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Point-of-care lung ultrasound in children with non-cardiac respiratory distress or tachypnea

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ABSTRACT

Objective: The purpose of this study was to evaluate the feasibility and diagnostic benefit of point-of-care ultrasound (PoCLUS) in children with non-cardiac respiratory distress or tachypnea.**Methods:** In this prospective observational study, children aged between 1 month and 18 years with respiratory distress, tachypnea, or both, at triage were included. Concordance and accuracy of the emergency department (ED) and ultrasound diagnoses, length of stay, and time elapsing until ED and ultrasound diagnoses were calculated.**Results:** One hundred forty-five patients were evaluated. The mean age of the children in the study was 67 ± 58 months. Seventy-nine patients (56%) were boys. Mean length of stay in the ED was 124.6 ± 76.5 min. Mean time to ultrasound diagnosis was 29.32 ± 15.71 min, compared to 46.75 ± 32.65 min for ED diagnosis, which was significantly longer ($p < 0.001$). Concordance between ultrasound and ED diagnoses was almost perfect for pneumonia, acute bronchiolitis, asthma and croup ($0.8 < \kappa < 1$), and good for other non-pulmonary causes ($0.6 < \kappa < 0.8$). Overall concordance for all diagnoses was also good ($\kappa = 0.76$). Ultrasound diagnosis was more sensitive than ED diagnosis for pneumonia, acute bronchiolitis, and other non-pulmonary causes (81.4%–74.42%; 97.3%–86.49%; and 100%–95.83%, respectively). In addition, ultrasound diagnosis was more specific than ED diagnosis for pneumonia, acute bronchiolitis and other non-pulmonary causes (100%–97.35%; 99.07%–98.15%; and 93.39%–88.43%, respectively). However, ultrasound and ED diagnoses exhibited similar sensitivity and specificity values for asthma (97.22%–97.22%; and 99.08%–100%).**Conclusion:** PoCLUS may constitute a beneficial and rational approach in the evaluation of children with increased work of breathing in the ED, and can also expedite the diagnostic process.

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1. Introduction

Pulmonary emergencies are some of the most common conditions encountered in pediatric emergency departments. Approximately 10% of children presenting to the pediatric emergency department are evaluated due to respiratory distress, representing 20% of causes of hospitalization [1]. Severe respiratory distress may be a precursor of respiratory failure. However, respiratory failure may sometimes occur without findings of respiratory distress. Rapid and accurate diagnosis is therefore required for early and appropriate treatment in the ED. At the same time, mortality and morbidity can be reduced by averting preventable complications.

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Respiratory distress or tachypnea are common or prominent symptoms of several diseases, and it may sometimes be difficult for the ED physician to quickly identify the underlying pathological condition. The clinician may suspect some diseases after careful history taking and comprehensive physical examination, and possible diagnoses can be supported by laboratory tests and imaging. However, time is required for clinical evaluation and diagnosis. Since respiratory problems are the most common cause of cardiac arrest in children, a delay in diagnosis and during patient management can have irreversible consequences. In addition, children with respiratory distress or tachypnea are usually assessed using an imaging technique. The first imaging technique applied is generally chest X-ray. However, the use of chest X-ray is limited since it causes exposure to radiation, it requires attendance at another unit outside the ED for non-critically ill patients, point-of-care images are not of optimal quality in critical patients, and due to

the possibility of misinterpretation. Although thoracic tomography has a high capacity for identifying causes at differential diagnosis, it is not generally employed for children for reasons such as high radiation exposure, cost, and being unfeasible in unstable patients.

Point-of-care ultrasound is widely employed as a diagnostic tool in several clinics, including the ED. It can easily be employed at the bedside in the ED, and is used as a complementary technique to physical examination by providing information about both anatomy and function. This permits early and accurate diagnosis and appropriate treatment or management.

Lung ultrasound has been reported to be diagnostically sensitive and as specific as chest x-ray and to be capable of effective use in various respiratory tract diseases, including pneumonia, acute bronchiolitis, asthma, pneumothorax, pulmonary edema, pleural effusion, pulmonary contusion, and ventilator-associated pneumonia [2–11].

Based on the above, there is a need for rapid and accurate point-of-care management in children with respiratory distress or tachypnea in the ED, and for a method, algorithm or diagnostic modality, or combinations thereof, that can permit early initiation of targeted treatment. Point-of-care lung ultrasound (PoCLUS) may be a promising candidate in meeting this need. The purpose of this study was to evaluate the feasibility and diagnostic benefit of PoCLUS in children with non-cardiac respiratory distress or tachypnea.

