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ORIGINAL RESEARCH

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A combined rapid clinical and lung ultrasound score for predicting bronchiolitis severity

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Abstract

Introduction Lung ultrasound (LUS) has demonstrated a good correlation with clinical severity scores in bronchiolitis but should be combined with clinical data to achieve the best results. The aim of the study is to create a quick and reliable clinical-ultrasound score to predict the risk of paediatric intensive care (Picu) admission as soon as the patient enters the emergency department (ED).

Methods A retrospective study conducted at two paediatric EDs. The lung was divided into six zones and scanned with ultrasound; every zone received a score. Clinical data were obtained. For the outcomes "PICU admission" and "CPAP support", a multivariate analysis was conducted and the significant factors resulting were used to create a 3-item score to predict PICU admission. Area under the receiver-operating curve (AUC) for specificity and sensibility of the score was obtained.

Results Seventy-four patients were enrolled; 34% were admitted to PICU. Thirty-one percent were treated with CPAP. For the outcome "PICU admission", multivariate analysis demonstrated the presence of wheezing and reduced oral intake to be significant together with ultrasound involvement of the right posterior upper zone and left posterior basal zone. For the outcome "CPAP support", same clinical factors plus involvement of the right posterior upper zone were significant. A 3-item score (1: presence of wheezing; 2: reduced oral intake; 3: LUS involvement of right posterior upper zone) for prediction of PICU admission was created which presents an AUC of 0.8249.

Conclusions We were able to create a simple and quick score to predict the need for PICU admission in bronchiolitis.

Keywords Bronchiolitis, Lung ultrasound, Severity score, Pediatric intensive care unit, Continuous positive airway pressure

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Introduction

The role of lung ultrasound (LUS) has significantly increased during the last decade in adult, paediatric and neonatal practice, with a growing number of centres using it as a first tool to diagnose pneumonia, pneumothorax, pleural effusions, neonatal respiratory diseases and, more recently, bronchiolitis and COVID-19 [1].

Several bronchiolitis studies have been performed by independent researchers, widely demonstrating that LUS is able to detect different lung manifestations of the diseases, from isolated vertical artefacts, to confluent ones to subpleural consolidations of different sizes, representing a probable continuum of severity of lung involvement [2–14]. A number of these studies have also attempted in comparing different LUS scores in children needing or not paediatric intensive care unit (PICU) admission or any type of oxygen support, finding that children with more severe bronchiolitis usually have higher LUS scores but with overall large overlaps between the two groups [15]. Most of these studies, however, were performed in single centres and involved relatively small numbers of children, or included little or no children that required higher steps of ventilation in PICU. More recently, the first national multicentric study has been performed in Italy, providing an extensive LUS assessment of all thoracic areas in more than 200 children, showing a good concordance of a score of the Italian Academy of Thoracic Ecography (ADET) with clinical severity scores; however despite large numbers, the study failed to include enough children needing PICU admission or a higher level of respiratory support such as continuous positive airway pressure (CPAP) [5]. Also, an extensive approach that requires a time-consuming LUS protocol may be difficult to be adapted in real-life contexts, and more specifically in busy emergency departments or with more severe children. Last, but not least, available literature mostly focused on finding LUS parameters that predict the most severe forms of bronchiolitis. However, the most modern view of LUS sees it as a clinical tool that should add information to clinical findings, and as such the best of LUS can be obtained when LUS and clinical information are used together in clinical practice [16–18]. Of note, several clinical scales are used to assess the severity of bronchiolitis but, as demonstrated by a recent study comparing them, none of the nine scales performed better than the other [19]. Therefore, new and modern predictive severity scores are highly needed.

For these reasons, we performed the present study with the aim to create a quick-to-use clinical-ultrasound score able to accurately predict which children are at the highest risk of CPAP or invasive ventilation and PICU admission.

Methods

Population

This is a retrospective study, conducted between November 2018 and April 2020 in the Paediatric Emergency Departments of the "Gemelli University Hospital" in Rome and of the "Vittore Buzzi Children's Hospital" in Milano (Italy).

Primary aim of the present study is to describe and compare clinical and LUS characteristics of infants with bronchiolitis needing admission to PICU to those who do not, in order to create a ready-to-use mixed clinical-ecographic score for the prediction of need of PICU admission. Secondary aim of the study is to describe and compare clinical and LUS characteristics of the patients needing CPAP respiratory support.

All consecutive children aged 0–12 months with a clinical diagnosis of bronchiolitis and admitted to the two centres were enrolled; for each child, demographic and clinical information were collected and saved on a standardized form before the execution of the ultrasound exam.

