent (2 points) PaO2 (mmHg)/FiO2 > 240 or ARDS present (0 points) \leq 240 or no ARDS present (2 points) Chest X-ray No infiltrate (0 points) Patchy or diffuse infiltrate (1 point) Distinct infiltrate (2 points) Quantitative pathogenic bacterial culture growth from tracheal aspirate \leq 1 + or no growth (0 points) > 1 + (1 point)>1 + and the same bacteria were seen on the gram stain (2 points)

WBC White blood cell count, PaO2 Partial pressure of oxygen in arterial blood, Fio2 Fraction of inspired oxygen, ARDS Acute respiratory distress syndrome

Primary outcome

Surveillance of critically ill patients admitted to PICU with CAP and comparing the efficiency of different diagnostic imaging tools (chest X-ray (CXR), bedside US, and CCT) in detecting and following up pneumonia.

Secondary outcome

Outcome of CAP patients either discharge with the improvement of clinical condition from PICU or death, in addition to the determination of risk factors that affect their outcome, another outcome is the efficiency of LUS to differentiate viral from bacterial pneumonia.

Statistical analysis

Statistical analysis was conducted using IBM© SPSS© Statistics version 24 (IBM© Corp. Armonk, NY) and MedCalc[®] version 20.218 (MedCalc[®] Statistical Software version 20.218 (MedCalc Software Ltd., Ostend, Belgium; < https://www.medcalc.org>; 2023). The results are presented as mean, standard deviation, minimum, maximum, and guartiles for numerical data, and as counts and valid percentages for categorical data. The Mann-Whitney U test was used to compare skewed numerical data, and Fisher's exact test was used to compare categorical data. Time-to-event (survival) analysis was carried out using the Kaplan-Meier method, and Kaplan-Meier curves were compared using the Log-rank chi-squared test. The intermethod agreement was evaluated using Cohen's kappa (κ), bias-adjusted kappa (BAK), and prevalence-adjusted and bias-adjusted kappa (PABAK). The coefficients of the agreement are interpreted as shown in Table 2.

The accuracy of chest imaging modalities for the diagnosis of pneumonia is tested against the standard criteria. The test result is cross-tabulated versus the



Fig. 1 The recommended twelve-zone pediatric lung ultrasound scanning protocol

Table 2 Value of ĸ

Value of κ	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

gold-standard criteria and the following counts are identified: true positive (TP), false positive (FP), true negative (TN), and false negative (FN). The following indices are then calculated:

• Sensitivity (The likelihood that a test will yield a positive result when the illness is present): *sensitiv*-ity = TP/(TP + FN).

• Specificity (The likelihood that a test will yield a negative result when the illness is not present): *specificity* = TN/(TN+FP).

• Accuracy (percentage correctly classified): *accuracy* = (TP + TN)/(TP + TN + FP + FN).

■ Misclassification rate (percentage incorrectly classified): misclassification rate = (FP+FN)/(TP+TN+FP+FN).

• Positive predictive value (PPV) (The likelihood of the disease being present when the test is positive): PPV = TP/(TP + FP).

■ Negative predictive value (NPV) (The likelihood of the disease being absent when the test result is negative): NPV = TN/(TN + FN).

Two-tailed P values < 0.05 are considered statistically significant.

Results

Our research conducted a cross-sectional analysis that included a cohort of 42 pediatric patients who were critically ill and undergoing treatment at the Pediatric Intensive Care Unit of University Children's Hospital with CAP. 27 (64.3%) patients were females while 15(35.7%) were males. Patients' ages ranged from 1 month to 13 years with a median age of 0.54 years (IQR 0.20 to 1.83 years). 59.5% with viral pneumonia (Table 3).

