BMC Medicine

GUIDELINE

Open Access

Guidelines for the use of lung ultrasound to optimise the management of neonatal respiratory distress: international expert consensus

Jing Liu[1*], Riccardo Inchingolo[2], Pradeep Suryawanshi[3], Bin-Bin Guo[4], Dalibor Kurepa[5], Rafael González Cortés[6], Wei Yan[7], Jing-Han Chi[8], Cecilia M. Acosta[9], Mateusz Jagła[10], Deepak Sharma[11], Erich Sorantin[12], Kai-Sheng Hsieh[13], Giulia Graziani[14], Bruna Malta[15], Patricia Woods[16], Qiong Meng[17], Chu-Ming You[17], Piotr Kruczek[18], Martin Kneyber[19,20], Natalia Buda[21], Andrea Smargiassi[22], Jovan Lovrenski[23,24], Xiao-Ling Ren[1,25], Ya-Li Guo[1,25], Ru-Xin Qiu[25], Abdul Razak[26,27,28] and Francesco Feletti[29]

Abstract

Background Respiratory distress is the main reason for the admission of infants to the neonatal intensive care unit (NICU). Rapid identification of the causes of respiratory distress and selection of appropriate and effective treatment strategies are important to optimise favourable short- and long-term patient outcomes. Lung ultrasound (LUS) technology has become increasingly important in this field. According to the scientific literature, LUS has high sensitivity (92–99%) and specificity (95–97%) in diagnosing neonatal respiratory distress syndrome. This diagnostic power helps guide timely interventions, such as surfactant therapy and mechanical ventilation.

Methods Our objective was to outline consensus guidelines among an international panel of experts on the use of LUS to support the decision-making process in managing respiratory distress in the NICU. We used a three-round Delphi process. In each Delphi round, 28 panellists rated their level of agreement with each statement using a four-point Likert scale.

Results In round 1, the panellists reviewed 30 initially proposed statements. In rounds 2 and 3, the statements were redeveloped based on the reviewers' comments, leading to the final approval of 18 statements. Among the 18 consensus statements, grade A was assigned a value of 10, grade B was assigned a value of 7, and grade C was assigned a value of 1.

Conclusions A panel of experts agreed on 18 statements regarding managing infants with respiratory distress. Using LUS may help design future interventional studies and improve the benchmarking of respiratory care outcomes.

Keywords Respiratory distress, Dyspnoea, Lung ultrasound, Neonate, Neonatal intensive care unit, Mechanical ventilation, Pulmonary surfactant, Diagnostic Imaging

*Correspondence:
Jing Liu
liujingbj@live.cn; liujing8001@mail.ccmu.edu.cn
Full list of author information is available at the end of the article

Background

Respiratory distress is the main reason that infants are admitted to the neonatal intensive care unit (NICU). Rapid identification of the causes of respiratory distress and selection of appropriate and effective treatment strategies are important to optimise favourable short- and long-term patient outcomes.

Mechanical ventilation (MV) is a cornerstone of therapy in modern NICUs. It has saved the lives of countless critically ill and premature neonates [1]. However, MV can lead to severe complications, including barotrauma, volumetric injury, ventilator-associated pneumonia, air leak syndrome, hyperventilation, and bronchopulmonary dysplasia (BPD) [2–5]. The current best practice in NICU care is to utilise noninvasive respiratory support, rather than MV, whenever possible. Nevertheless, invasive MV remains indispensable for neonates with severe lung disease [6]. The challenge for NICU clinicians is distinguishing neonates likely to benefit from noninvasive ventilation from those requiring MV [7]. Abundant and emerging evidence suggests that point-of-care lung ultrasound (LUS) can aid assessments of neonates receiving respiratory support by identifying the nature and severity of common lung diseases [8, 9]. LUS can characterise different causes of infant respiratory distress immediately, accurately, and dynamically [10]. Moreover, LUS can diagnose some lung diseases with greater accuracy and specificity than chest X-ray (CXR), and in some NICUs, LUS has entirely replaced the routine use of CXR [11, 12]. Point-of-care LUS is widely available, does not require transfer from the NICU, and does not involve exposure to ionising radiation [13].

LUS can also be used to dynamically assess the efficacy of MV, helping to guide the escalation or weaning of inspiratory and expiratory pressures or tidal volumes. Notably, LUS may improve decisions regarding the optimal time to extubate infants. Despite the best clinical judgement using currently available clinical parameters and physical assessment, approximately 30% of intubated preterm infants fail attempted extubation because of poor respiratory drive, atelectasis, oedema, residual pulmonary function abnormalities, or intercurrent illness [14]. LUS can help clinicians prospectively identify some of these conditions and track their severity in real time to determine the best time to extubate.

Another potential application of LUS is to select candidates for surfactant administration [15, 16]. Exogenous pulmonary surfactant (PS) is an important and effective intervention for treating respiratory distress syndrome (RDS) in premature neonates, as well as other conditions associated with surfactant insufficiency or inactivation [17–21]. However, surfactant administration may cause side effects, including bradycardia, oxygen desaturation, and pulmonary haemorrhage. Therefore, objective criteria are needed to identify the optimal candidates for surfactant administration, and these criteria are currently based almost solely on the amount of oxygen inhaled by neonates [22, 23]. Assessment and scoring by LUS may be a more sensitive tool, enabling earlier surfactant therapy, minimising oxygen exposure, and improving oxygenation after treatment [22].

Overall, LUS allows for more frequent monitoring of treatment results, informing clinicians about the resolution or aggravation of pulmonary pathology in real time. It enables lung function assessment in real time and provides improved evaluation associated with the daily clinical management of neonates with respiratory failure [24–26]. Although growing evidence supports the routine use of LUS, consensus regarding published guidelines or syntheses of evidence-based practice on LUS use in the NICU is lacking.

This study aims to outline consensus guidelines among an international panel of experts on the use of LUS to support the decision-making process in managing severe respiratory diseases in the NICU, including the use of MV and the administration of PS.

Methods

A three-step conventional Delphi process [27] was developed via e-mail [28]. A core group of investigators assembled and invited an expert panel to provide additional opinions. The selection criteria for panellists were that they had either authored published articles with a wealth of experience in this area or were representative members of the Division of Critical Ultrasound, Asia–Pacific Health Association Paediatric Medicine Branch, the World Interactive Network focused on Critical Ultrasound China Branch, China National Health Association Lung Ultrasound Technology Extension Expert Group, Beijing Association of Holistic Integrative Medicine Neonatal Critical Care Medicine Branch and the Neonatal Lung Ultrasound Training Centre in Beijing Obstetrics and Gynaecology Hospital Affiliated with Capital Medical University. Each core group member invited other experts using a 'snowball sampling' approach. The panel consisted of neonatologists and radiologists directly involved in the care and diagnostic imaging of infants in the NICU. It included members from different countries worldwide to minimise converging opinions and cross-contamination of ideas. The panellists were selected based on their publications and active clinical involvement in neonatal care. A minimum of 5 years of experience in thoracic ultrasound was mandatory for panellists. The guiding consensus has been registered on the Practice

guideline REgistration for transPAREncy (http://guidelines-registry.cn/) with a registration number of PREPARE-2025CN011. Based on published methodologies, we aimed for a panel of approximately 30 participants [27, 29–34].

