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REVIEW

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Lung ultrasound scores in neonatal clinical practice: A narrative review of the literature

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Abstract

Lung ultrasound (LU) has in recent years increasingly been used as a point-of-care method. Initially, LU was used as a so-called descriptive diagnostic method for neonatal respiratory diseases. Instead, this review article focuses on the use of LU as a "functional" tool using classification of findings in patterns or using semi-quantitative scores. We review and describe the evidence that led to the implementation of LU in predicting the need for surfactant replacement therapy in preterm infants and in the identification of newborns at risk of developing bronchopulmonary dysplasia. LU appears to be a very promising method for the future of clinical management of newborns in both acute and chronic phases of pulmonary pathologies related to prematurity. However, further studies are needed to define its role before full implementation.

KEYWORDS

lung disease, lung ultrasound, lung ultrasound score, neonatal intensive care, newborn

1 | INTRODUCTION

The evolution of ultrasound technology and development of compact ultrasound machines has led to widespread use of diagnostic ultrasound at bedside in multiple specialties.[1] In neonatal intensive care units (NICU), point-of-care ultrasound (POCUS) is now considered an extension of clinical examination and is used to address targeted clinical questions.[2] Among POCUS applications, a pivotal role is played by lung ultrasound (LU), as reported in the recent guidelines published by the European Society of Pediatric and Neonatal Intensive Care (ESPNIC).[3]

Initially, LU was used as a diagnostic tool, like conventional chest X-ray (CXR).[4] We extensively described this in a previous review.[5]

In the last few years, LU has been increasingly used as a semi-quantitative method or, as recently defined, as a "functional" tool.[6]

To allow quantification of the qualitative findings of LU, several patterns were identified and scores developed, first in adults [7–9] and later in children and neonates. Although lung ultrasound score (LUS) and patterns may differ from each other, they all provide a quantification of a wide sample of pulmonary pathologies, allowing the clinician to monitor the progress and predict the evolution of diseases and decide whether to perform a specific treatment. Furthermore, LUS and patterns are an important research tool as they quantify and grade specific diseases, allowing their objective comparison between different groups of patients.

As the use of LUS and patterns is well validated and grounded in clinical practice, in both adults and children,[10] the purpose of this narrative review is to provide readers with an overview of the current evidence regarding the use of LU patterns and scores in the clinical management of newborns in NICU.

2 | LUNG ULTRASOUND PATTERNS

The use of LU patterns consists in classifying LU findings into specific groups of recognizable images or patterns. A practical example can be found in the work published by Raimondi et al. in 2012.[11] In this study, there were three recognizable ultrasound patterns which were classified as follows:

Type 1—full hyperechoic image of the lung fields or "white lung" (Figure 1C);

Type 2—prevalence of B lines, lung sliding sign present (Figure 1B)

Type 3—A-line predominance, lung sliding sign present (Figure 1A)

The choice of patterns is due to modification of the ultrasound images based on air content as shown in Figure 1 where panel D shows an unventilated lung.

In this study, LU was performed between one and two hours of life in neonates with gestational age (GA) ≥ 34 weeks. Infants with Type 1 pattern (increased lung fluid content) were admitted to NICU for respiratory failure, whereas infants with Type 3 pattern remained in the nursery and did not develop respiratory complications.

Raimondi et al. demonstrated first that lung fluid content can be non-invasively assessed by ultrasound and second that LU could provide early prediction of neonates who will later develop respiratory distress and need respiratory support with NICU admission. This study, therefore, paved the way for the use of LU as a semi-quantitative method.