Patients have been excluded from the study if they presented immunodepression, heart diseases, neuromuscular diseases, cystic fibrosis, bronchopulmonary dysplasia (defined according to the perinatal history, dependence on oxygen), positive history of foreign body inhalation, unstable critical conditions that required immediate lifesaving procedures, and lack of parental consent.

An individual data sheet for the collection of demographic, medical, and clinical data, according to the clinical classification of bronchiolitis, was used.

The study was approved by the Ethics Committees of each participating centre (protocol numbers: 000136320 and 22/ST/059).

Lung ultrasound

Lung ultrasound examinations were performed in the Emergency Department, with a high frequency (12–3 MHz) linear probe (Affiniti 70, Philips, Amsterdam, Netherlands), at the patient's bedside, using a modified three-zone per hemithorax Bedside Lung Ultrasound in Emergency (BLUE) protocol (described by Lichtenstein) [20].

Each hemithorax was divided into anterior, lateral, and posterior zones, and upper and lower zones (divided by the internipple line); anterior aspect of the chest was identified by the anterior axillary line, lateral aspect of the chest by the anterior and posterior axillary lines, and posterior aspect of the chest by the posterior axillary line and the spine, not including the scapular area. Children were scanned in a recumbent or semirecumbent position and rolled onto their side to optimize posterior scanning.

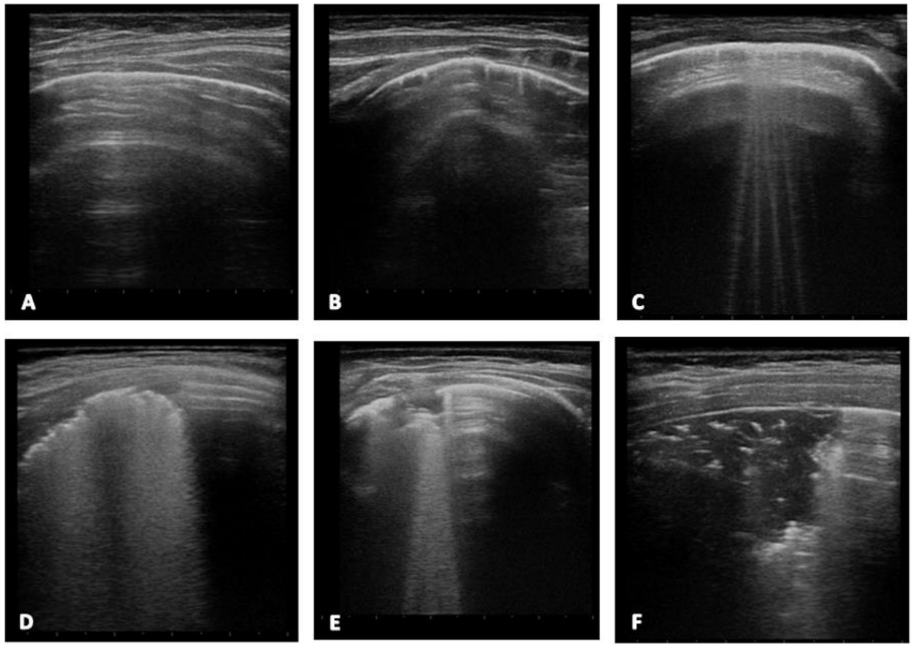

Fig. 1 LUS findings. **A** A-lines, normal ultrasound. **B** Short vertical artefact. **C** Multiple B lines. **D** White lung. **E** Subpleural consolidation smaller than 1 cm. **F** Subpleural consolidation bigger than 1 cm

In order to characterize the lung ultrasound patterns, the recently published definitions of the Italian Academy of Thoracic Ultrasound (Accademia di Ecografia Toracica, ADET) [21] were employed (Fig. 1):

0: normal A lines.
1: short vertical artefacts and isolated B lines.
2: multiple B lines (B lines with a distance of less than half centimetre to the confluence, remaining identifiable from each other).
3: white lung (subpleural field with various shades of grey/white without distinguishing B lines) and subpleural consolidations smaller than 1 cm.
4: subpleural consolidations bigger than 1 cm.

Anterior zones were grouped and defined as the sum of the right anterior superior zone, right anterior inferior zone, left anterior superior zone and left anterior inferior zone. *Lateral zones* were defined as the sum of the right lateral superior zone, right lateral inferior zone, left lateral superior zone and left lateral inferior zone. *Posterior Zones* were defined as the sum of the right posterior superior zone, right posterior inferior zone, left posterior superior zone and left posterior inferior zone (Fig. 2).

