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Article

Accuracy of Lung Point-of-Care Ultrasound (Pocus) for Diagnosing Acute Respiratory Diseases in Pediatric Intensive Care Patients

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Highlights

- Pediatric intensivists adequately trained acquire the necessary skills to realize POCUS.
- POCUS demonstrated good accuracy in diagnosing consolidation, pleural effusion, pneumothorax, and edema, when compared with chest X-ray.

Abstract: Objectives: Imaging exams are requested in intensive care units as a diagnostic, evaluation, and clinical monitoring method. While Chest Computed Tomography is the gold standard, Chest X-ray is the exam usually performed in routine care. Lung ultrasound has been gaining ground as it is a reliable exam performed at the bedside without exposure to radiation and at a low cost. This study aimed to evaluate the accuracy of bedside lung ultrasounds performed by pediatric intensivists as a diagnostic method. **Methods:** A prospective, diagnostic test-type study comparing bedside lung ultrasound performed by a pediatric intensivist with the evaluation of chest X-ray and lung ultrasound performed by a radiologist. **Result:** 48 patients on mechanical ventilation, aged from 1 month to 14 years, were analyzed, corresponding to 95 chest X-ray exams and 95 lung ultrasound exams. The Kappa agreement coefficients between the pediatric intensivist and the radiologist, both analyzing the lung ultrasound, were: normal report (1.0), atelectasis (1.0), pneumothorax (1.0), consolidation (0.97), pleural effusion (0.95), and pulmonary edema (0.90). Sensitivity, specificity, and accuracy of lung ultrasound were, respectively, normal report (50%; 91.8%; 82.1%), consolidation (88.3%; 57.1%; 76.8%), atelectasis (11.1%; 90.7%; 83.2%), edema (0; 70.2%; 70.5%), pneumothorax (83.3%; 94.4%; 93.7%), and pleural effusion (71.4%; 73%; 72.6%). **Conclusion:** The pediatric intensivist was skilled in examining and diagnosing lung injuries. Lung ultrasound showed good sensitivity, specificity, and accuracy when the pediatric intensivist performed when diagnosing consolidation, pleural effusion, and pneumothorax. Furthermore, lung ultrasound demonstrated better accuracy in evaluating pulmonary edema when compared with chest X-ray.

Keywords: pediatrics; ultrasound; lung; pediatric intensive care units; intensive care; radiography.

Introduction

Lung Ultrasound (US) has been gaining ground as an exam with good sensitivity for diagnosing lung injuries. It is available at the bedside and can be performed by the attending intensivist without radiation exposure and at a low cost. It can also be performed regularly, ensuring assessment and monitoring of the pathology[1,2].

Incorporating as a diagnostic method in clinical decisions has proven to be a dynamic and agile instrument. The physician who performs the exam is the same one who interprets and integrates this information within the clinical environment. If necessary, the examination can be repeated to identify changes associated with the interventions. POCUS can complement the medical record and physical examination, assisting in diagnosing, guiding, and directing clinical therapy. Furthermore, the exam can be performed where the patient is being treated, avoiding their displacement to other sectors[3].

Most recent studies have shown that POCUS was highly accurate for diagnosing pulmonary changes in children[2,4–7].

Our objective is to analyze the accuracy of the POCUS examination performed by pediatric intensivists as a diagnostic method for lung injuries when compared with lung US performed by radiologist physicians, in addition to comparing the findings of the POCUS performed by the pediatric intensivist with the radiologist's assessment of the chest X-ray.

Material and Methods

This prospective diagnostic test-type study was conducted in a ten-bed pediatric intensive care unit (PICU), admitting patients aged from 1 month to 14 years. With approximately 360 hospitalizations per year—30 patients per month, on average—160 are subjected to mechanical pulmonary ventilation per year. The patients admitted to this unit have a clinical, post-operative, or oncological profile. The leading cause of hospitalizations is respiratory diseases in the infant age group.

The lead researcher attended to a theoretical-practical ultrasound course in pediatric intensive care with physician specialists in lung US. After this training, data collection and lung US examinations began on patients.

The study included patients undergoing mechanical ventilation for more than 24 hours whose guardians signed an informed consent form. The researcher performed the chest X-ray and lung US, evaluating all patients taking part according to the inclusion criteria. Patients whose guardians withdrew the consent form were excluded.