The core group proposed a series of pertinent statements supported by relevant references during an e-mail brainstorming process. The first round included a qualitative open-ended questionnaire to generate extensive data. Panel members were invited to comment on the statements, expose their concerns, or reformulate the presented options. In further Delphi rounds, we asked for qualitative feedback at the end of each section and general feedback at the end of the questionnaire. In each Delphi round, panellists were required to rate their level of agreement with each statement using a four-point Likert scale [27]. Therefore, the options 'essential', 'important but not essential', 'somewhat important', and 'unimportant/irrelevant' were offered, whereas a neutral middle point was excluded, compelling respondents to express an opinion. The statements' content that achieved consensus in each round was merged and integrated with the proposed suggestions [27, 29]. Statements that did not reach consensus in the previous round were screened for redundancy or modified according to the feedback received.

Data collection and management

The list of statements in each Delphi round was compiled in a Microsoft Forms (© Microsoft 2022) document, and the link to the document was distributed to the panellists by e-mail. The panellists returned their opinions using the same Microsoft platform. Queries involved the following roles of LUS in the NICU:

A. Management of lung diseases, with primary manifestations of lung consolidation on LUS
B. Management of lung diseases, with primary manifestations of lung oedema on LUS
C. Diagnosing and managing pneumothorax via LUS
D. Guiding the adjustment of MV settings
E. Managing the initiation and discontinuation of MV
F. Guiding the administration of PS

The data were exported into an Excel spreadsheet for statistical analysis. Descriptive statistics were used to summarise the panellists' responses to each item. The median and mode are reported; we did not calculate the mean because Likert survey data are traditionally considered an ordinal scale. The interquartile range (IQR) was calculated as an index of the dispersion of responses [34]. We used the IQR to measure dispersion because it captures the spread of the middle 50% of observations, making it more robust and less sensitive to outliers than the standard deviation. Additionally, the IQR is more appropriate for ordinal data, such as Likert scales, where an IQR of 1 or less on a 4- or 5-point scale or two or fewer on a 10-point scale is generally considered indicative of consensus [34]. For these reasons, the IQR was chosen over the standard deviation to represent dispersion and consensus in our analysis.

We further quantified consensus using a system previously described in other studies using the Delphi methodology. The percentage of participants scoring ≥ 3 on the Likert scale for each item was calculated and assigned a grade: 'U' denotes unanimous (100%) agreement, 'A' denotes 90–99% agreement, 'B' denotes 78–89% agreement, and 'C' denotes 67–77% agreement [34–37].

Results

Twenty-eight panellists from 12 countries were included in this study. The panellists had a mean of 11.4 years of experience (median: 10; SD: 4.6) in using lung ultrasound, a mean of 10.3 years of experience (median: 8; SD: 5.5) specifically in using lung ultrasound in neonates, and 8.6 years (median: 8; SD: 3.7) in applying lung ultrasound for the management of neonatal respiratory distress.

Round 1 initially proposed 30 statements. After the panellists' feedback, the number of statements in round 2 included 23, and round 3 submitted 19 statements to the panellists, leading to a final approval of 18 statements. Through the rounds of review, statements were adjusted, added, deleted, and combined based on comments by the reviewers about precision, applicability, completeness, and/or redundancy.

From round 1 to round 3, 'essential' responses increased from 58.7 to 74.5%, whereas 'essential' or 'important but not essential' responses increased from 82.9 to 96.5%. There was no attrition of panellists. The results are shown in Table 1. Among the 18 consensus statements, grade A was assigned a value of 10, grade B was assigned a value of 7, and grade C was assigned a value of 1.

Our panel of experts agreed on various practices for using LUS to optimise neonatal respiratory distress management. These practices involve several important aspects of respiratory care and allow for more evidence-based LUS assistance in decision-making.

Discussion

LUS to support accurate differential diagnosis between the causes of neonatal respiratory failure

Clinicians agree that the role of LUS should be fully considered when determining the cause of neonatal respiratory failure and the clinical signs and symptoms.

Table 1 Statements shared by panellists

	Median	Mode	IQR	% essential or important	Grade
A. Management of lung diseases in which the primary LUS manifestation is lung consolidation					
1. If the diagnosis is respiratory distress syndrome (RDS) on LUS: 1.1. In the case of mild (grade I) RDS, noninvasive MV can be used firstly 1.2. Invasive MV should be strongly considered in cases of moderate (grade II) to severe (grade III) RDS 1.3. The severity degree of RDS can be scored on LUS according to the areas involved	4	4	0	96.80%	A
2. If the diagnosis is mild (grade I) RDS on LUS, the invasive MV should be administered immediately if the lung condition worsens	4	4	1	81.20%	B
3. In RDS treated with invasive MV, monitoring the lung changes by LUS every 2–4 h is necessary	4	4	1	84.30%	B
4. If the diagnosis is severe meconium aspiration syndrome (MAS), severe pneumonia, or atelectasis on LUS, the bronchoalveolar lavage (BAL) using 0.9% NaCl (at the dosage of 1.0–2.0 ml/kg per time) should be performed before MV. Occasionally, diluted PS may be used for lavage at the same dosage	4	4	1.5	71.80%	C
5. After BAL, the MV is not required if lung consolidation disappears on LUS; noninvasive MV should be provided if the extensive consolidation significantly decreases, while invasive MV should be provided if extensive consolidation shows no significant changes on LUS. However, if the diagnosis is pulmonary haemorrhage, the invasive MV therapy should directly instead of BLA	4	4	1	84.30%	B
6. If LUS supports a diagnosis of mild MAS, pneumonia, or atelectasis, MV is generally unnecessary if the infant is clinically stable with normal spontaneous breath	4	4	0	93.75%	A
B. Management of the lung in which the primary LUS manifestation is lung oedema					
1. Lung oedema is a common pathological change in neonates with various diseases, including intrapulmonary and extrapulmonary diseases (e.g. heart disease, hypoproteinemia). However, when excluding extrapulmonary diseases, lung diseases with lung oedema as the primary LUS manifestation are TTN, especially in infants with dyspnoea shortly after birth	4	4	0	93.75%	A
2. Noninvasive MV should be provided firstly if the LUS presents a confluent B-lines or compact B-lines pattern (white lung) because (according to studies on animal models) a baby would develop into type II respiratory failure	4	4	1	78.10%	B
3. LUS can be used to estimate lung water content. Noninvasive respiratory support may be needed if the estimated lung water content is > 10–15 ml/kg, while indication for invasive MV may be needed with an estimated lung water content > 15–20 ml/kg	4	4	1	78.10%	B
4. If the TTN was diagnosed on initial LUS, dynamic LUS observation is necessary until the TTN resolves. TTN can rarely result in secondary RDS due to the development of surfactant deficiency. In this case, LUS would be helpful with more timely identification and treatment of these changes	4	4	1	93.75%	A
5. Less invasive PS administration (LISA) could be adopted if the diagnosis is grade I RDS on LUS. However, invasive MV treatment with PS administration should be adopted if the diagnosis was grade II-III RDS on LUS	4	4	0	93.75%	A
C. Management of the condition of pneumothorax diagnosed on LUS					
1. LUS allows pneumothorax to be identified and its degree determined 2. Whether and how PTX needs to be treated depends on the degree of dyspnoea of the patient 3. Since MV in a patient with an undrained pneumothorax might severely worsen the patient's condition, pneumothorax drainage is required before MV is initiated 4. The MV is usually not required if LUS presented as mild pneumothorax 5. Invasive MV should be provided if moderate-severe pneumothorax is identified on LUS and the infant appears significant clinical distress. However, high-frequency oscillatory ventilation should be preferred	4	4	0	96.80%	A
D. Use of LUS monitoring to guide the adjustment of ventilator parameters					
1. The principle of guiding MV parameter adjustments for invasive or noninvasive treatment based on LUS imaging ensures that the lungs are fully expanded	4	4	0	90.60%	A
2. Neonatal lung overexpansion can be detected effectively by LUS 2.1 Overlapping the median borders of the lungs (transternal transverse section) is an easy-to-detect, specific, and sensitive sign of excessive lung volume 2.2 In addition to overdistension, atelectrauma can be easily detected. The ventilator-induced lung injury is due to repetitive opening and closing of collapsed alveoli and small airways within atelectatic areas during MV	4	4	1	87.50%	B
E. Use LUS to guide the weaning from MV					
1. Weaning from invasive MV can be performed when lung consolidation disappears on LUS in patients initially presenting with consolidated lungs	4	4	1	90.60%	A