Variables to be included in the score were chosen from the previously cited clinical and ultrasound variables, according to their odds ratios (OR) for the given outcomes. We decided to consider one single significant lung area in order to produce a rapid tool that does not imply sums of different scores but only some simple data. Relative importance of each variable was assigned based upon their odds ratios in the multivariate analysis with the given outcomes.

Lung ultrasound examinations were either directly performed or reviewed by D.B. and A.C. in order to reduce operator dependency of the technique.

CPAP respiratory support was initiated if the patient's peripheral saturation was $<92\%$ in room air or had the venous pCO_2 was ≥ 55 mmHg. PICU admission was deemed necessary if the patient presented with high supplemental oxygen requirement ($FiO_2 \geq 0.5$ to maintain $SaO_2 \geq 92\%$), need for non-invasive or invasive ventilation, rapidly progressive upper or lower airway disease, apnea observed by a physician or nurse or described as cyanosis and/or loss of consciousness and/or decreased muscle tone [22].

Outcomes

Primary aim of the present study is to describe and compare clinical and LUS characteristics of infants with bronchiolitis needing admission to PICU to those who do not, in order to create a ready-to-use mixed clinical-ecographic score for the prediction of the need for PICU admission. Secondary aim of the study is to describe and compare clinical and LUS characteristics of the patients needing CPAP ventilation.

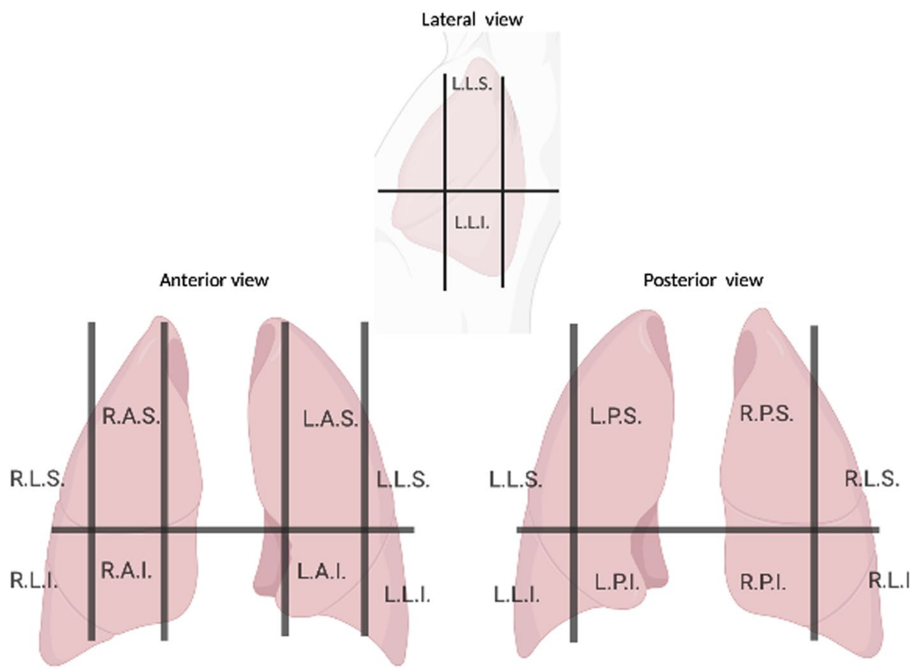

Fig. 2 Schematic representation of the 12 lung areas investigated by lung ultrasound (LUS), divided into 3 macro-areas: anterior macro-area, lateral macro-area, posterior macro-area. Single zone denomination: right anterior superior (RAS), right anterior inferior (RAI), left anterior superior (LAS) and left anterior inferior (LAI), right lateral superior (RLS), right lateral inferior (RLI), left lateral superior (LLS) and left lateral inferior (LLI), right posterior superior (RPS), right posterior inferior (RPI), left posterior superior (LPS) and left posterior inferior (LPI)

Statistical analysis

For the outcomes "PICU admission" and "CPAP respiratory support", a logistic regression was conducted after selecting potential variables of interest that presented a likelihood ratio of <0.25 in the univariate analysis. The potential candidate predictors were age, sex, ex-premature status (defined as birth before 36 + 6 weeks of gestational age), previous therapy at home; under a clinical aspect, symptom duration before medical consult expressed in hours, presence of rhinorrhea, fever, retractions, crackles, wheezing, reduced food intake, peripheral saturation of oxygen; under a microbiological aspect, detection of RSV or multiple viruses; under the ecographic aspect, the single zones' score and the macro-areas' score according to the previous definition, and the involvement of a zone by the pathologic process as defined by a score equal to or bigger than 2.