Clinical data

Vital signs of the studied group are shown in Table 4. CPIS was higher on the day of admission and decreased in 1 week after receiving appropriate management

Table 3 Characteristics of CAP patients

Characteristics	of CAP	patients
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Variable	Frequency (percentage)
Age (years), median (IQR)	0.54 (0.20 to 1.83), range 0.08 to 12.0
Sex, N (%)	
F	27 (64.3%)
Μ	15 (35.7%)
Type of pneumonia, N (%)	
Viral	25 (59.5%)
Bacterial	17 (40.5%)

CAP Community-acquired pneumonia, IQR Interquartile range, N Number, F Female, M Male

Table 4 Vital signs on admission

Variable	Min–max	Median (IQR)
HR (% of maximum for age)	69–124	91(79–101)
SBP index	0.80-1.83	1.23 (1.03–1.83)
DBP index	0.75-1.70	1.13 (1.13–1.30)
RR (% of maximum for age)	70–156	119 (105–124)

Min. Minimum, Max. Maximum, IQR Interquartile range, HR Heart rate, SBP Systolic blood pressure, DBP Diastolic blood pressure, RR Respiratory rate

 Table 5
 CPIS score of patients during PICU stay

Min–max	Median (IQR)	
0–11	6 (3–7)	
0–10	4 (3–5)	
0–10	2 (0–4)	
	Min-max 0-11 0-10 0-10	

CPIS Clinical pulmonary infection score, Min. Minimum, Max. Maximum, IQR Interquartile range

(Table 5). For respiratory support in patients, 23 patients (54.8%) needed only nasal oxygen, while 19 (45.2%) patients required mechanical ventilation ranging from 2 to 26 days with a median of 7 days and FiO2 of a median of 60 (40-70).

Laboratory data of patients

Patients in our study had anemia with a median hemoglobin was 9.8 g/dl. CRP was positive in 34/42 patients (Table 6). 10 (23.8%) had respiratory acidosis and 14 (33.3%) had respiratory alkalosis from tachypnea (Table 7).

In CAP patients with viral pneumonia, 45.8% have RSV in ETA bio fire and COVID-19 is the second most common (29.2%). The most common bacteria in the ETA culture at admission was pneumococcus (4.8%) (Tables 8 and 9).

Table 6 Laboratory data

CBC on admission		
Variable	Min-max	Median (IQR)
Hemoglobin (g/dl)	4.0-15.8	9.8 (8.5–10.8)
TLC (k/mm ³)	0.9–28.0	14.0 (9.1–18.0)
Neutrophils I/T ratio	0.0-0.4	0.10(0-0.20)
Platelets (k/mm ³)	7–741 369(250–54	
Biochemical workup on admission		
Na ⁺ (mmol/l)	130–173	140 (136–143)
K ⁺ (mmol/l)	2.0-5.8	4.3 (4–5)
Serum creatinine (mg/dl)	0.30-1.40	0.5 (0.4–0.6)
ALT (IU/I)	3-1195	27 (17–57)
AST (IU/I)	13-781	40 (30–76)
CRP		
	Ν	Valid %
Positive CRP at admission	34	81.0%

CBC Complete blood count, *Min.* Minimum, *Max.* Maximum, *IQR* Interquartile range, *TLC* Total leucocyte count, *I/T* Immature to total neutrophils, *ALT* Alanine transaminase, *AST* Aspartate aminotransferase, *CRP* C-Reactive protein, *N* Number

Table 7 Acid–base analysis for patients

Acid-base	Acid– base at admission	
	N (%)	
Normal	4 (9.5%)	
Respiratory acidosis	10 (23.8%)	
Respiratory alkalosis	14 (33.3%)	
Metabolic acidosis	6 (14.3%)	
Metabolic and respiratory acidosis	3 (7.1%)	
Compensated metabolic acidosis	1 (2.4%)	
Compensated respiratory acidosis	3 (7.1%)	
Compensated respiratory alkalosis	1 (2.4%)	
N Number		

Table 8 Results of ETA culture on admission

ETA/sputum culture on admission	N (%)
MDR Acinetobater	1 (2.4%)
Anaerobes	1 (2.4%)
Aspergillus	1 (2.4%)
E. coli	1 (2.4%)
H. influenza	1 (2.4%)
Klebsiella	1 (2.4%)
MDR Klebsiella	2 (4.8%)
Pneumococcus	4 (9.5%)
Ps. Aeruginosa	1 (2.4%)