Subsequently, the same ultrasound patterns were studied in a population of infants with respiratory distress syndrome (RDS) requiring nasal continuous airway pressure (nCPAP).[12] The aim of the study was to predict the need for intubation in infants with bilateral pattern 1 at 2 h of life. Failure of noninvasive ventilation (NIV) was defined as endotracheal intubation and surfactant administration without attempting further NIV strategies. Fifty-four infants of different GA were enrolled. All newborns with either unilateral or bilateral Type 1 pattern were intubated after an average interval of 6 h. No infant with Type 2 or 3 pattern required mechanical ventilation. Thus, bilateral Type 1 pattern on LU showed excellent accuracy in predicting NIV failure with a sensitivity of 88.9% (confidence interval [CI]: 67.2–96.8), specificity of 100% (CI: 94.9–100), positive predictive value (PPV) of 100% (CI: 80.6–100), and negative predictive value (NPV) of 94.7% (CI: 82.7–98.5).[12]

The same patterns classification has recently been used to predict the need for NICU admission in infants born by caesarean section (CS) with transient tachypnea of the newborn (TTN) or RDS.[13] Poerio et al. studied full-term or late-preterm infants born by CS. Admission to the NICU was based on occurrence in the delivery room of clinical signs of respiratory distress which did not resolve within 60 min of life. Upon admission, infants were classified according to the physio-pathology of the respiratory distress as having TTN or RDS. For each infant, LU examination was performed in the delivery room at approximately 30 min after birth (T0) and repeated at 4 h of life (T1). One hundred newborns were enrolled and only seven were admitted in NICU. The authors assessed the ability of Type 1 pattern in both lungs to predict the NICU admission and they found a specificity of 100% (95% CI: 95.4%–100%), a sensitivity of 71.4% (95% CI: 61.4%–79.8%) with a PPV of 100% (95% CI: 95.4%–100%), and a NPV of 97.9% (95% CI: 92.1%–99.6%).[13] Although the number of enrolled infants was relatively small to draw solid conclusions, these results demonstrated the potential of this method to guide clinical management in newborns. Further data are needed before implementation of this technique in clinical practice.

Lung ultrasound patterns have recently been used to predict the need for exogenous surfactant administration[14]; we will discuss this in the next section dedicated to LUS and surfactant replacement therapy.

In conclusion, the classification of LU findings in simple patterns according to lung air content may predict the need for increasing respiratory support and NICU admission, irrespective of pulmonary disease (RDS or TTN). This can be useful, especially in centers with a

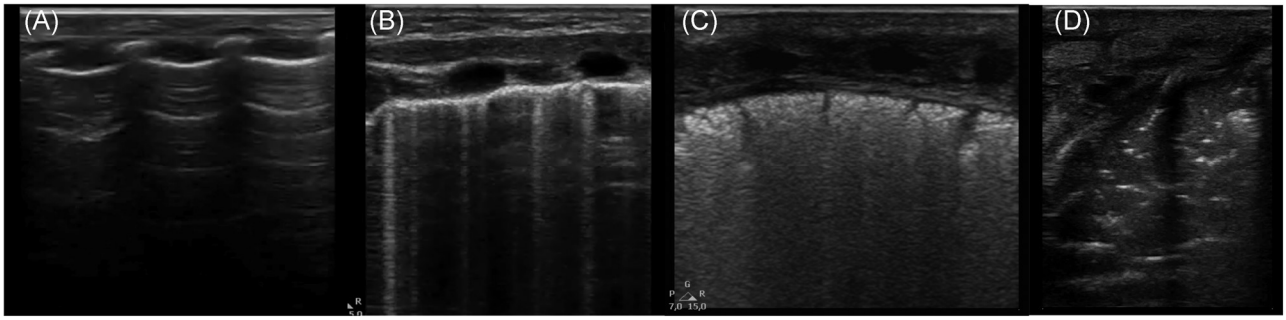

FIGURE 1 The figure shows the progressive reduction of air content in the lung from a normal condition (A) to interstitial syndrome (B), to white lung (C) up to consolidation (D). Three ultrasound patterns are also recognizable in the figure as classified by Raimondi et al.[11] Type 1—full hyperechoic image of the lung fields or "white lung" (C); Type 2—prevalence of B lines, lung sliding sign present (B) Type 3—A-lines predominance, lung sliding sign present (A). Lung ultrasound score for each area is attributed according to the following criteria: 0, A-pattern (defined by the presence of only A-lines; A); 1, B-pattern (defined as the presence of three or more B-lines, well spaced; B); 2, severe B-pattern (defined as the presence of crowded and coalescent B lines with or without consolidations limited to subpleural space; C); and 3, extended consolidation (D)[15]

lower level of care where early identification of neonates requiring transfer to centers with a higher level care is of paramount importance.