Sample size was calculated to estimate the sensitivity and specificity of US in detecting changes in the lung exam, compared with the results of the chest X-ray, which is usually performed in the PICU. To this end, an 8% margin of error was defined, and initial estimates of sensitivity and specificity were defined as 83.3% and 87.5%, respectively. These estimates were obtained from the results of the first 30 patients included in the study. Under these conditions, a sample of at least 83 exams would be necessary to estimate sensitivity and specificity values, adopting a 95% confidence level.

The study variables were: general characteristics of the patients, chest X-ray, and lung US. Chest X-ray examinations were performed using Phillips mobile X-ray equipment, model Aquilla Plus 300. The following data were evaluated: lung transparency (normal, consolidation, atelectasis, and pulmonary edema) and pleura (pneumothorax and pleural effusion).

A normal chest X-ray presented lung transparency with free costophrenic sinuses. For lung consolidation, the image was opaque, causing effacement of the pulmonary vessels without significant volume loss in the affected segment. The limits were generally poorly defined, and air bronchogram images could be present. Atelectasis presented pulmonary opacity, with a reduced volume of the affected segment and displacement of the pulmonary hilum towards the affected area. The image of pulmonary edema showed the margins of the vessels with poorly defined limits. The vessels at the apexes were wider, and the circulation was visible to the periphery, with a diffuse increase in density in the hilar regions, and Kerley lines could appear. The pneumothorax presented a hypodense image without pulmonary vessels and a thin radiopaque line parallel to the chest wall, corresponding to the visceral pleura. Depending on the size of the pneumothorax, there could be contralateral deviation of the mediastinal structures. Finally, the pleural effusion presented effacement of the costophrenic sinus due to a hyperdense image[2].

The study used a Philips ENVISOR C Version C.0.2 ultrasound equipment, preset Small parts – superficial, with the L12-3 10-12 MHz linear transducer.

The diagnostic findings considered by lung US were:

Normal: association of pleural sliding with horizontal repetitions of the pleural line called "A-lines." The normal pattern, when viewed in M mode, is represented by the "seashore sign" image with a linear pattern that corresponds to the chest wall and does not present motion, just below a hyperechogenic line that is the pleura followed by a homogeneous granular pattern generated by respiratory cycles and air movement.

Consolidation: echogenicity structure of solid tissues with hyperechogenic punctate images, which may vary in size, shape, and location, corresponding to the air bronchogram finding.

Atelectasis: loss of aeration, generating an area of visible, hyperechogenic parenchyma, which may have ill-defined and irregular edges.

Pulmonary edema: the presence of pleural sliding and B-lines, which arise due to the thickening of the interlobular septa and a reduction in peripheral aeration. B-lines are vertical artifacts—which can be multiple in the same intercostal space—hyperechogenic, originating from the pleural line and extending to the end of the screen, erasing the A-lines at their intersections. The B-lines motion in synchrony with the respiratory cycle. Although their presence can be detected in normal lungs, their number is directly related to the degree of thickening of the interlobular septa and the reduction in lung aeration.

Pleural effusion: characterized by a hypoechogenic image. Echotexture will be evaluated if it is anechoic or suggestive of transudate. Presence of hyperechoic fibrous particles or beams: suggestive of exudate or hemothorax.

Pneumothorax: absence of pleural sliding and presence of A-lines; on M-mode US, presence of multiple horizontal bands of hyperechoic artifacts, mimicking a barcode ("barcode sign"), and presence of lung point, which represents the visualization of the aerated lung expanding at the site of the pneumothorax.

In the chest X-ray, both the official report carried out by the hospital radiologist and the report carried out by the pediatric intensivist were considered. The X-ray considered for the study was the chest X-ray performed on the same day as the lung US.

In patients who met the inclusion criteria, lung US was performed independently by the radiologist and the researcher. The same patients were evaluated more than once on different days when they still met the inclusion criteria, with each evaluation on the same patients considered a new exam.

Lung US exams were performed exclusively by the lead researcher , i.e., the intensivist, and always by the same radiologist. Each person carried out their report without interference from either side. The exams were carried out at the same time of day. The pediatric intensivist and the radiologist were blinded when performing the chest US. They also did not know the patient's clinical history before performing US. The chest X-ray was examined by other radiologists who did not know the result of the lung US and did not know the patient's clinical history.

The lung was scanned in the anteroposterior, craniocaudal, transverse, and longitudinal direction to the costal arches. The exams were initially performed with the patient in the dorsal decubitus position at zero degrees, lateralized to evaluate the posterior lung region.

All data was collected and recorded exclusively by the researcher and subsequently typed into an electronic spreadsheet, checked, and exported to the Stata v.14 statistics program.