N Number, ETA Endotracheal aspirate, *MDR* Multi-drug resistant, *E. coli* Escherichia coli, *H. influenza* Haemophilus influenza, *Ps. Aeruginosa* Pseudomonas aeruginosa

Table 9 Results of ETA PCR (ETA Bio Fire) on admission

Variable	N (%)
ETA/sputum BioFire on admission	
Adenovirus	3 (12.5%)
SARS-CoV-2	7 (29.2%)
H1N1	1 (4.2%)
Influenza A virus	3 (12.5%)
Rhinovirus	1 (4.2%)
RSV	11 (45.8%)

N Number, ETA Endotracheal aspirate, SARS-CoV-2 Severe acute respiratory syndrome coronavirus 2 (COVID-19), RSV Respiratory syncytial virus

Table 10 Results of blood culture on admission

Blood culture on admission	N (%)
Fungus	1 (2.4%)
E. coli	1 (2.4%)
MDR Klebsiella	1 (2.4%)

N Number, E. coli Escherichia coli, MDR Multi-drug resistant

Blood culture on admission mostly shows no growth in 71.4% of CAP patients (Table 10).

Radiological data of patients

CXR, CT chest, and LUS were done for all patients admitted with CAP with only 50% (21 patients) of CXR positive for pneumonia, while the LUS was positive in 88.1% (37 patients), CT chest being most accurate was positive in 95.2% (40 patients) (Fig. 2).

In LUS 45.2% of patients showed consolidation with air bronchogram denoting bacterial pneumonia, while 54.8% showed thickened pleural line and confluent B lines denoting viral pneumonia (alveolar interstitial syndrome) while only 8% of viral pneumonia patients showed subcentric consolidation at the pleural line (Fig. 3).

Results of radiological findings of pneumonia show strong agreement between LUS and CCT being the most accurate diagnostic tool, but very weak agreement between CXR and CCT findings, it is also worth mentioning that there is a weak agreement between CXR and LUS (Table 11) (Fig. 4).

CCT shows the highest sensitivity of 95% in the diagnosis of pneumonia among CAP patients, LUS sensitivity is 88% while CXR is only 50% sensitive (Table 12).

Treatment data of patients

All patients with CAP were admitted on empirical antimicrobials according to general condition, 54.8% were



Radiological findings in patients admitted with

Fig. 2 Radiological findings in patients diagnosed with CAP

LUS findings in patients admitted with CAP



Fig. 3 LUS findings in CAP patients

admitted on ampicillin/sulbactam and amikacin as the most used combination.

Antimicrobial changes in CAP patients occur in only 54.8% of patients according to ETA, blood, culture, and/ or chest imaging, 26% of 23 patients have their antibiotics changed according to chest imaging (Tables 13 and 14).

Survival analysis of patients

The outcome of patients admitted with CAP was 78.6% discharged after improvement and 21.4% died with a median survival of 21 days from the time of admission. Survival probability decreases to 20% with a prolonged ICU stay of more than 24 days (Fig. 5).

Discussion

The prevalence of community-acquired pneumonia in childhood is most severe in regions with low- and middle-income economies. Although the number of pneumonia-related deaths has plummeted from 1.8 million in 2000 to 900,000 in 2013, the majority of these fatalities remain preventable [12].

The diagnosis of pneumonia is typically dependent on obtaining a microbiological test from the distal airways. In spite of this, there is ongoing debate regarding the reliability of such samples in distinguishing between lung parenchyma invasion and lower airway colonization. Furthermore, obtaining these samples can take up to 48 h for ultimate results. When a patient is clinically suspected of having CAP, there is no consensus on initiating antibiotic treatment, with clinical, biochemical, and imaging parameters being the primary considerations [8].