3 | LUNG ULTRASOUND SCORE

To calculate an LUS, LU findings are classified into specific groups of recognizable images or patterns and a number is assigned to each pattern. The chest is divided into zones and a number is assigned by the observer for each zone, according to the ultrasound findings or pattern. Their sum provides an overall score that allows assessment of the magnitude and severity of the lung disease in a given subject. A different number of scores have been proposed and the main differences lie in chest partitioning and score attribution according to ultrasound findings. The first LUS in neonates was proposed by Brat et al. in 2015, based on those previously validated in adult population.[15]

Figure 2 shows how the three main LUS currently available to predict the need for surfactant therapy evaluate different pulmonary zones.[15–17] In fact, although the considered number of zones is the same (three per hemithorax), their location is different. In the score proposed by Brat et al. (Figure 2A), antero-superior, antero-inferior, and lateral zones are studied in both hemithoraces.[15] In the one developed by Rodriguez-Fanjul et al. (Figure 2B), anterior, lateral, and posterior zones are evaluated in both hemithoraces, thus requiring examination of the infant's back.[16] Raimondi et al. proposed a score (Figure 2C) in which the zones of interest are bilaterally located along the midclavicular, anterior axillary, and posterior axillary lines, without the need to change infants' position and thus minimizing handling.[17]

Each of these methods is based on the attribution of a score from 0 to 3 for each area. The sum of the individual scores represents the patient's overall score. The score for each area is attributed according to the following criteria: 0, A-pattern (defined by the presence of only A-lines; Figure 1A); 1, B-pattern (defined as the presence of three or