Wilcoxon rank-sum test was conducted to compare the ultrasound scores of patients admitted to PICU respectively in the posterior, lateral and anterior areas and in every single lung zone scanned.

The presence of a score ≥ 2 in at least one lung zone was tested for correlation with PICU admission and CPAP respiratory support with Fisher's exact test.

Quantitative variables were described by mean and standard deviation (SD) or median and interquartile range (IQR), depending on the variable distribution. Frequencies and percentages were used for qualitative variables.

Data were analysed with Stata 17 BE (Statacorp LLC, USA). $P < 0.05$ were considered significant.

Results

Seventy-four patients were enrolled in the study, 25 (34%) of which were admitted to PICU. Twenty-three (31%) were treated with continuous positive airway pressure (CPAP) and 38 (51%) with high flow nasal cannula (HFNC). All patients treated with CPAP were admitted to PICU and of the HFNC group, 14/38 (36.8%) were admitted to PICU and 24/38 (63.2%) were not.

Twenty-three (31%) patients received steroids, 22 (30%) bronchodilators and 4 (5%) nebulized epinephrine. No patient required invasive ventilation. Respiratory syncytial virus was identified in 85% of patients.

Demographic and clinical data of the patients are presented in Tables 1 and 2 with the relative outcomes of "PICU admission" and "CPAP respiratory support", together with the number of patients presenting involvement of single lung areas (defined as a single area score equal or bigger than 2). Single centre's data are described in the Supplementary Material.

When analysed singularly, the presence of a score higher or equal to 2 in the following lung areas was

Table 1 Demographic data and clinical symptoms upon presentation in patients admitted and not admitted to PICU together with relative Odd Ratios (OR). Data are presented as median (IQR) for continuous measures, and *n* (%) for categorical measures

	All patients (*n* = 74)	No PICU admission (*n* = 49)	PICU admission (*n* = 25)	*p*-value	OR (95% CI)
Clinical data					
Age, months	2.2 [1.0–6.4]	2.2 [1.0–5.4]	2.0 [1.0–8.0]	0.54	1.07 (0.97–1.18)
Male sex	38 (51%)	27 (55%)	11 (44%)	0.37	0.64 (0.24–1.68)
Symptom duration, h	72 [24–96]	72 [48–96]	48 [24–96]	0.21	0.99 (0.98–1.00)
Rhinorrhea	66 (89%)	49 (100%)	17 (68%)	< 0.001	-
Reduced oral intake	53 (72%)	31 (63%)	22 (88%)	0.026	4.25 (1.11–16.24)
Ex premie status	12 (16%)	7 (14%)	5 (20%)	0.53	1.50 (0.42–5.31)
Crackles	70 (95%)	49 (100%)	21 (84%)	0.004	-
Wheezing	16 (22%)	3 (6%)	13 (52%)	< 0.001	16.61 (4.06–67.83)
Retractions	73 (99%)	48 (98%)	25 (100%)	0.47	-
Fever	33 (45%)	22 (45%)	11 (44%)	0.94	0.96 (0.36–2.54)
LUS score					
Right lung areas					
Anterior inferior	21 (28%)	14 (29%)	7 (28%)	0.96	0.97 (0.33–2.83)
Anterior superior	35 (47%)	19 (39%)	16 (64%)	0.04	2.8 (1.03–7.61)
Lateral inferior	21 (28%)	13 (27%)	8 (32%)	0.62	1.30 (0.45–3.73)
Lateral superior	27 (36%)	12 (24%)	15 (60%)	0.003	4.62 (0.45–3.73)
Posterior inferior	42 (57%)	26 (53%)	16 (64%)	0.37	1.57 (0.58–4.23)
Posterior superior	54 (73%)	32 (65%)	22 (88%)	0.038	3.89 (1.01–14.90)
Left lung areas					
Anterior inferior	33 (45%)	19 (39%)	14 (56%)	0.16	2.00 (0.75–5.33)
Anterior superior	21 (28%)	9 (18%)	12 (48%)	0.007	4.10 (1.41–11.92)
Lateral inferior	36 (49%)	22 (45%)	14 (56%)	0.37	1.56 (0.59–4.11)
Lateral superior	25 (34%)	9 (18%)	16 (64%)	< 0.001	7.9 (2.65–23.51)
Posterior inferior	37 (50%)	19 (39%)	18 (72%)	0.007	4.06 (1.42–11.54)
Posterior superior	51 (69%)	31 (63%)	20 (80%)	0.14	2.32 (0.74–7.25)

associated with PICU admission: right anterior superior, left anterior superior, left lateral superior, right posterior superior, left posterior inferior area. Same results were obtained for "CPAP respiratory support".