In these patients, administering antibiotics either untimely or incorrectly has been shown to escalate mortality rates. Nevertheless, excessive exposure to antibiotics can also lead to heightened morbidity/mortality and the emergence of bacterial resistance. Hence, an early and precise diagnosis of CAP must be made to strike a

Table 11 Agreement between CXR, LUS, and CC	T as regards the	diagnosis of CAP
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		LUS		
		Positive	Negative	Total
CXR	Positive	21	0	21
	Negative	16	5	21
	Total	37	5	42
Index	Estimate	SE	Lower 95% CI	Upper 95% Cl
Cohen's kappa (κ)	0.238	0.097	0.048	0.428
Bias-adjusted kappa (BAK)	0.109			
Prevalence and bias-adjusted kappa (PABAK)	0.238			
		CCT		
CXR		Positive	Negative	Total
	Positive	21	0	21
	Negative	19	2	21
	Total	40	2	42
Index	Estimate	SE	Lower 95% CI	Upper 95% Cl
Cohen's kappa (к)	0.095	0.065	-0.033	0.223
Bias-adjusted kappa (BAK)	-0.138			
Prevalence and bias-adjusted kappa (PABAK)	0.095			
		CCT		
		Positive	Negative	Total
LUS	Positive	37	0	37
	Negative	3	2	5
	Total	40	2	42
Index	Estimate	SE	Lower 95% Cl	Upper 95% Cl
Cohen's kappa (κ)	0.540	0.227	0.095	0.985
Bias adjusted kappa (BAK)	0.532			
Prevalence and bias adjusted kappa (PABAK)	0.857			

Numbers in crosstabs are counts. SE Standard error, 95% CI 95% confidence interval, CXR Chest X-ray, LUS Lung ultrasound, CCT Chest CT scan



Fig. 4 Agreement among CXR, LUS or CCT as regards pneumonia diagnosis in patients admitted with CAP. Error bars represent a 95% confidence interval (95% CI)

Table 12 Accuracy of CXR, LUS, and CCT as regards diagnosis of CAP

		CXR		Total
		Positive	Negative	
Criterion diagnosis	Positive	21	21	42
	Negative	0	0	0
	Total	21	21	42
Index	Estimate	SE	Lower 95% Cl	Upper 95% Cl
Sensitivity	50%	8%	34%	66%
Specificity	-	-	-	-
Efficiency (correct classification rate)	50%	8%	34%	66%
The predictive value of the positive test	100%	0%	84%	-
Predictive value of the negative test	0%	0%	-	16%
False positive rate	_	_	-	-
False negative rate	50%	8%	34%	66%
Misclassification rate	50%	8%	34%	78%
Prevalence	100%	0%	92%	-
		LUS		Total
		Positive	Negative	
Criterion diagnosis	Positive	37	5	42
	Negative	0	0	0
	Total	37	5	42
Index	Estimate	SE	Lower 95% Cl	Upper 95% Cl
Sensitivity	88%	5%	74%	96%
Specificity	-	-	-	-
Efficiency (Correct classification rate)	88%	5%	74%	96%
The predictive value of the positive test	100%	0%	91%	-
Predictive value of the negative test	0%	0%	-	52%
False positive rate	-	-	-	-
False negative rate	12%	5%	4%	26%
Misclassification rate	12%	5%	4%	36%
Prevalence	100%	0%	92%	-
		CCT		Total
		Positive	Negative	
Criterion diagnosis	Positive	40	2	42
	Negative	0	0	0
	Total	40	2	42
Index	Estimate	SE	Lower 95% CI	Upper 95% Cl
Sensitivity	95%	3%	84%	99%
Specificity	-	-	-	-
Efficiency (correct classification rate)	95%	3%	84%	99%
The predictive value of the positive test	100%	0%	91%	-
The predictive value of the negative test	0%	0%	-	84%
False positive rate	-	-	_	_
False negative rate	5%	3%	1%	16%
Misclassification rate	5%	3%	1%	22%
Prevalence	100%	0%	92%	-

Numbers in cross-tabs are counts. SE Standard error, 95% CI 95% confidence interval, CXR Chest X-ray, LUS Lung ultrasound, CCT Chest computed tomography scan