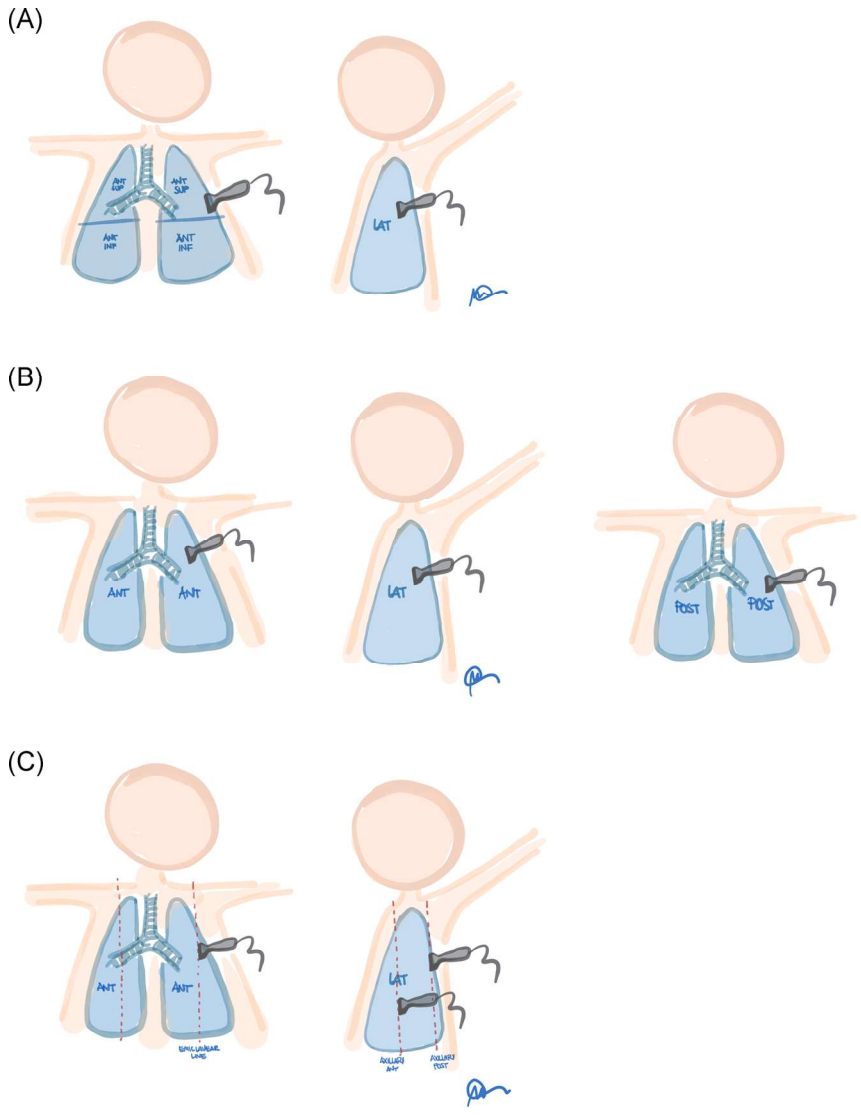

FIGURE 2 Different divisions of the chest in the three lung ultrasound scores proposed by: (A) Brat et al. (zones: antero-superior, antero-inferior and lateral for each hemithorax).[15] (B) Rodriguez-Fanjul et al. (zones: anterior, lateral and posterior, for each hemithorax).[16] (C) Raimondi et al. (zones: midclavicular, anterior axillary and posterior axillary lines, for each hemithorax)[17] [Color figure can be viewed at wileyonlinelibrary.com]

more B-lines, well-spaced; Figure 1B); 2, severe B-pattern (defined as the presence of crowded and coalescent B lines with or without consolidations limited to subpleural space; Figure 1C); and 3, extended consolidation (Figure 1D).[13] The score can, therefore, have values from 0 (completely normal) to 18 (bilateral white lung findings with diffuse consolidations).

Particular attention must be paid to the ultrasound technique, especially in the presence of images with non-coalescing B lines. In this case, the imperfect positioning of the probe (i.e., probe not perpendicular to the pleura) can cause a false increase of the number of artifacts (B-lines) with apparent thickening of the pleural line and consequent overestimation of the score.

All these proposed LUS are valid for predicting the need for exogenous surfactant therapy, as demonstrated by the data. While waiting for studies that clarify the variability between different types of LUS, it is particularly important within a NICU to standardize the method of execution, the type of LUS used, and the cut-off value used.

Particular attention must be paid to the intra- and inter-observer repeatability of LUS. These depend both on the experience of the operator and on the technique used. The recent paper published by Gomond-Le Goff et al.[18] showed a strong agreement both intra- and inter-operator, even in non expert observers, especially when a high definition linear probe was used.

Finally, a new modified score was proposed by Szymansky et al.[19] The areas explored are four (two per hemithorax: anterior and posterior) and the scale of values for each area varies from 0 to 4. At the moment there are no other studies that support this type of LUS and increasing the variability of the score per area up to 4 may have detrimental effects on reproducibility of the technique. Further data are needed to evaluate the role of this LUS.

Although these scores were studied focusing on their ability to predict the need for surfactant therapy in preterm infants, other applications are emerging, in particular the ability to predict the development of bronchopulmonary dysplasia (BPD). We address both these applications of LUS below.

3.1 | Lung ultrasound score and exogenous surfactant therapy

In Table 1, we summarize the main characteristics of studies that investigated the ability of LUS to predict the need of surfactant replacement therapy in infants with respiratory failure.[14,15,20–23]

Brat et al. enrolled two groups of newborns, with GA < 34 or ≥34 weeks, respectively. LU was performed as soon as possible after admission of the newborn to NICU and always before administration of surfactant.[15] The authors found that LUS was effective in predicting the need for surfactant replacement with cut-off values of 2 and 4 for the population of infants with GA ≥ 34 or <34 weeks, respectively.[15] However, this score performed better in more preterm infantswith GA < 34 (area under curve [AUC] 0.83, 95% CI: 0.86–0.99), than in infants with GA ≥ 34 weeks (AUC 0.71, 95% CI: 0.54–0.9).[15]

In 2018, De Martino et al. explored the ability of LUS to predict the need for surfactant in a population of infants with GA ≤30 weeks.[20] ROC analysis showed an AUC of 0.94 (95% CI: 0.90–0.98), whereas the AUC in infants with GA > 28 or ≤ 28 weeks was 0.93 and 0.98, respectively. The suggested cut-off values of LUS predicting the need for surfactant were 6 and 8 in the subgroups of infants with GA > or ≤ 28 weeks, respectively.[20] The need for a second dose of surfactant was predicted with less accuracy since AUC was 0.803 (95% CI: 0.72–0.89). As reported by authors, the response to surfactant administration depends on several factors, such as the type of mechanical ventilation, surfactant dose, degree of its catabolism, and lung inflammation. Thus, LU may not be as good in predicting clinical response to surfactant administration and the need for subsequent doses.