Continuous variables were evaluated regarding their distribution. They were presented as mean and standard deviation for continuous variables with normal distribution and minimum and maximum median for those with asymmetric distribution. Frequencies and percentages described categorical variables. Kappa coefficients were estimated to assess the agreement between the two raters (intensivist and radiologist) regarding the evaluations performed via X-ray and US.

Sensitivity, specificity, and accuracy values were estimated to analyze the quality of the US, considering the X-ray result as the standard usually used in the PICU.

Values of $p<0.05$ indicated statistical significance, and 95% confidence intervals were presented for all estimated coefficients. The Research Ethics Committee of the Hospítal das Clínicas of the

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Federal University of Paraná approved the study, registered on Plataforma Brasil with the Certificate of Presentation of Ethical Appreciation number 89782618.9.0000.0096.

Results

The study sample comprised 48 patients who underwent mechanical ventilation during the study period, with 95 lung US examinations performed. No patient was excluded from the sample. The distribution of patients and exams was the following:

a) 26 patients underwent only one examination;
b) 12 patients underwent the exam twice;
c) four patients underwent the exam three times;
d) three patients underwent the exam four times;
e) one patient underwent the exam six times;
f) one patient underwent the exam seven times;
g) one patient underwent the exam eight times.

The median age of the patients was 17 months; 31 were male (64.6%), and 17 were female (35.4%). Patient mortality was 12.5% (six patients). Of the patients' admission diagnoses, 37 had respiratory diseases, six had post-operative diseases (three abdominal and three neurological), four had abdominal diseases, and one had Central Nervous System (CNS) disease (Table 1).

Table 1. General characteristics of patients.

Characteristic	n = 48
Age (months)[1]	17 (1 – 147)
Sex[2]	
Female	17 (35.4 %)
Male	31 (64.6%)
Mortality[2]	6 (12.5%)
Admission Diagnosis[2]	
Lung diseases	37 (77.1%)
Post-operative	6 (12.5%)
Abdominal diseases	4 (8.3%)
CNS diseases	1 (2.1%)

Source: The author (2021). Note: [1]values described in median, minimum, and maximum; [2]values described in frequency and percentage.

Nineteen patients had no comorbidities, and 29 had some, as detailed in Table 2.

Table 2. Comorbidities of patients in the sample.

Comorbidity	n = 48[1]
No comorbidity	19 (39.6%)
Pulmonary broncho-dysplasia	4 (8.3%)
Congenital microcephalies	3 (6.3%)
Esophageal atresia	2 (4.2%)
Cerebral palsy	2 (4.2%)
Down syndrome	2 (4.2%)
West syndrome	1 (2.1%)
Apert syndrome	1 (2.1%)
Lennox Gastaut syndrome	1 (2.1%)

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Wolf Hirschhorn syndrome	1 (2.1%)
Fragile X syndrome	1 (2.1%)
Suspected inborn error of metabolism	1 (2.1%)
Cystic fibrosis	1 (2.1%)
Glottic stenosis	1 (2.1%)
Asthma	1 (2.1%)
Congenital diaphragmatic hernia	1 (2.1%)
Congenital intestinal atresia	1 (2.1%)
Intestinal post-enterocolitis stenosis	1 (2.1%)
Acute myeloid leukemia	1 (2.1%)
Acute lymphoblastic leukemia	1 (2.1%)
Retinoblastoma	1 (2.1%)
Chronic renal failure	1 (2.1%)

Source: PrThe author (2021). Note: [1] values described in frequency and percentage.

Table 3 presents the frequencies and percentages of cases according to the assessments of the intensivist and the radiologist, with lung US being evaluated. The frequencies and percentages of concordant and discordant cases and the Kappa agreement coefficients are also presented.

Table 3. Evaluation of the kappa agreement coefficient between intensivist and radiologist regarding ultrasound evaluations.

PARAMETER	%	KAPPA (95% CI)	KAPPA INTERPRETATION
US - NORMAL			
Agreement	100%	1.0	Very good
Disagreement	--	(0.8–1.0)	
US - CONSOLIDATION			
Agreement	98.9 %	0.97	Very good
Disagreement	1.1%	(0.77–1.0)	
US - ATELECTASIS			
Agreement	100%	1.0	Very good
Disagreement	--	(0.8–1.0)	
US - EDEMA			
Agreement	95.8%	0.90	Very good
Disagreement	4.2%	(0.70–1.0)	
US - PNEUMOTHORAX			
Agreement	100%	1.0	Very good
Disagreement	--	(0.8–1.0)	
US - EFFUSION			
Agreement	97.9%	0.95	Very good
Disagreement	2.1%	(0.75–1.0)	

NOTE: Values described in frequency and percentage

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Table 4 presents the frequencies and percentages of cases according to the assessments of the intensivist and the radiologist, with the chest X-ray being evaluated. The frequencies and percentages of concordant and discordant cases and the Kappa agreement coefficients are also presented.