2. Method

2.1. Design, setting, protocol, and population

This prospective, observational study was performed between August 2017 and September 2018 at the Trabzon Kanuni Teaching and Research Hospital Numune Campus Pediatric Emergency Department, Turkey, which receives approximately 140,000 presentations a year. The study protocol was approved by the Health Sciences University Trabzon Kanuni Teaching and Research Hospital local ethical committee. Informed consent was received from the parents or legal guardians of all children in the study.

All patients arriving at the pediatric emergency department were assessed in the triage area and differentiated on the basis of symptoms, vital sign findings, and short medical histories. All children (aged <18 years) with respiratory distress, tachypnea or a combination of both were included in the study. All patients in whom life-threatening conditions (seizures etc.), approaching cardiac arrest due to respiratory failure, receiving cardiopulmonary resuscitation, in advanced shock, who had presented with similar symptoms and had received treatment within the previous month, with underlying chronic lung disease (such as cystic fibrosis, primary ciliary dyskinesia, or bronchiectasis), newborn patients (<1 month), pregnant subjects, patients presenting due to trauma, or with structural anomalies representing an obstacle to thoracic ultrasonography at the beginning of the study, or with respiratory distress of cardiac origin identified during or after the study were excluded.

The patient was first evaluated by the treating physician using vital sign findings, medical history and physical examination. Blood specimen analysis, chest X-ray, computed tomography, and electrocardiograms were planned when necessary. A cardiologist was consulted in cases of suspected tachypnea or respiratory distress of cardiac origin during patient management. The treating physician produced an ED diagnosis by examining all data with the exception of lung ultrasound findings. Lung ultrasound was performed by a pediatric emergency physician (sonographer) (AKÖ) working 40 h per week in the pediatric emergency department, who had received theoretical and practical training, and with

at least 2 years' experience and 200 previous lung ultrasound applications. The sonographer carried out the lung scanning independently of the ED physician and blinded to the patient's information, and produced a specific ultrasonographic diagnosis (such as pneumonia, pleural effusion, asthma, pneumothorax and bronchiolitis) or other non-pulmonary diagnosis (psychogenic dyspnea, metabolic disorder, neurological disease, febrile reaction, pain, etc.) following ultrasonographic examination in full knowledge of the initial assessment (vital findings, medical history and physical examination) for all children. If the sonographer didn't have a specific ultrasonographic diagnosis, he then had access to all the patient information to arrive at a non-pulmonary diagnosis. A maximum of two inter-related diagnoses were present for each patient. Final diagnosis was made by an independent pediatrician on the basis of history, physical examination, clinical file data, laboratory findings, ultrasonography and radiological imaging data. The pediatrician was not aware of the sonographer's interpretation of the ultrasound and the ED diagnosis. Length of stay in the ED, time elapsed to ultrasonography, and time to final diagnosis were recorded for each patient. Final diagnosis was regarded as the gold standard diagnosis and was compared with the ED and ultrasound diagnoses.

2.2. Lung ultrasound evaluation

PoCLUS was performed using a device with 5–10 MHz linear and 2.5–5 MHz curved probes (Mindray M5, Mindray, P.R.C.). Longitudinal and oblique scans of the anterolateral and posterior pulmonary regions were performed with the patient in a supine or nearly supine position, or seated or in the mother's lap when necessary. Sonographic findings in the lungs were first determined in line with the information in our study and with 'International evidence-based recommendations for point-of-care lung ultrasound' [4,10]. Consolidated areas with air bronchograms with or without fluid bronchograms and/or accompanying focal interstitial syndrome were interpreted as pneumonia. The presence of an anechoic area between the pleural leaves was interpreted as pleural effusion, while absence of lung pulse, lung sliding and B lines together with a lung point sign were interpreted as pneumothorax. Decreased or absence of lung sliding together with subpleural anterior consolidations and occasional preserved areas were interpreted as pleural irregularity, and occasional consolidated areas with multiple consolidated B-lines as ARDS/acute lung damage, while the supporting medical history and clinical evaluation without a specific sonographic lung pattern, lung ultrasound images were interpreted as asthma or, as in our previous study, acute bronchiolitis [5,6,12]. Croup was suspected with clinical evaluation in the absence of a specific lung scan finding, or in the presence of lung ultrasound findings such as bronchiolitis. Patient data and ultrasound findings were collected on standardized forms.