Table 1 (continued)

	Median	Mode	IQR	% essential or important	Grade
2. Weaning from invasive MV should be considered when lung oedema shows signs of absorption when the confluent B-lines or compact B-lines become more sparse B-lines or AIS 3. The endotracheal tube can be removed directly when weaning from the ventilator without lowering the parameters (i.e. keeping the original ventilator parameters unchanged) 4. The need for noninvasive respiratory support after weaning from an invasive ventilator should be decided by patient's gestational age, weight, and overall condition	4	4	1	93.75%	A
F. Use LUS to guide exogenous neonatal PS application					
1. Exogenous PS should be provided if the RDS is diagnosed by LUS including the mild (grade I) RDS, and the dosage of PS at 75–100 mg/kg per time is sufficient	4	4	0	96.80%	A
2. The BAL is necessary firstly when severe MAS, pneumonia, or atelectasis exists on LUS; the PS is not required if lung consolidation disappears or the size significantly decreases after BAL Otherwise, PS could be given to the patient. 3. The PS is also unnecessary if the diagnosis is TTN on LUS	4	4	1	84.30%	B

In this respect, the misdiagnosis rate based on traditional diagnostic criteria is high, and only 40% of clinical respiratory distress syndrome (RDS) diagnoses were confirmed in a necropsy study [38]. Among differential diagnoses, the consensus focuses on meconium aspiration syndrome (MAS), pneumonia or atelectasis, transient tachypnoea of the newborn (TTN), and pneumothorax. The LUS pattern is characterised by diffuse and coalescing B-lines, pleural line anomalies, subpleural consolidations with irregular shapes, and air bronchograms distributed in different areas of the lungs and is sufficiently specific to distinguish between MAS, pneumonia, and other causes of neonatal respiratory dyspnoea [39].

RDS and TTN have similar histories and clinical presentations, whereas chest X-ray (CXR) has low sensitivity and specificity [40]. Moreover, owing to improvements in standard prenatal and postnatal care, RDS-like CXR images have also become more uncommon [41].

In contrast, LUS easily detects distinctive signs [41–49], resulting in extremely high accuracy in RDS diagnosis. A systematic review and meta-analysis revealed that the LUS sensitivity was 99% (95% CI: 96–100%), and the specificity was 97%, whereas these values were 91% and 84% for CXR, respectively [40, 50].

The diagnostic value of LUS in RDS was confirmed by Wu et al. in their meta-analysis; they reported a pooled sensitivity of 0.92 (95% CI, 0.89–0.94), specificity of 0.95 (95% CI, 0.93–0.97), positive likelihood ratio of 20.23 (95% CI, 8.54–47.92), negative likelihood ratio of 0.07 (95% CI, 0.03–0.14), and diagnostic odds ratio of LUS in the diagnosis of RDS of 455.30 (95% CI, 153.01–1354.79) [51].

Therefore, LUS may be a viable and superior alternative to CXR in diagnosing TTN and can help differentiate TTN from other aetiologies of respiratory distress in neonates [52].

In particular, the LUS score is often used in differential diagnosis. Using an LUS score resulted in a sensitivity and specificity of 89.0% and 92.5%, respectively, in the differential diagnosis of neonatal RDS and other lung diseases, whereas the scores were 0.914 and 0.933, respectively, in the differential diagnosis of mild versus moderate RDS and moderate versus severe RDS [53].

Similarly, LUS also has increased sensitivity and specificity for diagnosing pneumothorax (PTX). A recent meta-analysis reported a sensitivity and specificity of 98% and 100%, respectively, for the diagnosis of PTX, whereas the sensitivity and specificity of CXR were 82% and 96%, respectively [54].

Using LUS to guide MV therapy in newborn infants with dyspnoea

As discussed previously and supported by the literature, LUS is crucial in choosing candidates for mechanical ventilation and can guide the management of neonatal MV [15, 55–57]. In long-term clinical practice, LUS may support clinicians in formulating an accurate differential diagnosis as a starting point in the decision process for MV administration; it also outperforms conventional radiology in predicting the need for intubation [58] and allowing the monitoring of lung aeration [13].

In particular, a grade A consensus was reached, which stated that LUS allows the assignment of a severity score according to the areas involved that helps define the opportunity to resort to invasive rather than noninvasive MVs. According to Brat et al. [59], each lung can be divided into three areas: upper anterior, lower anterior, and lateral. The lung ultrasound pattern is assessed using a linear microprobe and transverse and longitudinal scans.

A score from 0 to 18 is obtained by assigning each area a score ranging from 0 to 3 points, where 0 indicates an A-line pattern, 1 indicates a B-pattern ($\geq$3 B-lines), 2

indicates a coalescent B-line pattern with possible subpleural consolidations, and 3 indicates extended consolidations. A threshold of 8 was recently associated with the greatest global accuracy (82%; 95% CI) when LUS was used as a replacement for other tests [60].

Therefore, the panellists proposed that invasive MV can be considered when LUS has a score ≥ 8, which indicates that at least two areas examined have a type 2 pattern [59]. For lower scores, however, noninvasive MV should initially be used. Because LUS scores could be early predictors of treatment response [61], the panellists claimed that LUS imaging can guide invasive or noninvasive mechanical ventilation adjustments, ensuring that the lung is fully expanded for the adopted ventilation parameters.

Given the outstanding advantages of guiding MV application under LUS monitoring, according to the expert consensus in Table 1, we summarise the following guidance opinions. Simply, invasive MV treatment should be provided if moderate or severe RDS is diagnosed on LUS, whereas noninvasive MV can initially be provided if the diagnosis is mild RDS on LUS (Fig. 1). Bronchoalveolar lavage (BAL) using 0.9% NaCl is proposed before MV is initiated if LUS suggests a diagnosis of severe meconium aspiration syndrome (MAS), severe pneumonia, or severe atelectasis; if BAL leads to the complete disappearance of a consolidation, MV is not required (Fig. 2); in contrast, in the case of a significant but incomplete reduction, noninvasive MV should be provided (Fig. 3). Invasive ventilation should be provided if the image of large consolidations shows no significant changes after BAL. Although MV is generally unnecessary in mild MAS, pneumonia, or atelectasis cases when the infant is clinically stable and breathing spontaneously. However, if severe lung consolidation occurs in a patient with pulmonary haemorrhage, invasive ventilator therapy with higher parameters should be used instead of BLA (Fig. 4 and Video 1). Another crucial differential diagnosis that may lead to improper use of MV is between TTN and RDS [40–45]. Specifically, lung oedema may depend on TTN, especially in infants with dyspnoea shortly after birth. When identification is unclear, clinicians tend to treat TTN as RDS, leading to an expansion of the administration of MV. In general, invasive MV is unnecessary if the diagnosis is TTN on LUS unless disease progression leads to secondary RDS. Moreover, noninvasive MV can be given if the patient has severe dyspnoea (Fig. 5). PTX is also a common lung disease that threatens the safety of newborns in the NICU. Generally, MV is usually not required if LUS presents as mild PTX (Fig. 6 and Video 2). Invasive MV should be provided if moderate–severe PTX is observed via LUS and if the infant appears to be in significant clinical distress (Fig. 7). However, in this case, we should choose invasive high-frequency oscillatory ventilation instead of conventional invasive ventilation.