The role of LUS in the prediction of surfactant requirement is based on the assumption that ultrasound findings are detectable earlier than clinical signs and critical oxygen-dependency, defined as $FiO_2 > 0.3$. The latter criteria is usually used when deciding to administer surfactant in newborns affected by RDS. Since "early rescue" surfactant treatment (within 3 h of life) is known to improve outcomes,[24] incorporating LUS in the management of neonates with RDS could increase the number of babies receiving surfactant timely, including those patients who later develop clinical criteria for surfactant administration.[25]

Based on this assumption, the ESTHER (echography-guided surfactant therapy) study enrolled infants with GA ≤ 32 weeks and was designed as a before-after study.[26] In the standard period, criteria for giving surfactant were those reported in the European guidelines ($FiO_2 > 0.30$),[25] while in the ESTHER period a LUS > 8 was added to previous criteria. More infants had early treatment during the ESTHER period than in the standard period (90% vs. 71.4%) and a lower FiO_2 before treatment (0.33 [0.26–0.50] vs. 0.40 [0.40–0.55]). Moreover, in the ESTHER period there was a decrease in invasive ventilation duration and an increase of ventilator-free days, without increasing the need of surfactant.[26]

In 2020, Rodriguez-Fanjul et al. published the first randomized control trial on the use of LUS to guide surfactant treatment.[16] Infants with GA < 32 weeks were enrolled in the study. The control group received surfactant according to the current European guidelines ($FiO_2 > 0.30$) [25] and the LU group received surfactant when LUS was >8 or FiO_2 was >0.30. Primary outcome was the increase in proportion of infants treated "early" (within 3 h of life) in the experimental group compared to the control group.[14] Although the number of infants enrolled was small (29 vs. 27) and infants who had "early" treatment in the control group were few (6%), the study showed that the use of LUS guaranteed early treatment in all neonates with RDS. Moreover, none of the patients with a LUS ≤ 8 required surfactant treatment, suggesting that LUS can help clinicians select the correct population to treat.[14] After these monocentric studies, Raimondi et al.[23] published the first multicenter trial demonstrating that a LUS ≥ 9 predicts surfactant treatment with an AUC of 0.86 (95% CI: 0.81–0.91), a sensitivity of 0.79 (95% CI: 0.70–0.86), and a specificity of 0.83 (95% CI: 15, 0.76–0.89). This

TABLE 1 Proposed lung ultrasound score cut-off and predictive characteristics relating to the need for exogenous surfactant replacement therapy in preterm infants

Author	GA (weeks)	Hours of life	LU protocol	LUS cut-off for predicting first surfactant dose	Sensitivity, % (95% CI)	Specificity, % (95% CI)	AUROC (95% CI)	LUS cut-off for predicting second surfactant dose	Time	Sensitivity, % (95% CI)	Specificity, % (95% CI)	AUROC (95% CI)
Brat[15]	<34	First hours of life	6-regions	>4	100	61	0.93 (0.86–0.99)	NR	NR	NR	NR	NR
De Martino[20]	≤30	First hours of life	6-regions	>8	82 (71–90)	92 (83–98)	0.94 (0.90–0.98)	>10	First hours of life	84 (60–97)	70 (61–78)	0.80 (0.72–0.89)
Perri[21]	<37	NR	6-regions	NR	NR	NR	NR	≥7	2 h after first surfactant administration	94	60	0.80 (0.76–0.85)
Badurdeen[14]	<32	1–3 h	6-regions	Type 1 or worse	86 (64–97)	73 (50–89)	0.86 (0.75–0.97)	NR	NR	NR	NR	NR
Vardar[22]	<34	First hours of life	6-regions	>4	96	100	1 (0.97–1)	NR	NR	NR	NR	0.99 (0.978–1)
Raimondi[23]	25 + 0-33-6	2 hours of life	6-regions	≥9	79 (70–86)	83 (76– 89)	86 (81–91)	NR	NR	NR	NR	NR

Abbreviations: AUROC, area under the receiver operating characteristic curve; GA, gestational age; LU, lung ultrasound; LUS, lung ultrasound score.