Table 4. Evaluation of agreement between intensivist and radiologist regarding radiography evaluations.

PARAMETER	%	KAPPA (95% CI)	AGREEMENT
X-RAY - NORMAL			
Agreement	95.8%	0.87	Very good
Disagreement	4.2%	(0.67–1.00)	
X-RAY – CONSOLIDATION			
Agreement	84.2%	0.64	Good
Disagreement	15.8%	(0.44–0.84)	
X-RAY - ATELECTASIS			
Agreement	90.5%	0.52	Moderate
Disagreement	9.5%	(0.32–0.72)	
X-RAY - EDEMA			
Agreement	85.5%	0.11	Poor
Disagreement	14.8%	(0.01–0.21)	
X-RAY - PNEUMOTHORAX			
Agreement	96.8%	0.75	Good
Disagreement	3.2%	(0.55–0.95)	
X-RAY - EFFUSION			
Agreement	89.5%	0.69	Good
Disagreement	10.5%	(0.49–0.89)	

NOTE: Values described in frequency and percentage;

Table 5 presents the indices observed to evaluate the sensitivity, specificity, and accuracy of the US examination by the intensivist, using the X-ray report by the radiologist as the gold standard.

Table 5. Diagnostic test indexes for evaluating the accuracy of ultrasound examination in the intensivist's evaluation.

EVALUATION	S	95% CI	E	95% CI	A	95% CI
US - normal	50.0	29.1–70.9%	91.8	85.5–98.1%	82.1	74.4–89.8%
US - consolidation	88.3	80.2–96.5%	57.1	40.7–73.5%	76.8	68.4–85.3%
US - atelectasis	11.1	0-31.6%	90.7	84.6–96.8%	83.2	75.6–90.7%
US - edema	-	-	70.2	61–79.5%	70.5	61.4–79.7%

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US - pneumothorax	83.3	53.5–100%	94.4	89.6–99.2%	93.7	88.8–98.6%
US - pleural effusion	71.4	52.1–90.8%	73	62.9–83.1%	72.6	63.7–81.6%

NOTE: Values described in frequency and percentage; S = Sensitivity; E = Specificity; A = Accuracy; CI = Confidence interval.

The Kappa agreement coefficients between the intensivist's US and the radiologist's US showed very good agreement. Therefore, a comparative table was not created between the radiologist's lung US and X-ray report.

Discussion

In this series, the interrater agreement in the assessment of the chest X-ray was very good, especially if the chest X-ray was considered normal (Kappa 0.87). In the radiological changes of consolidation, pneumothorax, and pleural effusion, there was also good interrater agreement, as also found by Test[8] and Voigt[9]. Hopstaken[10] reinforces that the interrater agreement of chest X-ray images is greater when the report is normal than when any change alteration is observed.

However, there was no good correlation when evaluating the presence of pulmonary edema. In diagnosing pulmonary edema, the Kappa agreement coefficient was very poor when assessed by chest X-ray. Such outcome is related to diverging assessments between the pediatric intensivist and the radiologist; while the former described the presence of pulmonary edema, the latter did not. Despite defined criteria for identifying pulmonary edema on chest X-ray, significant interrater variability is still described [9,11].

Therefore, considering the interpretative variability of chest X-rays, we conclude that we cannot rely solely on this exam to define the diagnosis of lung lesions. According to Nesterova[12], this agreement could be improved if daily discussions with the radiology team were feasible.

Despite being one of the most used imaging tests in the PICU routine, chest X-rays have a significant interrater interpretation variability. Also, it exposes the patient and the team to ionizing radiation[1,10,13,14]. As a result, POCUS has been gaining ground in the PICU routine as it is a safe and validated tool, highly sensitive and specific when compared with chest X-rays to differentiate the causes of respiratory failure. Furthermore, the numerous benefits of POCUS in the pediatric setting include the absence of ionizing radiation, immediate reporting, time optimization at the seriously ill child's bedside, and ease of serial assessments. POCUS can be used to support diagnosis, evaluate complications, and monitor patient progress[15].