For lavage methods, we recommend the following steps: (1) Place the patients in an appropriate position. (2) Connect electrocardiogram monitoring and transcutaneous oxygen saturation monitor. (3) Connect invasive ventilator and adjust the parameters to the optimal condition. (4) 0.9% NaCL1.0–2.0 ml/kg was injected into the endotracheal tube per-times and maintain positive

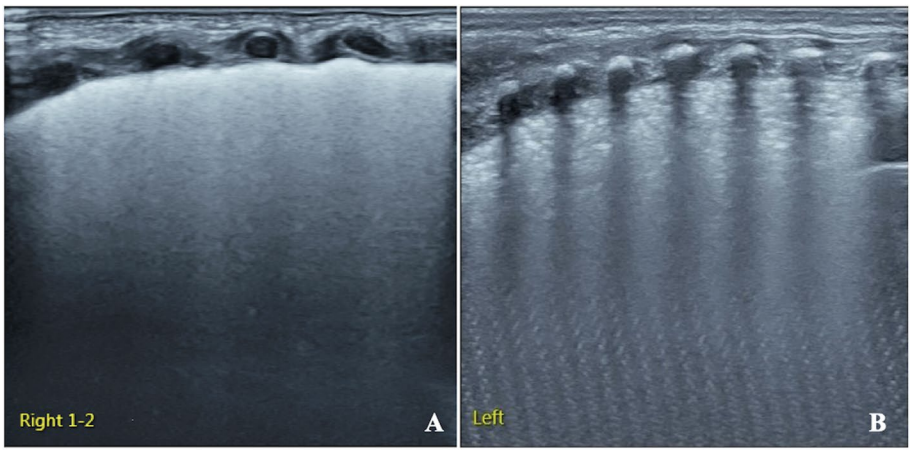

Fig. 1 MV is needed if the diagnosis is RDS on LUS. **A**: A female infant with a GA of 28^{+5} Weeks, cesarean section with birth weight of 1090g. She was admitted to NICU at 11 minutes because of breath difficulty immediately after birth. Arterial blood gas analysis showed $PaCO_2$ 57.7 mmHg, PaO_2 41.2 mmHg, SaO_2 75.4%. LUS showed typical groundless opacity signs, which suggesting the Grade I RDS. The noninvasive MV can be given to this infant firstly, then we dynamically observe the lung condition changes using LUS. **B**: Another infant with gestational age of 34^{+1}Weeks, cesarean section with birth weight of 2010g. Who was admitted to NICU at 20 minutes after birth due to dyspnea 15 minutes. Arterial blood gas analysis showed $PaCO_2$ 70.6mmHg, PaO_2 25.4 mmHg, SaO_2 43.7%. LUS showed snowflake-like lung consolidation, which was the typical LUS manifestations of Grade II or III RDS. This infant should accept invasive MV treatment

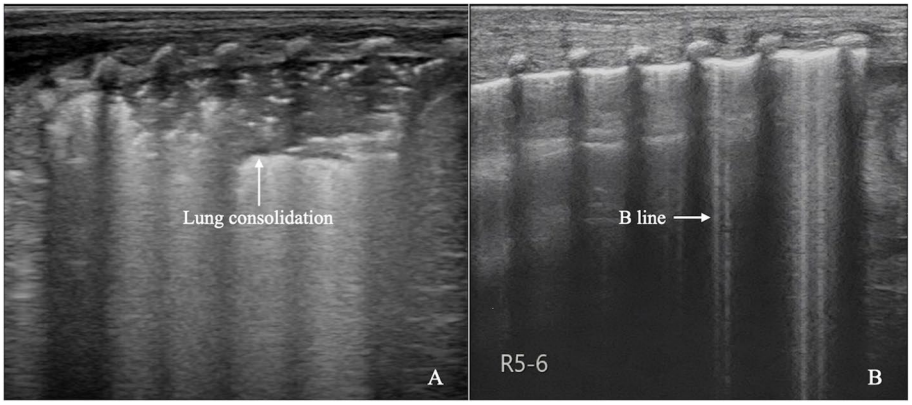

Fig. 2 No need MV after BAL. This was a premature infant with a gestational age of 30 weeks and a birth weight of 1430g. Re-invasive MV was needed because of reemergence of severe dyspnea during hospitalization. LUS showed large area of lung consolidation and atelectasis in the right lung (**A**). After several times of BAL, re-examination of LUS showed that the lung consolidation completely disappeared, only a few B-lines existed (**B**), and thus the invasive MV could be removed

pressure ventilation for 20–30 min. (5) Perform continuous tapping the lung lesion site for 3–5 min, and then the sputum and secretion suction with negative pressure, and each suction period lasts no more than 10 s. (6) The reexamination by LUS should be performed immediately after the lavage and aspiration, and it is determined whether further lavage needed or not is based on the lung re-expansion situation. (7) The times of continuous lavage should not exceed 3 times. (8) For critically ill patients who failed to achieve satisfactory results after 2–3 circles lavage with 0.9% NaCL, lavage with diluted pulmonary surfactant (PS) can be given, or PS treatment can be administered after lavage.

LUS can also be used to monitor changes and responses during MV and treatment for respiratory failure [62]. Specifically, in RDS patients treated with invasive MV, lung changes must be monitored by LUS every 2–4 h. Indeed, LUS is effective in detecting lung overexpansion in neonatal patients. Overlapping the median borders of the lungs (transternal transverse section) is an easy-to-detect, specific, and sensitive sign of excessive lung volume. LUS, in addition to overdistension, can easily detect atelectrauma, a type of ventilator-induced lung injury caused by the repetitive opening and closing of collapsed alveoli and small airways within atelectatic areas during MV.

Using LUS to guide the adjustment of MV settings and weaning from MV

Maintaining normal oxygenation in infants with minimum ventilator parameters is not appropriate for

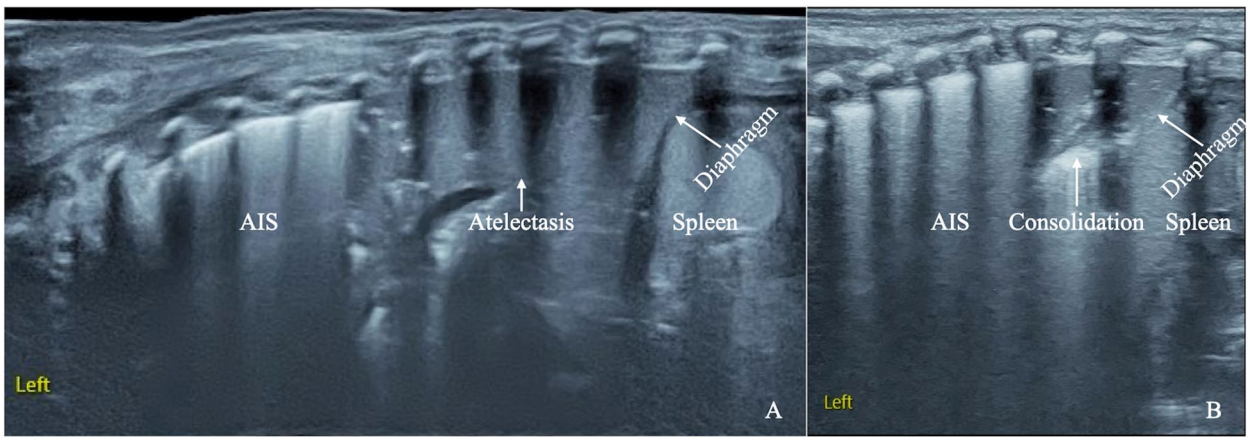

Fig. 3 Need noninvasive MV after BAL. LUS (extend view) showed significant atelectasis involving more than 5 intercostal spaces which need invasive MV treatment to the patient before BAL (**A**), while only small consolidations involved two intercostal spaces remained after BAL (**B**). Therefore, noninvasive MV is required for this infant. Please also refer to video 1