TABLE 2 Proposed lung ultrasound score cut-offs and predictive characteristics relating to the diagnosis of bronchopulmonary dysplasia in preterm infants

Author	BPD definition	Gestational Age (weeks)	LU protocol	LUScut-off for predicting BPD	Days of life	Sensitivity, % (95% CI)	Specificity, % (95% CI)	AUROC (95% CI)
Abdelmawla[30]	Need of positive pressure support or supplemental oxygen therapy at 36 weeks PMA	<30	8-areas (Four areas per hemithorax: upper anterior, lower anterior, lateral, and costophrenic angle for assessment of pleural effusions)	≥6	2–8 weeks	76	97	0.94 (0.7[illegible].97)
Alonso-Ojembarrena[31]	Walsh 2004, any degree	≤32 and/or Birth weight ≤1500 g	6-areas (Three areas per hemithorax: upper anterior, lower anterior and lateral)	≥5	7	71 (47–87)	79 (59–87)	0.8 (0.65–0.91)
				≥5	14	74 (51–88)	100 (82–100)	0.93 (0.8–0.99)
	Walsh 2004, moderate to severe			≥4	28	100 (65–100)	78 (61–89)	0.89 (0.75–0.97)
Hoshino[32]	NICHD 2001, moderate to severe	<32	6-areas (Three areas per hemithorax: anterior, lateral and posterior)	≥7	28	85 (72–94)	92 (79–98)	0.95 (0.91–0.99)
Oulego-Erroz[33]	NICHD 2001, moderate to severe	<32	8-areas (Four areas per hemithorax: upper anterior, lower anterolateral, lower posterolateral, and lower posterior)	≥8	7	93	91	0.94 (0.87–1)
	NICHD 2001, Any grade			≥5	7	90	81	0.93 (0.86–1)
Liu[34]	Jensen 2019, any grade	<32	10-areas (Five areas per hemithorax: upper anterior, lower anterior, lateral, upper posterior, and lower posterior)	>8	12	72 (57.5–83.8)	85.9 (76.2–92.7)	0.832 (0.756–0.892)
			12-areas (Six areas per hemithorax: upper anterior, lower anterior, upper lateral, lower lateral, upper posterior, and lower posterior)	>8	12	74 (59.7–85.4)	84.6 (74.7–91.8)	0.834 (0.758–0.894)
Mohamed[35]	Need of oxygen or respiratory support at 36 weeks of PMA or at the time of discharge, if earlier. Any grade	<29	6-areas (Three areas per hemithorax: upper anterior, lower anterior and lateral)	>11	3	95 (90–100)	80 (72–89)	0.964 (0.94–0.987)
				>10	7	89 (82–97)	90 (83–96)	0.966 (0.943–0.989)
				>11	14	91 (84–98)	83 (75–91)	0.948 (0.918–0.977)

TABLE 2 (Continued)