When considering macro-areas (namely anterior, lateral, and posterior), ultrasound scores in the lateral areas ($p = 0.014$) but not in the posterior ($p = 0.058$) and anterior ones ($p = 0.06$) differed significantly between patients admitted to PICU and patients not admitted to PICU. Similarly, ultrasound scores in the lateral areas ($p = 0.04$) and in the posterior ones ($p = 0.024$) were associated with CPAP respiratory support.

Scores of single lung areas differed significantly between those admitted to PICU and those not in two areas, namely the left lateral superior and the right lateral superior one (Supplementary file).

For the outcome "PICU admission", the univariate analysis selected the following variables among the clinical ones: the presence of wheezing and reduced oral intake. These were then tested in the multivariate logistic model with the score of every single lung area, the score of every macro-area (anterior, lateral, or posterior), and the variable defining the zone involvement in a dichotomic way, if the score is equal to or bigger than 2.

Results of the multivariate analysis are presented in Table 3. Hosmer–Lemeshow test was used to assess the goodness of fit of the model.

For the occurrence of "CPAP respiratory support", results are presented in Table 4.

Combined clinical-ultrasound score

Given these preliminary results, a combined clinical-ultrasound score was created for the determination of the risk of PICU admission and CPAP ventilation,

Table 2 Population's demographic, clinical and ultrasound characteristics upon presentation divided by CPAP ventilation with relative Odds Ratios (OR). Data are presented as median(IQR) for continuous measures, and *n* (%) for categorical measures. *CPAP*, continuous positive airway pressure

	All patients (*n* = 74)	No CPAP ventilation (*n* = 51)	CPAP ventilation (*n* = 23)	*p*-value	OR (95% CI)
Clinical data					
Age, months	2.2 [1.0–6.4]	2.3 [.0–5.5]	2.0 [1.0–7.0]	0.98	1.04 (0.94–1.15)
Male sex	38 (51%)	28 (55%)	10 (43%)	0.36	0.63 (0.23–1.70)
Symptom duration, h	72 [24–96]	72 [48–96]	48 [24.0–96]	0.18	0.99 (0.98–1.00)
Rhinorrhea	66 (89%)	50 (98%)	16 (70%)	< 0.001	0.04 (0.005–0.40)
Reduced oral intake	53 (72%)	33 (65%)	20 (87%)	0.049	3.63 (.094–13.92)
Ex premie status	12 (16%)	8 (16%)	4 (17%)	0.850	1.13 (0.30–4.21)
Crackles	70 (95%)	51 (100%)	19 (83%)	0.002	-
Wheezing	16 (22%)	4 (8%)	12 (52%)	< 0.001	12.81 (3.46–47.42)
Retractions	73 (99%)	50 (98%)	23 (100%)	0.500	-
Fever	33 (45%)	23 (45%)	10 (43%)	0.900	0.93 (0.34–2.52)
LUS score					
Right lung areas					
Anterior inferior	21 (28%)	14 (27%)	7 (30%)	0.790	1.15 (0.39–3.40)
Anterior superior	35 (47%)	20 (39%)	15 (65%)	0.038	2.90 (1.04–8.10)
Lateral inferior	21 (28%)	13 (25%)	8 (35%)	0.410	1.55 (0.53–4.51)
Lateral superior	27 (36%)	13 (25%)	14 (61%)	0.003	4.54 (1.59–12.96)
Posterior inferior	42 (57%)	26 (51%)	16 (70%)	0.140	2.19 (0.77–6.24)
Posterior superior	54 (73%)	32 (63%)	22 (96%)	0.003	13.06 (1.62–104.85)
Left lung areas					
Anterior inferior	33 (45%)	21 (41%)	12 (52%)	0.38	1.55 (0.57–4.19)
Anterior superior	21 (28%)	11 (22%)	10 (43%)	0.053	2.79 (0.96–8.07)
Lateral inferior	36 (49%)	24 (47%)	12 (52%)	0.680	1.22 (0.45–3.28)
Lateral superior	25 (34%)	11 (22%)	14 (61%)	< 0.001	5.65 (1.93–16.50)
Posterior inferior	37 (50%)	21 (41%)	16 (70%)	0.024	3.26 (1.14–9.31)
Posterior superior	51 (69%)	32 (63%)	19 (83%)	0.088	2.82 (0.83–9.53)