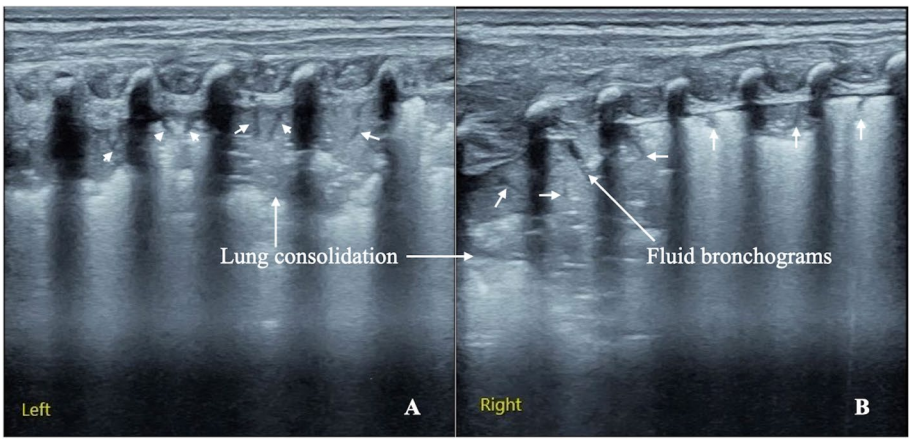

Fig. 4 Invasive MV should be implemented as quickly as possible for Pulmonary hemorrhage. Examination of the lung showed large area of lung consolidation with air bronchograms (the highperechoic reflection within consolidation area), fluid bronchograms (the linear hypoechoic reflection within the consolidation area) and shred signs (the highperechoic reflection on the edge of consolidation area) in both lungs (**A**: left lung, **B**: right lung), which are consistent with ultrasound imaging findings of pulmonary hemorrhage. The invasive MV should be implemented as soon as possible in this case

administering ventilator applications under LUS monitoring, whereas the fundamental principle of guiding the ventilator parameter adjustments under ultrasound monitoring is to ensure that the lung can fully expand under the parameter settings (Fig. 8).

LUS-guided recruitment manoeuvres (RMs) in ventilated preterm neonates with respiratory distress syndrome (RDS) demonstrated superior outcomes compared with non-LUS-guided RMs. LUS guidance resulted in earlier optimal oxygenation with lower FiO requirements and shorter durations of oxygen dependency, invasive ventilation, and NICU stay. Additionally, LUS-guided RM significantly reduced lung inflammation, as evidenced by decreased tracheal IL-6 levels, likely due to minimised atelectrauma and optimised lung recruitment parameters [63].

LUS also supports the decision-making process when weaning from MV, which is a critical issue, especially in mechanically ventilated preterm infants, because each additional week of MV increases the risk of ventilator-induced lung injury, ventilator-associated pneumonia, bronchopulmonary dysplasia (BPD), long-term neurodevelopmental impairment, or even death [64]. The panellists proposed that weaning from noninvasive or invasive MV can be performed when lung consolidation disappears on LUS or when lung oedema shows signs of significant absorption (Figs. 9 and 10).

A prospective, multicentre cohort study showed that LUS may predict weaning success [65]. The clinicians who participated in this survey propose that in the decision to wean from MV, the reduction in pathological signs on LUS must be evaluated in the context of the overall clinical picture. Extubation failure is defined as the need for reintubation in the first 2–7 days after extubation and occurs in as many as 10–80% low birth weight infants of different populations [66, 67]. Any tool potentially useful to improve this rate must be carefully considered because reintubation is significantly associated with increased risks of respiratory morbidities and death or BPD [64].

Using LUS to assess the lung water content

Despite an ongoing debate on the effective utility of LUS in the semiquantitative estimation of the extravascular lung water index (EVLWI) at lower thresholds, higher thresholds (> 20 ml/kg) of the EVLWI have acceptable sensitivity and specificity in a paediatric population [68].

Moreover, LUS can be used to evaluate the lung water content in very-low-birth-weight preterm neonates [69]. B-line protocols provide an accurate noninvasive evaluation of lung water in critically ill patients by predicting lung oedema with an EVLWI ≥ 10 and severe pulmonary oedema with an EVLWI ≥ 15 [70]. A randomised controlled trial recently confirmed that lung ultrasound is a noninvasive and convenient tool for predicting fluid overload in neonatal septic shock patients [71].

Therefore, based on clinical experience, the panellists have suggested the use of LUS to stratify the need for MV in patients with pulmonary oedema. In particular, noninvasive respiratory support may be needed if the estimated lung water content is > 10–15 ml/kg, whereas invasive MV should be reserved for patients with an estimated lung water content > 15–20 ml/kg. Further studies are necessary to confirm the validity of these statements in neonates affected by pulmonary oedema.

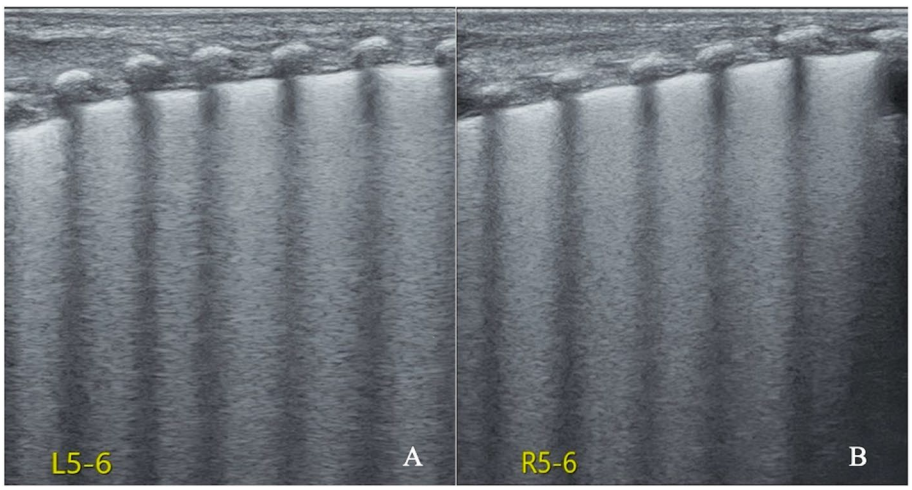

Fig. 5 Noninvasive ventilation is required for severe TTN. LUS showed confluent B-lines and alveolar-interstitial syndrome (AIS) in both lungs (**A**:left lung, **B**:right lung), and no consolidation with air bronchograms were found, which was consistent with the ultrasound imaging features of TTN. Patients may have a certain degree of dyspnea, and noninvasive MV can be given firstly