2.3. Data analysis and sample size calculation

Constant variables were expressed as mean \pm standard deviation or median (interquartile range) values, and continuous variables as number and percentage values. Normally distributed variables were compared using the unpaired Student *t*-test, while non-normally distributed and non-continuous data were compared using the Mann Whitney *U* test or Wilcoxon's Signed Ranks test. Sensitivity, specificity, positive predictive values, negative predictive values and likelihood ratios were calculated for PoCLUS and ED diagnostic performance. Concordance between diagnostic methods was calculated using Cohen's kappa (κ) coefficient. κ values between 0.21 and 0.40 were considered fair agreement, 0.41 to 0.60 moderate agreement, 0.61 and 0.80 good agreement, and 0.81 to 1.0 almost perfect agreement [13]. Statistical analysis was per-

formed on IBM SPSS Statistics for Windows version 21.0 software. *p* values <0.05 were regarded as statistically significant.

The sample size required was calculated based on the rates of agreement between the two diagnostic methods. We predicted that a minimum sample size of 133 patients would be required when minimum agreement of 0.70, $\beta = 0.20$, and $\alpha = 0.05$ were adopted for all ED and ultrasonographic diagnoses [14].

3. Results

One hundred fifty-three children were initially included in the study. Eight of these were subsequently excluded for reasons such as presence of cardiac diseases, shock, presentation with similar symptoms in the preceding month, or chronic lung disease. The study was thus completed with 145 children. The mean age of the children enrolled was 67 ± 58 months, median age was 52 months (IQR, 15–100 ay), and 79 (56%) were boys. The clinical characteristics of the patients in the study are shown in Table 1. Chest x-ray was performed on 120 (82.8%) patients during the study period. Lung scans with PoCLUS were performed on all patients. Mean time to lung ultrasound was 6.07 ± 3.92 min, and median time was 4.5 min (IQR: 2.5–7.1). Mean length of stay in the ED was 124.6 ± 76.5 min, with a median value of 110 min (IQR: 75–150). Time elapsing until ED diagnosis was 46.75 ± 32.65 min, and mean time elapsing to ultrasonographic diagnosis was significantly shorter, at 29.32 ± 15.71 min ($p < 0.001$).

Causes of increased work of breathing by ultrasound, ED and final diagnoses are shown in Table 2. Concordance was calculated between ED and ultrasound diagnoses. Concordance was almost perfect for pneumonia, acute bronchiolitis, asthma and croup ($0.8 < \kappa < 1$). Overall concordance for all diagnoses and specific concordance of non-pulmonary causes was good ($0.6 < \kappa < 0.8$) (Table 3). The diagnostic performances of ultrasound and emergency diagnoses were compared with the final diagnosis. Ultrasound diagnosis was more sensitive and specific than ED diagnosis for pneumonia, acute bronchiolitis and other non-pulmonary causes (Tables 4 and 5). However, ultrasound and ED

Table 1
Characteristics of the children in the study.

Characteristics	Value
Age, mean \pm SD, years	5.5 \pm 4.8
Sex	
Male, n (%)	79 (56)
Female, n (%)	66 (44)
History of fever, n (%)	82 (57)
Fever at triage, n (%)	26 (18)
Cough, n (%)	136 (94)
Wheezing or rale, n (%)	98 (68)
Phlegm, n (%)	30 (21)
Thoracic pain, n (%)	27 (19)
Rhinorrhea, n (%)	112 (77)
Duration of symptoms, days	3.5
Duration of fever, days	1.3
Accompanying disease, n (%)	25 (17)
History of URTI, n (%)	105 (72)
Parental smoker in the home, n (%)	63 (43)
History of atopia, n (%)	21 (15)
Impaired nutrition, n (%)	18 (12)
Systolic blood pressure, mm Hg	100.7
Diastolic blood pressure, mm Hg	62.6
Heart rate, beats/min	121.4
Respiration rate, breaths/min	37
Body temperature, °C	37
SaO ₂ , %	96.6

SD: standard deviation, SaO₂: oxygen saturation, URTI: upper respiratory tract infection.

Table 2

Causes of increased work of breathing by ultrasound, emergency department, and final diagnoses (n = 145).