Table 3 Multivariate analysis for prediction of PICU admission in infants presenting to the ED

	p-value	OR (95% CI)
Model 1		
Wheezing	< 0.001	34.84 (5.16–235.22)
Reduced oral intake	0.031	7.01 (1.19–41.24)
Right posterior superior zone involvement	0.038	6.60 (1.10–39.45)
Model 2		
Wheezing	< 0.001	22.55 (4.08–124.55)
Reduced oral intake	0.023	8.72 (1.34–56.74)
Lateral posterior inferior zone involvement	0.031	4.10 (1.13–14.84)

Table 4 Multivariate analysis for prediction of CPAP ventilation in infants presenting to the ED

	p-value	OR (95% CI)
Wheezing	0.001	41.38 (4.43–386.08)
Right posterior superior zone involvement	0.010	41.50 (2.46–699.25)

with the aim to be a quick tool when the patient enters the ED.

As mentioned, variables to compose the score were chosen from the previously cited clinical and ultrasound variables: for the clinical side, wheezing and reduced oral intake, and under the ultrasound aspect, involvement of the right superior posterior lung zone, which was chosen because highly predictive for both outcomes. Their relative importance was assigned according to their ORs of the previous analysis.

To calculate the score, we therefore considered the presence of reduced oral intake *7.01 + presence of wheezing * 34.84 + involvement of right posterior superior zone * 6.60.

Area under the curve for this model was 0.8249 (Fig. 3), thus showing excellent discrimination for the outcome.

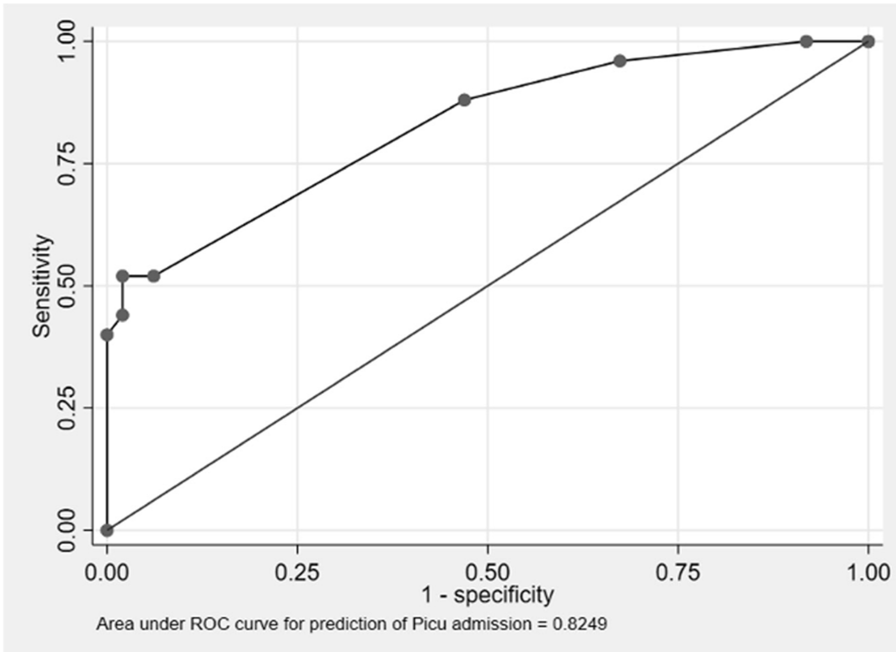

Fig. 3 AUC for prediction by the clinical-ecographic score of PICU admission

For "CPAP" respiratory support, the same score predicted the outcome with a very excellent AUC as well (0.8291).

Discussion

In this study, we found that a rapid combined clinical and ultrasound score was accurate for discriminating during the first clinical evaluation of the risk for PICU admission and CPAP respiratory support in children with bronchiolitis. To our knowledge, this is the first study including evaluating a relatively large number of children requiring PICU and using a score that combines both clinical and ultrasound information.

The use of lung ultrasound is rapidly growing worldwide and scientists are expanding its clinical use and physical knowledge in both adult and paediatric practice, including neonatology [1]. Specifically, to the initial use of LUS in pleural effusions and pneumonia, several other applications including interstitial lung disease, traumas, pneumothorax, acute respiratory distress syndrome, neonatal RDS, TB and bronchiolitis have been added and further investigated [1].