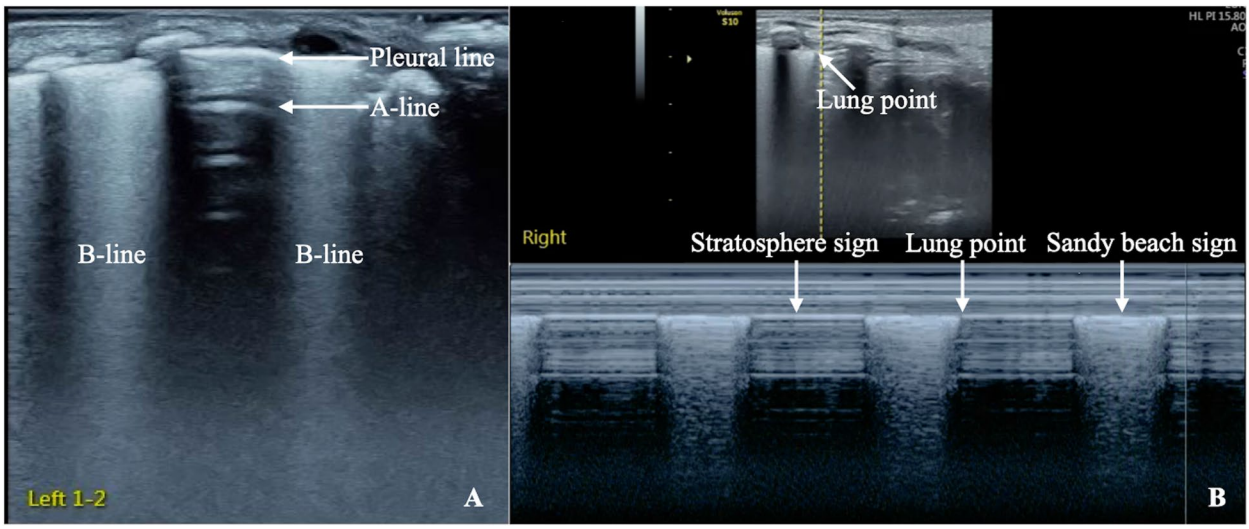

Fig. 6 MV is generally unnecessary for mild pneumothorax. For pneumothorax patient, if spared area (the area that pleural line and A line clearly display surrounded by edema)(**A**) or lung point (**B**) exists in the LUS images. It could be mostly mild pneumothorax, usually no MV treatment needed, the real-time ultrasound examination clearly display the presence of lung point, which was a mild pneumothorax involves less than one intercostal space. Please also refer to Video 2

Using LUS to guide PS administration in newborn infants with severe dyspnoea

LUS can support the selection of patients to receive PS and timing of PS administration. Supplementation with PS represents an important measure for treating severe neonatal breathing difficulties in newborns, especially for patients with RDS [15, 16, 24–27]. Specifically, the panellists stated that exogenous PS should be provided if the diagnosis is RDS on LUS (Figs. 1, 8, 9A), whereas a significant decrease or disappearance of lung consolidation after BAL should discourage PS administration (Figs. 2, 3). Of course, if the diagnosis is TTN on LUS, PS is usually unnecessary (Figs. 5, 10A).

Surfactant administration is currently guided only by the newborn's need for oxygen therapy based on a cut-off, which can be considered entirely arbitrary and cannot accurately reflect the patient's oxygenation [72]. In contrast, some studies reported a strong correlation between

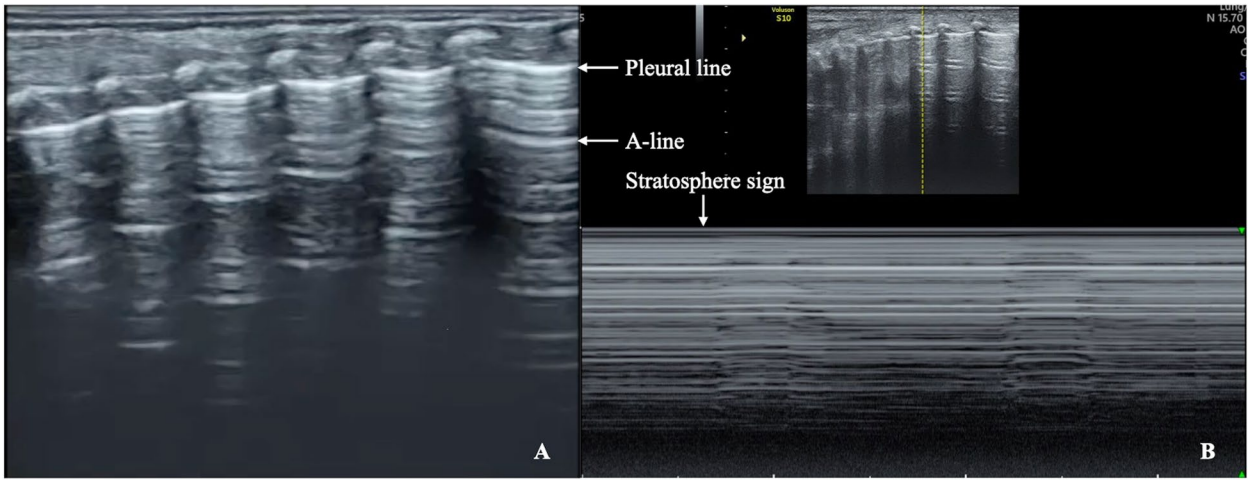

Fig. 7 MV is often used for severe pneumothorax. LUS showed clear presence of pleural line and A-line on B-mode image (**A**) and a stratospheric sign on M-mode (**B**), lung sliding disappeared under real-time ultrasound scanning, while there are no spared area and lung point in the entire lung field. Which was consistent with the ultrasound imaging characteristics of severe pneumothorax. In most cases, the infants with severe pneumothorax need for invasive high-frequency oscillatory ventilation treatment

LUS findings and the need for surfactant therapy [59, 73]. The reported sensitivity and specificity of LUS in predicting and guiding PS administration are 0.86 and 0.82, respectively [50, 74]. Similarly, a recent prospective study confirmed that LUS improved the timeliness of PS administration [75]. When used under ultrasound guidance, the dose of PS is usually one-half the dose recommended by the European guidelines for managing RDS. A recent meta-analysis concluded that LUS is a powerful technique for customising the first dose of surfactant in infants with RDS [76].

In line with the European guidelines [77], the panellists proposed that noninvasive ventilation and less invasive surfactant administration (LISA) are the most suitable initial management methods when LUS is consistent with mild RDS, leaving MV for those with insufficient respiratory drive or higher oxygen requirements. Instead, invasive MV treatment with surfactant administration should be chosen if the sonography diagnosis is grade II-III RDS.

Limitations and challenges of LUS

Neonatal LUS is an increasingly utilised diagnostic tool because of its diagnostic potential, ability to perform repeated examinations without exposure to ionising radiation, and ability to provide real-time imaging. However, compared with CXR, this technique presents several significant limitations that restrict its applicability and effectiveness in specific clinical settings. First, LUS has limited utility in hyperinflated lungs and does not allow visualisation of deep focal lesions when the peripheral lung is normally aerated. Moreover, unlike chest X-ray, which