		N (%)
Empirical antibiotic	Meropenem and azithromycin	1 (2.4%)
	Amphotericin B	1 (2.4%)
	Ampicillin/sulbactam, amikacin, and oseltamivir	1 (2.4%)
	Ampicillin/sulbactam and gentamicin	1 (2.4%)
	Ampicillin/sulbactam and amikacin	23 (54.8%)
	Ampicillin/sulbactam and ceftazidime	1 (2.4%)
	Ampicillin/sulbactam and ceftriaxone	2 (4.8%)
	Ampicillin/sulbactam, amikacin, and clarithromycin	1 (2.4%)
	Cefepime and clarithromycin	1 (2.4%)
	Ceftriaxone	4 (9.5%)
	Ceftriaxone and azithromycin	1 (2.4%)
	Imipenem and amikacin	1 (2.4%)
	Vancomycin and meropenem	1 (2.4%)
	Vancomycin, meropenem, and fluconazole	3 (7.1%)

N Number

Table 14 Antimicrobial changes in CAP patients

	N	%
Antibiotic change	23	54.8%
Antibiotic change per ETA/sputum culture/Bio Fire	17	73.9%
Antibiotic change per blood culture	4	17.4%
Antibiotic change per chest image	5	21.7%
Reason for antibiotic change in 23 patients		
chest imaging	5	11.9%
Empirical	1	2.4%
ETA and blood culture	4	9.5%
ETA Bio Fire	1	2.4%
ETA Bio Fire and culture	1	2.4%
ETA culture	11	26.2%

N Number, ETA Endotracheal aspirate

balance between the prevention of multi-drug resistance and the reduction of mortality rates [8].

Point of care ultrasound (POCUS) is commonly employed to assess adult emergency department (ED) patients who present with respiratory distress. Standard protocols utilizing cardiopulmonary ultrasound as a guide for clinical checkups, control, and recovery are frequently used in adults. Imaging modalities that facilitate the safe and prompt evaluation of pediatric patients with respiratory complaints are crucial due to the high prevalence and potential severity of community-acquired pneumonia (CAP) disease processes. A comparative analysis of pediatric populations has shown that lung ultrasound (LUS) is just as effective as, and in some cases, superior to physical examination and chest X-ray (CXR) in diagnosing a range of respiratory tract diseases, including pneumonia, bronchiolitis, pneumothorax, pulmonary edema, acute chest syndrome, pleural effusion, and pulmonary contusion. These findings are in agreement with studies conducted in adult patients [9].

The present study aimed to evaluate the ability of lung ultrasound to diagnose community and hospital-acquired pneumonia in critically ill children.

The study population included 42 patients admitted to PICU with community-acquired pneumonia, from which 64.3% are females and 35.7% are males with a mean age of 6.5 months old. The mean age of the present study was younger than a study of 50 children of confirmed CAP with a mean age of 2.4 years. Forty-six percent were males and 54% were females [10] and another study involved 120 cases with community-acquired pneumonia, 64.4% were males, and 35.6% were females, with a mean age of 24.11 months [11] that could be explained by the fact in the present study we were concerned with critically ill CAP patients only admitted to PICU not general hospital wards as well.

In our study, a total of 42 patients were admitted with CAP, a total of 45.2% needing mechanical ventilation, out of which 38.1% needed conventional mechanical ventilation with different modes of ventilation and only 7.1% needed high-frequency ventilation with a median length of mechanical ventilation 5 days. This is different from a study of 187 children with severe CAP. A total of 94% (175) required mechanical ventilation [13]. Viral pneumonia was the most common cause of CAP (59.5%) with RSV as the most common virus followed by COVID-19, this agrees with Global data from 2015 stated that RSV is the most common viral cause of CAP [14]. COVID-19 also counts for some pediatric critical pneumonia cases



Fig. 5 Survival probability for patients admitted with CAP. Median survival (95% Cl). = 21 (11, 24) days

in the last few years as agreed with Kazi et al. stated that the proportion of SARS-CoV-2 infected children who were admitted to the pediatric intensive care unit (PICU) during hospitalization was 22.1% (92 out of 416 patients), of which 28.3% required invasive mechanical ventilation [15].