Diagnoses	Ultrasound diagnosis	Emergency department diagnosis	Final diagnosis
Pneumonia	35	35	43
Acute bronchiolitis	37	34	37
Asthma	36	35	36
Croup	3	2	3
Pneumothorax	1	1	1
Diaphragmatic hernia	1	1	1
Other non-pulmonary causes	32	37	24

Table 3

Concordance between ultrasound and emergency department diagnoses.

Diagnosis	κ
Pneumonia	0.81
Acute bronchiolitis	0.83
Asthma	0.94
Croup	0.80
Other, non-pulmonary causes	0.61
Total	0.76

Kappa analysis: $0.8 < \kappa < 1$ almost perfect concordance, $0.6 < \kappa < 0.8$ good concordance.

diagnoses exhibited similar sensitivity and specificity for asthma (97.22% vs 97.22, and 99.08% vs 100%, respectively).

4. Discussion

In terms of the first of our study aims, we investigated the feasibility of PoCLUS in children presenting to the pediatric emergency department due to increased work of breathing with non-cardiac origin. Another aim was to determine the benefit of PoCLUS at differential diagnosis in children with tachypnea or respiratory distress of non-cardiac origin. Accurate and rapid identification of the causes of dyspnea in children may sometimes be problematic for emergency physicians. In addition, there is no ideal test capable of identifying pulmonary emergencies. Lung ultrasound, a promising and proven method in some areas, is increasingly used in the evaluation of patients with respiratory tract diseases in the ED [3,5,12,15–18]. In our study, ultrasound and ED diagnosis exhibited good concordance in total, and almost perfect concordance in terms of pneumonia, acute bronchiolitis and asthma. Additionally, PoCLUS exhibited higher specificity and sensitivity than ED diagnosis in determining pneumonia, acute bronchiolitis and non-pulmonary causes. The most common cause of increased work of breathing in our study population was pneumonia (29% of diagnoses). One recent meta-analysis reported that lung ultrasound exhibited lower specificity in determining pneumonia than in our study, but higher sensitivity (92.48% vs 100% and 93.16% vs 81.4%, respectively) [8]. One important reason for this may be that other studies generally compared the effectiveness of lung ultrasound with that of chest X-ray. However, chest X-ray is not routinely recommended in determining pneumonia and is not a gold standard diagnostic technique.

Similarly to pneumonia, ultrasound diagnosis exhibited greater sensitivity and specificity in determining acute bronchiolitis than ED diagnosis (97.3% vs 86.49% and 99.07% vs 98.15%, respectively). In contrast to Varshney et al.'s report, we observed significantly high sensitivity and specificity for ultrasonographic diagnosis of acute bronchiolitis (46% and 72.7% vs 97.3% and 99.07%, respectively) [16]. Varshney et al. included patients younger than two years with respiratory tract infection and wheezing and without

Table 4
Diagnostic accuracy of emergency department diagnosis.

Diagnoses	Sensitivity, % (95% CI)	Specificity, % (95% CI)	PPV, % (95% CI)	NPV, % (95% CI)	+LR (95% CI)	–LR (95% CI)
Pneumonia	74.42 (58.83–86.48)	97.35 (92.44–99.45)	91.43 (77.5–97.06)	90.91 (85.72–94.34)	28.03 (9.05–86.78)	0.26 (0.16–0.43)
Acute bronchiolitis	86.49 (71.23–95.46)	98.15 (93.47–99.78)	94.12 (80.12–98.45)	95.5 (90.3–97.96)	46.7 (11.76–185.43)	0.14 (0.06–0.32)
Asthma	97.22 (85.47–99.93)	100 (96.67–100)	100	99.09 (94.04–99.87)	–	0.03 (0–0.21)
Non-pulmonary causes	95.83 (78.88–99.89)	88.43 (81.35–93.53)	62.16 (49.92–73.03)	99.07 (94.01–99.86)	8.28 (5.02–13.65)	0.05 (0.01–0.34)

PPV: positive predictive value, NPV: negative predictive value, +LR: positive likelihood ratio, –LR: negative likelihood ratio, CI: confidence interval.

Table 5
Diagnostic accuracy of ultrasound diagnosis.