Author	BPD definition	Gestational Age (weeks)	LU protocol	LUScut-off for predicting BPD	Days of life	Sensitivity, % (95% CI)	Specificity, % (95% CI)	AUROC (95% CI)
Alonso-Ojembarrena[36]	Walsh 2004, moderate to severe	<32	6-areas (Three areas per hemithorax: upper anterior, lower anterior and lateral)	≥7	3	80 (58–92)	71 (61–79)	0.77 (0.68–0.85)
				≥8	7	70 (58–80)	79 (72–84)	0.79 (0.74–0.84)
				≥7	21	77 (59–88)	74 (65–81)	0.80 (0.72–0.86)
Aldecoa-Bilbao[37]	NICHD 2001, any grade	<32	6-areas (Three areas per hemithorax: clavicular line, anterior axillary line, posterior axillary line)	≥8	7	70 (55–80)	91 (79–96)	0.87 (0.79–0.94)
	Jensen 2019, any grade		6-areas (Three areas per hemithorax: mid-clavicular line, anterior axillary line, posterior axillary line)	≥9	7	65 (45–81)	82 (71–89)	0.80 (0.70–0.90)
Raimondi[17]	Jensen 2019, any grade	25 + 0 – 33 + 6	6-areas (Three areas per hemithorax: mid-clavicular line, anterior axillary line, posterior axillary line)	≥10	7	68	82	0.82 (0.71–0.93)

Abbreviations: AUROC, area under the receiver operating characteristic curve; BPD, bronchopulmonary dysplasia; CI, confidence interval; LU: lung ultrasound; LUS, lung ultrasound score; PMA, post menstrual age.

study also reported the possibility of predicting the need for surfactant based on an algorithm based on the use of GA, $SatO_2$/FiO_2 ratio, and LUS. The algorithm, not available for clinical use, appears online at the https://model-pred.shinyapps.io/shinyapp/.

A recent paper by Perri et al.[21] explored changes of LUS 2 h after the first dose of surfactant (Poractant-alfa) in preterm infants with RDS. They found that a LUS ≥ 7 predicted the need for a second dose with a sensitivity of 94% and a specificity of 60% with a NPV of 95% and a PPV of 56%.[21]

The administration of a second dose of surfactant is fairly rare with poractant-alfa and more common with bovine more diluted surfactants. This has been well known for years and has recently been meta-analyzed.[27] The distending pressure applied and the relative leaks are other factors that may influence the outcome.[28] Therefore, the results of this study are not generalizable and clearly depend on the type of surfactant used.

Furthermore, it is clearly very important to establish standardized criteria to define the need for a second dose of surfactant, taking into account that the mean half-life of palimitc acid dipalmitoyl phosphatidylcholine is around 10–12 h[29] in newborns needing retreatment. Thus, many second doses may have been given too early compared to the real need of the newborns.

Badurdeen et al. did not calculate a LUS but evaluated if LU patterns were able to predict the need of surfactant in a population of infants with a GA < 33 weeks.[14] They studied ultrasound patterns at 5–10 min, 11–20 min, and 1–3 h of life. They used five patterns, where pattern 0 represents a totally unventilated lung, Type 3 a normal lung, and Type 0.5, 1, and 2 intermediate conditions.[14] A pattern defined as Type 1/2 (Type 1 or worse, at least onone side of the chest) had a specificity of 73% (95% CI: 50–89) and sensitivity of 86% (95% CI: 64–97) at 1–3 h of life to identify newborns requiring surfactant treatment, whereas a pattern defined as Type 1/1 (Type 1 or worse on both sides of the chest) had a specificity of 86% (95% CI: 65–97) and sensitivity of 81% (95% CI: 58–95) at 1–3 h of life.

These results highlight again the potential of LUS to predict the need for surfactant replacement therapy and support the incorporation of LU findings in the decision-making process, when managing preterm neonates with RDS in the first hours of life. Multicentric randomized controlled trials are needed to evaluate the impact of this method to guide surfactant treatment on more important clinical outcomes such as the reduction of mechanical ventilation and BPD.

In conclusion, as evidenced by Table 1, there is a certain variability in the recommended LUS cut-offs for predicting the administration of exogenous surfactant (range: 4–9). We believe that the threshold value of 8, proposed by De Martino et al. and Raimondi et al., should be considered more accurate.[20,23] This opinion is based on the data reported by the studies of Raschetti et al.[26] and Rodriguez-Fanjul et al.[16] which showed that in infants evaluated by LUS there was no increase in the proportion of those treated. In the case of using lower score cut-offs, there could be, in our opinion, a significant risk of overtreatment.

3.2 | Lung ultrasound score and prediction of bronchopulmonary dysplasia

Recently, the use of LUS has also been applied to predict the development of BPD in the first weeks of life.