After discussing some of the demographic data of this study, the primary purpose was to compare the sensitivity of various radiological tools in the detection of pneumonia. Additionally, the study aimed to evaluate the effectiveness of chest ultrasound as a feasible, easily accessible, and reliable option for the timely diagnosis of community-acquired pneumonia (CAP) and the subsequent monitoring of patients. Chest CT has the highest sensitivity (95%), Lung ultrasound is also more sensitive (88.1%) while Chest X-ray is only 50% sensitive. This finding concurs with the discovery of Basanti et al., who have reported that lung consolidation was observed in 48 patients (with a sensitivity of 96%) through the use of chest X-ray, while 49 patients (with a sensitivity of 98%) demonstrated the same through lung ultrasound. However, the CT chest's sensitivity was even higher, with a rate of 100% [10]. Also, the findings are in conjunction with Brece et al.'s study, which revealed that lung ultrasound has a notable sensitivity (91%) regarding the detection of pneumonia in children under 12 years old [16].

CT chest is commonly deemed the optimal method for identifying pneumonia. Regrettably, its routine implementation in children is not feasible due to their higher susceptibility to radiation and associated risks compared to adults [17]. It should be mentioned that even CCT in the present study was negative in a few cases (96% sensitivity). Later after revising data with more senior radiologist staff, the report shows pneumonia in some of these negative cases while others need to repeat CCT due to bad imaging techniques, thus technical errors in reading CCT and poor imaging techniques could mislead pneumonia diagnosis.

In a study conducted by Yilmaz et al. involving a cohort of 149 children with community-acquired pneumonia (CAP), it was observed that 95.3% of the children presented with lung ultrasound (LUS) features indicative of pneumonia, whereas only 88.5% of them showed chest X-ray (CXR) features suggestive of the same. Additionally, a significant variation was noted in the diagnostic efficacy of LUS and CXR as tools to identify CAP [18]. In addition, recent meta-analyses have indicated that the employment of LUS for the diagnosis of childhood pneumonia has yielded sensitivity and specificity rates of 93.0% [95% confidence interval (CI), 88.0–96.0%] and 96.0% (95% CI, 92.0–98.0%), respectively [19].

Chen et al. have arrived at the determination that lung ultrasound (LUS) is not only valuable for identifying pneumonia in children who are hospitalized but also for forecasting the progression of the illness and the resulting outcome [20]. Hence, Musolino et al. conducted a study that centered on the benefits of a radiation-free test that is repeatable provides instant results at the bedside, and is cost-effective [21].

In the present study, it was observed that utilizing lung ultrasound (LUS) aided in the differentiation of bacterial pneumonia and viral pneumonia, despite the presence of various commonalities between the two conditions on LUS, irregular pleural line with focal consolidation of dynamic air bronchogram with or without scattered B lines more compatible with bacterial pneumonia, while alveolar interstitial syndrome (thickened pleural line, confluent B lines) with or without sub-centric pleural consolidation was more compatible with viral pneumonia, this agrees with Kharasch et al. [22]. Also, Brece et al. have published findings indicating that lung ultrasound is a highly effective diagnostic tool in detecting bacterial pneumonia in children under 12, with a sensitivity of 91% and specificity of 91.3% [16]. Nonetheless, the diagnostic accuracy of viral pneumonia through lung ultrasound was less sensitive and specific, with a recorded sensitivity of 78.4% and specificity of 90.4% [23].

To emphasize the role of chest imaging for the diagnosis of pneumonia in the present study, it was found that out of 42 patients, 23 patients had their antimicrobial regimen changed, and a total of 26% changed their antimicrobial depending on the results of chest imaging without Waiting for ETA results even in cases where CXR was negative, the decision was made depending on results of LUS and CCT.

LUS was also useful in following up on patient improvement on treatment. Musolino et al. the employment of the Lung Ultrasound Score (LUS) has been deemed a valuable instrument in monitoring the progress of pediatric pneumonia, administering treatment, and identifying potential complications at an early stage.