In paediatrics, a large number of studies have focused on bronchiolitis [2–14, 23]. It is now well established that LUS can detect different patterns of lung involvement in children with bronchiolitis, including vertical artefacts and different-size subpleural consolidations, which, according to a recent study with a standardized follow-up, seem to be mostly peripheral areas of disventilation/atelectasis given their rapid resolution [23]. Moreover, previous studies using different ultrasound approaches showed that children with bronchiolitis have frequent posterior paravertebral small consolidations or that patients requiring oxygen or ventilation usually have higher LUS scores, however with large overlaps of LUS scores between the different groups and mostly including small or no patients needing PICU admission [2–14, 23]. These overlaps on the one hand may imply a low accuracy of LUS in predicting bronchiolitis severity and on the other hand may highlight that our use of this tool can still be improved.

In this regard, experience can be gained through adult and neonatal practice, as well as knowledge of the physical bases of lung ultrasound. Experts from adult and neonatal practice are suggesting that the semi-quantification of LUS scores may be used as a tool to quantify the aeration of the peripheral lung, and this is particularly evident from several studies from De Luca's team on preclinical and clinical data on neonatal respiratory conditions [24–28]. The rationale for such an approach is the relatively obvious hypothesis that the less the peripheral lung is expanded, the less lung areas are available for gas exchanges and, therefore, the clinical manifestation of that specific disease is expected to be more severe. This hypothesis has, importantly, fundaments on the growing knowledge of the bases of LUS and specifically from several studies of the Italian Academy of Thoracic Ultrasound, coordinated by Soldati et al., which demonstrated that vertical artefacts, white lung and consolidations are expression of a spectrum of increasing loss of the peripheral alveolar structure up to the total hepatization of the lung, which does not contribute anymore to gas exchange [29–33]. While this is all true, clinical observations from several studies, from COVID-19 to bronchiolitis, show that although most severe patients have usually higher LUS scores, the use of LUS scores may be limited in predicting disease severity, suggesting that other parameters besides the status of the peripheral lung (which is the lung area that can be explored with LUS) contribute to pathophysiology.

For example, bronchiolitis is frequently characterized by wheezing [34]. Interestingly, in fact, in our cohort, the patients admitted to PICU had significantly higher rates of wheezing, while those not admitted mostly have upper respiratory involvement with rhinitis. However, wheezing has not a direct consistent pattern/expression on LUS, and therefore excluding such an important parameter from a severity-predicting score would make no sense. Indirectly, the bronchial obstruction could cause a peripheral disventilatory picture downstream of the obstruction which can lead to an indirect visibility subpleural consolidation, as previously described also by our team in a case series [35]. However, it is currently unknown if every functional wheezing leads to peripheral dysventilation and, therefore, we cannot speculate that every wheezing has a concomitant ultrasound-visible atelectasis, and more importantly there is no grading in the current literature linking the severity of wheezing with dimension of peripheral atelectasis. Therefore, although there is space for future research to better understand how wheezing can be seen and quantified through indirect LUS features, at the moment, we believe that the clinical finding of wheezing (the sound) is easier to be documented compared with the LUS pattern, and therefore we suggest to include wheezing in the clinical prediction rules of bronchiolitis-severity, in adjunction of the LUS features.

Wheezing is an expression of bronchial obstruction, and since bronchi do not touch the pleura, they cannot be explored by ultrasounds. Also, reduced oral intake is one of the most important complications in more severe diseases and, obviously, no LUS patterns can detect this. This observation induced us to unify clinical and LUS parameters. Importantly, the concept that LUS is an adjunctive clinical tool that should add to the clinical examination has already been established, and previous studies have already demonstrated that the use of both clinical and LUS parameters significantly improves the accuracy of patient assessment compared with clinical or LUS used independently [17]. Interestingly, in our score including the most important clinical and LUS on the univariate models, we found that including both wheezing and LUS parameters gave a very accurate model for predicting PICU admission and CPAP need. To our knowledge, such a combination of easy and relevant clinical and LUS parameters has never been studied before and, importantly, its high accuracy is very promising.