Xin and Hu *et. al.*[16] describe in their meta-analysis that even in a short training period, it is possible to detect lung lesions using POCUS, with a 93% sensitivity and 96% specificity. Millington[17] found that great part of the learning curve of the POCUS occurs during the first 25–30 exams performed.

For this study, the lead researcher carried out a total of 84 hours of training, of which 20 hours were theoretical-practical courses and 64 hours were in-service training. In this series, the Kappa agreement coefficient had very good agreement when comparing the ultrasounds performed by the pediatric intensivist with those of the radiologist in all findings of pulmonary changes. This demonstrates that, provided that pediatric intensivists are adequately trained, they acquire the necessary skills to perform this examination. The long training period of the lead researcher may have contributed to the very good agreement shown in all lung changes.

When evaluating lung consolidation, pleural effusion, and pneumothorax, lung US showed high sensitivity and specificity compared with chest X-ray. These data agree with those found in the literature[2,18-20].

When evaluated by chest X-ray, pulmonary edema showed a poor Kappa agreement coefficient. However, when evaluated by lung US, it showed very good agreement (Kappa 0.97). Such outcome is probably related to both the pediatric intensivist and the radiologist identifying pulmonary edema in the lung US. Thus, we can suggest that lung US performed better when compared with chest X-ray for evaluating this diagnosis by the intensivist[20,21].

Assaad[22] found high accuracy, with sensitivity and specificity > 90%, when correlating the B-line finding on lung US as a marker of pulmonary edema, compared with other classic methods of evaluating pulmonary edema, such as chest CT and chest X-ray. Furthermore, the linear correlation between the number of B-lines and the amount of excess water in the pulmonary extravascular space and clinical pulmonary edema is well known. It may provide a useful clinical tool in the daily assessment of pulmonary edema[21].

As it is safe for both the patient and the team, lung ultrasound can be performed daily, which allows for monitoring the patient's progress, with the advantage of being performed by the pediatric intensivist at the bedside in a precise, quick, and safe manner. Jones[23] considers POCUS a valid alternative to replace chest X-rays. Iorio[24] promotes POCUS as the first-choice exam.

However, an adequate lung assessment employing ultrasound requires evaluating the entire circumference of the patient's chest. In the intensive care environment, a complex case would be a hemodynamically unstable patient who cannot tolerate postural changes, making it impossible to evaluate the entire lung parenchyma. There are also technical difficulties in patients with large dressings occupying a significant area of the chest, which does not enable evaluating the entire lung parenchyma[25]. However, these difficulties can be overcome by evaluating the patient more than once and examining each change in position, i.e., evaluating the lung parenchyma in parts. In the case of dressings, if necessary, examine at the time of change.

As an imaging method that has been increasingly used in intensive care units, as it requires a short learning curve and because it is safe and effective, it is essential that this knowledge must be trained during medical residency[26].

The main limitation of this study is using chest X-rays as the gold standard. However, obtaining a chest Computed Tomography was impossible for obvious ethical reasons. Among the other limitations of this study is the significant variability in age range. While the median age was 17 months, the study group ranged from 1 month to 147 months. In the outcomes analysis, there was no differentiation between fully developed and developing lungs. However, lungs at different stages of development may have different interpretations, mainly when evaluated by chest X-ray.

Patients with comorbidities were included, including patients with chronic lung disease, such as cystic fibrosis. The patient's previous illness could alter the interpretation of the chest X-ray and lung US, and some findings could be related to the patient's comorbidity and not caused by an acute injury.

No score was used for the interpretation of lung US. In this study, lung US findings were analyzed, and in pediatrics, there is still no established score, and most studies in pediatrics do not use scores to interpret lung US.

Conclusion

When evaluating lung US, the Kappa coefficient of the agreement had a very good agreement when comparing the pediatric intensivist's POCUS with the radiologist's US in all findings of pulmonary changes.

The pediatric intensivist and the radiologist agreed on the chest X-ray, with a report considered normal, and there was a presence of pulmonary consolidation, pleural effusion, and pneumothorax. There was no good agreement between the pediatric intensivist and the radiologist in determining pulmonary edema using chest X-rays.

Compared with chest X-ray, POCUS showed high sensitivity and specificity when diagnosing consolidation, pleural effusion, and pneumothorax. The intensivist's POCUS demonstrated better performance in diagnosing pulmonary edema when compared with chest X-ray.

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Abbreviations List

US - Lung Ultrasound
POCUS - Point of Care Ultrasound
PICU - pediatric intensive care unit
CNS- Central Nervous System

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