In the present study changing antibiotics without waiting for ETA culture was in favour of the outcome of these patients as decision delay might worsen their condition. This agrees with Xirouchaki et al. stating that LUS has a significant impact on decision-making and therapeutic management where non-invasive changes including antibiotics initiation/change occur in 38 of 253 cases depending on LUS findings. It should be mentioned that ETA culture results take 48–72 h. It also has some limitations like insufficient and contaminated samples [24].

Ultrasound, despite being relatively easy to learn, is reliant on the operator's technique, and the most accurate images are produced by expert operators. Unlike chest X-rays, lung ultrasound is unable to offer complete visualization of the lung field due to the presence of bony structures, such as the scapula and clavicle, which obstruct the view. Additionally, there are challenges in visualizing the perihilar areas. Furthermore, ultrasound may have difficulty in detecting tiny and localized parenchymal lesions that do not reach the pleura. However, it should be noted that clinically significant abnormalities, especially those requiring ICU admission, typically about the pleural line, thereby allowing for their detection by lung ultrasound in critically ill patients.

Another limitation is that reference images are typically reported by experienced radiologists, while bedside ultrasound images are analyzed by attending clinicians, which can result in different results based on the sonographic examiner's level of experience. Some experts also suggest that the type of ultrasound machine used and the quality of the images could be additional factors to consider. Despite this limitation, well-trained attending clinicians should be able to detect most cases.

It is worth mentioning that the outcome of CAP patients was 78.6% discharged after improvement and 21.4% died with a median survival analysis of a PICU stay was 21 (11, 24) days. This study resembles the research conducted by Zeeshan et al., which delved into the cases of 187 children inflicted with severe CAP. Among the cohort, a mortality rate of 20.3% was observed, with a prolonged stay in the PICU for 14 (\pm 2) days correlating with augmented fatality rates among critically ill children admitted with CAP [13].

The present study was subject to some limitations, which should be taken into account in future investigations. Given the high prevalence of the associated illness, the sample size was relatively small, as the study was conducted in a tertiary care setting and only focused on critically ill children admitted to the PICU. A lack of funding and concerns regarding the potential radiation hazards prevented the inclusion of a control group in the study. Therefore, additional research is required to evaluate the diagnostic accuracy of LUS as a screening tool for CAP in comparison with other chest conditions, such as cystic fibrosis. It is important to note that LUS is unable to visualize pulmonary abnormalities that do not involve the pleural line due to the mismatch between the acoustic impedance of air and that of soft tissue. Consequently, using LUS did not readily detect consolidation in the para-hilar lung areas, as it did for peripheral and subpleural abnormalities.

Conclusion

In conclusion, lung ultrasound can play a vital role in the diagnosis of CAP, early pneumonia, detection, and follow-up of patients' improvement. it can be an alternative to CXR and CCT in the detection of CAP. LUS can be used at the bedside easily, repetitively, and safely in terms of the dose of ionizing radiation and the need for sedation in younger infants. In the present study, the most common cause of CAP is viral pneumonia. Lung ultrasound has some advantages in distinguishing viral and bacterial pneumonia that might help in the restriction of antibiotic overuse.

Acknowledgements

The authors would like to acknowledge all the staff (the heads, managers, and workers) in the Unit of PICUs, Department of Radiology and Children's Hospitals, Faculty of Medicine, Cairo University in Egypt for making this work possible.

Authors' contributions

Professor H. B, S. I, S. M, and M. H. conceived the study and conducted its design. S. I, and M. G. coordinated the implementation of the study. M. G. helped to perform the statistical analysis, collected the data, and was responsible for interpreting laboratory and radiological data of patients. M. G. and S. M. drafted the manuscript. S. I. and S. M. revised the manuscript. All authors revised the manuscript and approved its publication.

Funding

The authors totally funded this work.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

Approval from the Research Ethics Committee of the Faculty of Medicine, Cairo University, Cairo, Egypt as governed by the ethical committee, was duly obtained. With code: MD-178–2021. Patients' guardians signed a written consent to participate in the study.

Consent for publication

Not applicable.

Competing interests

All authors declare that they have no competing interests.

Received: 16 September 2023 Accepted: 23 October 2023 Published online: 06 November 2023

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