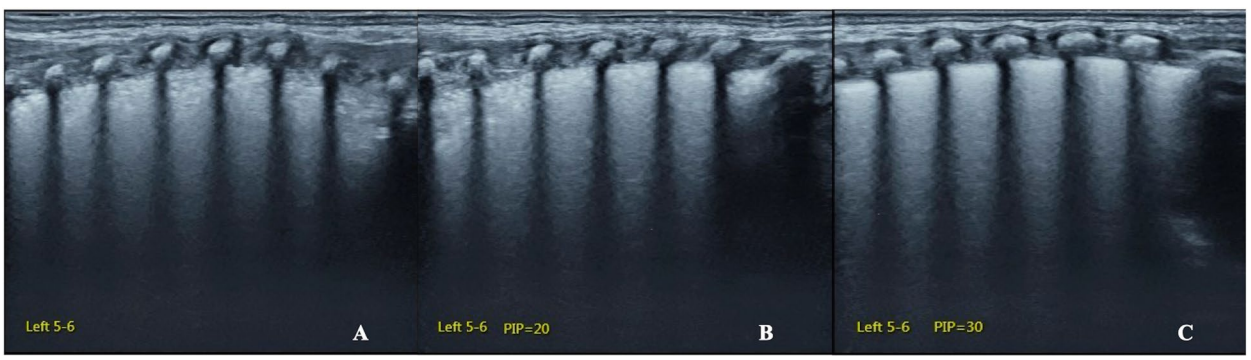

Fig. 8 LUS to guide the adjustting of MV settings. A preterm infant with a gestational age of 31 weeks and a birth weight of 1700g was treated with invasive MV for severe RDS. When the peak inspiratory pressure (PIP) was 0 cm H2O, LUS showed severe snowflake sign-like lung consolidation (**A**). LUS showed that the degree of consolidation decreased slightly when PIP increased to 20 cm H2O (**B**). However, the lung consolidation almost disappeared when PIP increased to 30 cm H2O (**C**). Therefore, the 30 cm H2O of PIP is the most appropriate parameter for this patient

provides a comprehensive anatomical overview of thoracic structures, ultrasound produces sectorial images, creating limitations in diagnosing diffuse diseases and conditions involving the chest wall. Additionally, LUS is limited in assessing bony abnormalities or lesions, such as rib fractures or spinal deformities, which can be easily identified through radiography. Therefore, while LUS provides high sensitivity for detecting certain neonatal lung conditions, CXR remains preferable in specific scenarios, such as severe lung trauma or when assessing conditions requiring comprehensive thoracic visualisation.

Additionally, unlike CXR, LUS is highly operator dependent, requiring specialised training and experience to ensure accurate interpretation. This dependency poses challenges in resource-limited settings where access to training and equipment may be restricted. The cost of acquiring and maintaining ultrasound machines, including portable ultrasound machines, and implementing comprehensive training programs can be significant barriers to widespread adoption. Addressing these barriers through low-cost training initiatives and simplified protocols could enhance LUS accessibility. Moreover, while expert consensus supports LUS use, there is a pressing

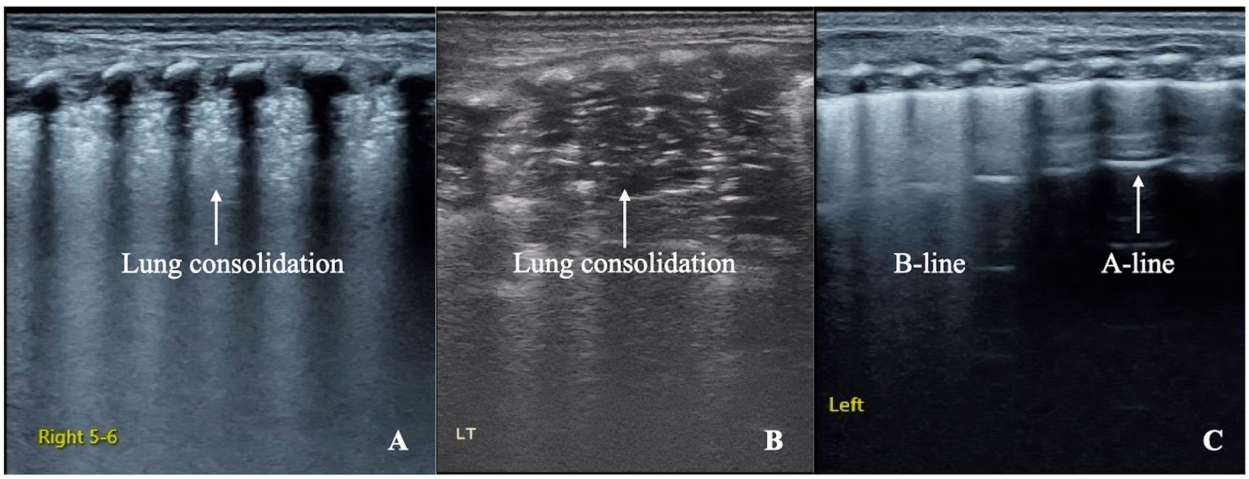

Fig. 9 Weaning from MV in patients with significant lung consolidation. We can withdraw MV when consolidation disappeared in patients with lung consolidation as the main ultrasound manifestation, such as RDS (**A**), pneumonia or atelectasis (**B**) even if the image has not fully returned to normal (**C**)

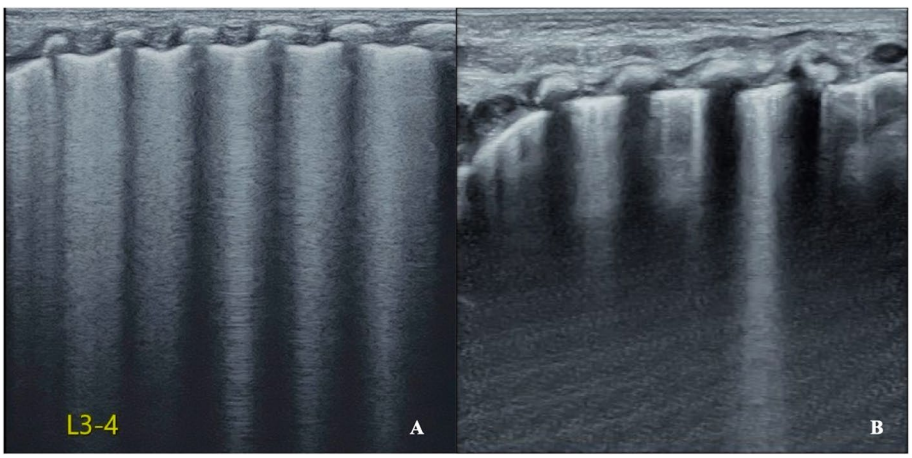

Fig. 10 Weaning from MV in patients with severe lung edema. MV could be withdrawed when lung edema absorbed almostly in patients with severe edema as the major performance on LUS. When edema absorption happens, confluent B-lines, compact B lines or white lung (**A**) will gradually become general B-lines (**B**) on LUS

need for large-scale, prospective randomised controlled trials to validate its efficacy and establish standardised protocols. Future research should focus on these areas to strengthen the evidence base for LUS in neonatal respiratory management.

Limitations

On the basis of all the expert opinions and suggestions, the manuscript was revised more than 28 times. Nevertheless, several limitations also remain that need to be clarified. Because the panellists involved in elaborating and voting on the different statements primarily included professionals previously involved in LUS research, their position towards its use might be biased in a positive sense. Another limitation of our consensus might be the number and selection of the participants involved. We aimed to include experts from different areas worldwide, but the expertise level might differ among participants. Important experts in neonatal LUS were not involved in the study. Moreover, some statements of the present consensus are mainly based on the panellists' clinical experience, and some may need confirmation in further high-quality prospective studies. For example, statements related to the precise estimation of lung water content highlight the need for experimental trials on neonates, and further research is necessary.

However, the clinical perspective remains crucial for guiding practice and clinical research. One of the main strengths of the present study is that the clinicians involved in developing this consensus were from very different backgrounds. Although important differences may exist in the management of neonatal pulmonary disease and the use of LUS among different countries, the inclusion of experts from different specialties and geographical areas has enriched the content of the consensus.