Diagnosis	Sensitivity, % (95% CI)	Specificity, % (95% CI)	PPV, % (95% CI)	NPV, % (95% CI)	+LR (95% CI)	–LR (95% CI)
Pneumonia	81.4 (66.6–91.61)	100 (96.45–100)	100	92.73 (87.22–95.97)	–	0.19 (0.1–0.36)
Acute bronchiolitis	97.3 (85.84–99.93)	99.07 (94.95–99.98)	97.3 (83.64–99.61)	99.07 (93.93–99.86)	105.08 (14.93–739.76)	0.03 (0–0.21)
Asthma	97.22 (85.47–99.93)	99.08 (94.99–99.98)	97.22 (83.25–99.6)	99.08 (93.99–99.87)	105.97 (15.05–746.12)	0.03 (0–0.21)
Non-pulmonary causes	100 (85.75–100)	93.39 (87.39–97.1)	75 (60.56–85.42)	100	15.13 (7.74–29.56)	–

PPV: positive predictive value, NPV: negative predictive value, +LR: positive likelihood ratio, –LR: negative likelihood ratio, CI: confidence interval.

severe respiratory distress in their study. Tachypnea and wheezing were present in approximately half of these patients (51% and 56%, respectively), and respiratory difficulty in 61%. In addition, and interestingly, although this was not included among the exclusion criteria, patients diagnosed with respiratory tract infection other than pneumonia and acute bronchiolitis were not reported (for instance croup). Moreover, since there were no cases without respiratory distress or tachypnea among patients with acute bronchiolitis in our study, on rare occasions these children may also not have been involved. For that reason, PoCLUS may have reflected a different performance in the determination of acute bronchiolitis. Additionally, due to the use of different methodologies in other studies, the diagnostic performance of ultrasound diagnosis in children with respiratory distress may not have been determined exactly [16,19–21]. From that perspective, compared with other studies in the pediatric age group, our study design was intended to reveal the contribution of PoCLUS to patient management in addition to ED physician evaluations.

The almost perfect concordance in asthmatic children between ultrasound and ED diagnoses in this study ($\kappa = 0.94$) and PoCLUS having similar sensitivity and specificity to ED diagnosis suggests that it is quite effective in identifying children with asthma. In contrast, positive lung findings were present in half the asthmatic children in Dankoff et al.'s study [19]. However, there was no gold standard tool available for comparing the ultrasound findings of children with asthma or asthmatic flare-up in this study. In addition, underlying viral infections in asthmatic children or capable of causing asthma exacerbations may have caused sonographic lung scanning findings in both our study population and in Dankoff et al.'s study. Furthermore, there is no asthma-specific sonographic finding in lung scanning of asthmatic children capable of confirming our findings, and sonographic findings usually exhibit no specific pattern. In other words, lung ultrasound findings may reveal or confirm children with asthma exacerbations with specific signs and symptoms.

Our study suggests that PoCLUS may be useful in differentiating patients with tachypnea for non-pulmonary causes from those with non-cardiac respiratory distress or tachypnea. Ultrasound diagnosis exhibited greater sensitivity and specificity in identifying children with non-pulmonary tachypnea than ED diagnosis (100% and 95.83% vs 93.39% and 88.43%, respectively). When non-pulmonary causes capable of resulting in tachypnea are considered, PoCLUS appears to represent a complementary diagnostic tool for pulmonary emergencies. In addition, time to diagnosis of children with increased work of breathing of non-cardiac origin was significantly shorter with ultrasound compared to ED diagnosis

($p < 0.001$). Lung ultrasound can therefore also permit rapid evaluation and early target-based treatment.

5. Limitations

There are a number of limitations to our study. First, it involved a single sonographer with experience of performing lung ultrasound. We were unable to assess whether there might be a difference in findings obtained from less experienced or novice or different sonographers. Another limitation is that we determined no patients with acute lung injury or pediatric acute respiratory distress syndrome. This may be due to the exclusion from the study at the assessment stage of patients with poor general and obvious life-threatening conditions, or severe cardiac or underlying lung disease.

6. Conclusions

In conclusion, our study revealed good concordance between lung ultrasound and ED evaluation in the differential diagnosis of children with increased work of breathing of non-cardiac origin, and that lung ultrasound shortened time to diagnosis. At the same time, the diagnostic performance of PoCLUS is markedly better than that of ED diagnosis in several conditions in children presenting with non-cardiac respiratory distress. PoCLUS can also make a positive contribution to prognosis by permitting accurate and timely diagnosis of causes of respiratory distress in children.

If our findings can be confirmed with studies involving larger series, then PoCLUS can be integrated in the diagnostic approach steps at initial evaluation of children presenting with respiratory stress or tachypnea. This can also result in an improvement in burdens imposed by the use of resources and health spending.

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None declared.

Declaration of Competing Interest

AKÖ, FBV, ŞA report no conflict of interest.

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