In our combined LUS-clinical score, the most relevant areas of the lung for prediction of the need for high support were the posterior ones. Several studies have documented that common lung diseases, including bronchiolitis, neonatal RDS, and recently COVID-19, are commonly characterized by involvement of the posterior lung areas [36]. This finding may be also due to the frequent supine positions of young infants and the consequent gravitational deposits of airways secretions or a less ventilation of these areas [37]. Regional atelectasis is potentially easier to be found in infants and children, as the relative and absolute airway diameter is smaller compared to adults; thus, smaller volumes of secretions are needed to occlude them [38]. The involvement of the right upper zone and the left basal one (both posteriorly) has been already described [36, 39]. Potential explanations for this preferential atelectasis can be looked for in the anatomy—the right upper lobe bronchus arises at a 90° angle from the right mainstem bronchus [40]—or in its position in space—the right upper lobe is the most dependent bronchus in the supine position, making it a steeper way to clear secretions [41]; the left posterior basal area, also, could be involved because of being compressed by the heart [38]. Changing position from supine to prone has shown benefits on oxygenation and CO2 elimination because of recruitment of well-perfused but previously collapsed alveoli, in every age [42]. We do not have precise data on the period patients had spent in the supine position before our ultrasound evaluation, so that a correlation with position cannot be drawn from the presented data. It is however improbable that patients had been kept in prone position in the period before admission to the ED, if ever; international guidelines recommend supine position for babies during sleep as the safest in protecting from sudden death [43] and usual care such as nursing or changing diapers occurs in the supine position.

Also, in our population, lateral areas' scores were significantly different in those admitted to PICU and in those supported with CPAP compared to those who were not. Infants with bronchiolitis, in particular the most severe ones, are usually still breastfed/formula fed and the usual positions for milk feeding require the infant to be in a supine but partially lateral position. This may somehow predispose to microaspirations that gravitationally deposit on lateral area, which in turn appear less ventilated on LUS. Also, the tridimensional dynamics of thorax motion during breathing and growth is still unclear, although very recent advances suggest that different parts of the thorax may contribute differently during respiration and that this may change with development [44–46]. This may lead to the speculation that lateral sections of the ribs are less expanded during pathological breathing in more severe bronchiolitis, since children mostly use the diaphragm and other accessory muscles like sternocleidomastoid muscles, and therefore those areas are more easily atelectatic. This hypothesis requires, obviously, further confirmations but, in our opinion, was strong and interesting enough to require validation and also new pathophysiology studies.

A strength of our model is its simplicity. As clinicians involved in routine clinical practice, we focused our efforts under a paediatric emergency medicine/intensive care perspective. In these settings, it is pivotal to have tools that are quickly and easily feasible at the patient bedside. Although several associations [36], including the ADET and also our previous studies, have highlighted the importance of a comprehensive assessment of all lung areas while performing LUS, in very urgent settings scanning all lung areas is not feasible. Therefore, a quick tool like ours can serve as a useful first assessment that might serve in better triaging children with bronchiolitis assessed in the paediatric emergency department, and leaving a more comprehensive LUS assessment during follow-up visits in hospitalized children. For example, predicting which infants with bronchiolitis will develop severe disease later during disease course is still a challenge, as re-visits in the PED of previously discharged children coming back with worsening bronchiolitis are still a problem with organizational and legal consequences [47]. In this setting, our approach, if confirmed by other studies, can have a positive impact on the management of bronchiolitis.

Our study has limitations, mainly the relatively small number of children included, particularly for the PICU group, and the absence of patients requiring invasive ventilation. Also, the score did not include some clinical findings that may be relevant such as apnea or respiratory rate. We intentionally excluded respiratory rate because it can be lengthy to obtain and could require more than one attempt; apnea history during the disease could have been an interesting data to collect that we will include in future studies.

However, this is still the largest cohort including PICU patients actually available and has the strength of being a dual clinical and ultrasound score (thus including the advantages of both aspects) which is quick and easy to perform.

In conclusion, we developed a combined clinical-ultrasound score able to accurately predict the need for PICU admission and CPAP respiratory support in children with bronchiolitis. Hopefully, given the very promising findings of our study, we hope that this model will be tested in further multicentric studies including larger cohorts of patients, since such a rapid tool may significantly improve the initial assessment of children with bronchiolitis.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44253-023-00012-3.

Additional file 1: Table 1S. Demographic- clinical characteristics and treatments in the cohort divided by center. HFNC: High Flow Nasal Cannula. CPAP: Continuous Positive Airway Pressure. PICU: Pediatric Intensive Care Unit.

Code availability
Code used for statistical analysis (Stata 17 BE—Statacorp LLC, USA) is available upon request.

Authors' contributions
Conceptualization: A.C. and D.B. Data curation: A.C., D.B. and C.D.R. Formal analysis: A.C. Investigation: all authors. Writing, original draft: A.C and D.B. Writing, review and editing: all authors.

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Availability of data and materials
Data available on request due to privacy.

Declarations

Ethics approval and consent to participate
Informed consent was obtained from all participants' legal guardians.

Competing interests
The authors declare that they have no competing interests.

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