In Table 2, we report the most important studies on this topic[17,30–37] whose results are clearly affected by BPD definition used in the study population [38–40] and type of score adopted. In most of the studies carried out to date, LUS were shown to be able to predict the development of BPD as early as 7–14 days of life, with a predictive cut-off value ranging between 4 and 10.[17,30–37]

Although BPD is a disease characterized by a non homogeneous lung picture[41] with particular involvement of the gravity-dependent areas,[42] the inclusion of posterior areas in the LUS does not seem to improve the predictive characteristics as demonstrated by Alonso-Ojembarrena et al.[36] and in the recent meta-analysis published by Pezza et al.[43]

A novel approach was proposed by Raimondi et al. who developed a logistic regression model to describe the interaction between GA and LUS in predicting BPD.[17] Similar results were obtained from the model proposed by Aldecoa Bilbao et al.[37] These models had a higher predictive capacity compared to the LUS alone.

As for LUS and exogenous surfactant therapy, even in BPD all presented LUS are valid for prediction of this disease, as demonstrated by the data obtained. While waiting for studies that further clarify the differences among types of LUS, it is particularly important within a NICU to standardize the method of execution, the timing, cut-off, and the type of LUS used. Clearly, the protocols that we consider most useful are those that allow the identification of infants at risk of BPD as soon as possible, therefore at 7 or at most 14 days of life.

It is evident that the application of LUS in the monitoring of preterm newborns in NICU is extremely interesting as it seems to allow early identification of newborns at risk of developing BPD and to carry out their follow-up, helping the clinician make more targeted therapeutic choices.

4 | CONCLUSION

The use of LU is widely increasing in NICUs, not only as a traditional diagnostic tool but also as a semi-quantitative method with the introduction of LUS.

Patterns of LU can be useful in the management of infants with respiratory failure especially in centers with low level of care, where LU can help identify ear early neonates who will later require respiratory support and NICU admission and may need to be transferred to centers with a higher level of care.

Recent studies have highlighted the role of LUS in the management of preterm infants with RDS by timely prediction of the need of surfactant replacement therapy during noninvasive ventilation. This result, obtained without increasing the percentage of treated infants, might contribute to improving both the short-

(i.e., decrease of need and duration of mechanical ventilation and oxygen-therapy) and long-term outcomes (i.e., decrease of BPD or death). Multicentric randomized control trials are needed to confirm this hypothesis.

Finally, LUS allows early identification of patients at risk of developing BPD who can benefit from early treatment which can potentially modify the evolution of this severe complication.

In conclusion, LU has been found to be a helpful and accurate bedside diagnostic tool. Further studies are needed to standardize its use, favoring its incorporation in the guidelines and clinical practice.

CONFLICT OF INTERESTS

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Iuri Corsini: Conceptualization-Lead, Methodology-Lead, Supervision-Lead, Validation-Lead, Visualization-Lead, Writing—original draft-Lead, Writing—review, and editing-Lead. Martina Ciarcià: Validation-Supporting, Visualization-Supporting, Writing—review, and editing-Supporting. Benjamim Ficial: Conceptualization-Supporting, Validation-Equal, Visualization-Supporting, Writing—original draft-Supporting, Writing–review and editing-Supporting Letizia Capasso Methodology-Supporting, Validation-Supporting, Visualization-Supporting, Writing—review and editing-Supporting. Fiorella Migliaro: Validation-Supporting, Visualization-Supporting, Writing–review & editing-Supporting Javier Rodriguez Fanjul Validation-Supporting, Visualization-Supporting, Writing—review and editing-Supporting. Maria Clemente: Validation-Supporting, Visualization-Supporting, Writing—original draft-Supporting, Writing—review and editing-Supporting. Francesco Raimondi: Conceptualization-Supporting, Supervision-Equal, Validation-Supporting, Writing—review, and editing-Supporting. Carlo Dani: Conceptualization-Equal, Methodology-Equal, Validation-Supporting, Visualization-Supporting, Writing—original draft-Supporting, Writing—review and editing-Equal Funding Source.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable—no new data generated, or the article describes entirely theoretical research.

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