Conclusions

In conclusion, the present study suggests that LUS should play a crucial role in the management of neonatal respiratory diseases, as supported by previous findings of high sensitivity (88%) and specificity (82%) in determining the need for PS treatment or MV in infants with RDS [15, 50]. Furthermore, as a repeatable and dynamic bedside method, LUS allows frequent monitoring of treatment results, resolution of pulmonary pathological signs, and timely identification of worsening pulmonary conditions. LUS enables lung function assessment at the regional level, which may offer the precision currently lacking to clinicians to meaningfully individualise respiratory therapies [24–26]. Finally, LUS is an easy-to-learn imaging method with a high degree of interobserver agreement. The time needed for accurate image acquisition was approximately 3 min in highly skilled hands [26].

According to animal model research, microvascular pulmonary capillary haemorrhage (PCH) injury is possible with clinical LUS use, which could introduce extraneous occurrence of the B-line sign. This possibility is of clinical significance and should be explored in future pathological investigations [78, 79].

The authors propose this document as a starting point for further international discussion of the existing evidence, reliability of the proposed statements, and future perspectives on the use of LUS in optimising the management of neonatal respiratory dyspnoea to obtain shared benefits for research, the health care sector, and patients.

Abbreviations

NICU	Neonatal intensive care unit
PS	Pulmonary surfactant
RDS	Respiratory distress syndrome
VAP	Ventilator-associated pneumonia
BPD	Bronchopulmonary dysplasia
LUS	Lung ultrasound
CXR	Chest X-ray
MAS	Meconium aspiration syndrome
PTX	Pneumothorax
MV	Mechanical ventilation
BAL	Bronchoalveolar lavage
TTN	Transient tachypnoea of the newborn
AIS	Alveolar–interstitial syndrome
GA	Gestational age
PIP	Peak inspiratory pressure
VLBW	Very low birth weight infants
HFOV	High-frequency oscillatory ventilation
EVLWI	Extravascular lung water index
IQR	Interquartile range
LISA	Less invasive surfactant administration
PCH	Pulmonary capillary haemorrhage

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12916-025-03879-5.

Additional file 1: Video 1. Before bronchoalveolar lavage (BAL), real-time LUS revealed extensive lung consolidation and atelectasis spanning more than four intercostal spaces, accompanied by air and fluid bronchograms and a lung pulse.

Additional file 2: Video 2. Mild pneumothorax: real-time LUS image showing a lung point located in the last intercostal space of the right lung, indicating mild PTX. The infant displayed no significant respiratory distress, and ventilator support or thoracentesis was not needed.

Acknowledgements

We thank Dr Haiying Cao from GE Healthcare for providing guidance for lung ultrasound. We thank the NICU staff from Beijing Obstetrics and Gynaecology Hospital Affiliated with Capital Medical University for their work support.

Authors' contributions

JL and FF conceived the study together. JL proposed the first series of statements, invited panellists from Asia and the USA, wrote the article's first draft, reviewed its concepts, and provided related ultrasound pictures. FF organised and coordinated the Delphi process, invited panellists from other continents, collected and analysed the results, wrote the materials and methods section, and revised the manuscript critically for important intellectual content. KD wrote the statements for round 2 of the Delphi process. BM critically revised the manuscript for important intellectual content. All the authors provided their scores, important comments, and proposals for the statements. All the authors read, corrected, and approved the final manuscript.

Funding
This project was supported by the Wu Jie-Ping Medical Foundation Research Fund (320.6750.2024–03-32).

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This work is a methodological study that does not involve human or animal subjects and does not require ethical approval. Informed consent from guardians or study subjects was not needed.

Consent for publication
Informed consent was obtained from all individual participants included in the study.

Competing interests
The authors declare no competing interests.

Author details
[1]Department of Neonatology and NICU, Beijing Obstetrics and Gynecology Hospital, Capital Medical University, Beijing Maternal and Child Health Care Hospital, No.251 Yaojiayuan Road, Chaoyang District, Beijing 100026, China. [2]UOC Pneumologia, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy. [3]Department of Neonatology, Bharati Vidyapeeth University Medical College, Pune, India. [4]Department of Ultrasound, Sixth Affiliated Hospital of Harbin Medical University, Harbin, China. [5]Cohen Children's Medical Center, Northwell Health, New York, USA. [6]Pediatric Intensive Care, Marañón General University Hospital, Madrid, Gregorio, Spain. [7]Department of Ultrasound, Zhumadian Central Hospital of Henan Province, Zhumadian, China. [8]Senior Department of Pediatrics, The Seventh Medical Centerof, PLA General Hospital, Beijing, China. [9]Department of Anesthesia, Hospital Privado de Comunidad, Mar del Plata, Argentina. [10]Jagiellonian University Collegium Medicum, Krakow, Poland. [11]Department of Neonatology, Cradle Children Hospital, Jaipur, Rajasthan, India. [12]Division of Pediatric Radiology, Department of Radiology, Medical University Graz, Graz, Austria. [13]Children's Hospital, China Medical University, Taichung, Taiwan. [14]Unità Operativa Di Pediatria E Neonatologia, Ospedale Santa Maria Delle Croci, Ausl Romagna, Ravenna, Italy. [15]Unità Operativa Di Radiologia, Ospedale Santa Maria Delle Croci, Ausl Romagna, Ravenna, Italy. [16]King Edward Memorial Hospital, Perth, Australia. [17]Department of Paediatrics, Guangdong Second Provincial General Hospital, Guangzhou, China. [18]Department of Neonatology, Czerwiakowski Hospital at Siemiradzki St., Cracow, Poland. [19]Department of Paediatrics, Division of Paediatric Critical Care Medicine, Beatrix Children's Hospital, University Medical Center Groningen, University of Groningen, Groningen, the Netherlands. [20]Critical Care, Anaesthesiology, Perioperative & Emergency Medicine (CAPE), University of Groningen, Groningen, the Netherlands. [21]Simulation Laboratory of Endoscopic and Minimally Invasive Techniques, Medical University of Gdansk, Gdansk, Poland. [22]Dipartimento Neuroscienze, UOC Pneumologia, Organi Di Senso E Torace, Fondazione Policlinico Universitario A. Gemelli IRCCS, Rome, Italy. [23]Faculty of Medicine Novi Sad, University of Novi Sad, Novi Sad, Serbia. [24]Institute for Children and Adolescents Health Care of Vojvodina, Novi Sad, Serbia. [25]Department of Neonatology, Beijing Chao-Yang District Maternal and Child Healthcare Hospital, Beijing, China. [26]Department of Paediatrics, Monash University, Melbourne, VIC, Australia. [27]Monash Newborn, Monash Children's Hospital, Melbourne, VIC, Australia. [28]The Ritchie Centre, Hudson Institute of Medical Research, Melbourne, VIC, Australia. [29]Dipartimento Di Medicina Traslazionale e per la Romagna, Università Di Ferrara, Ferrara, Italy.

Received: 24 September 2024 Accepted: 16 January 2025
Published online: 24 February 2025

References

1. Jain D, Bancalari E. New developments in respiratory support for preterm infants. Am J Perinatol. 2019;36(S02):S13–7.
2. Liu G, Wu H, Li Z. Current views of complications associated with neonatal ventilation. Minerva Pediatr. 2020;72:60–4.
3. Kohbodi GA, Rajasurya V, Noor A. Ventilator-associated pneumonia. In: StatPearls. Treasure Island (FL): StatPearls Publishing; 2021.
4. Cernada M, Brugada M, Golombek S, Vento M. Ventilator-associated pneumonia in neonatal patients: an update. Neonatology. 2014;105:98–107.
5. Solberg MT, Solevåg AL, Clarke S. Optimal conventional mechanical ventilation in full-term newborns: a systematic review. Adv Neonatal Care. 2018;18:451–61.
6. Wheeler CR, Smallwood CD. 2019 year in review: neonatal respiratory support. Respir Care. 2020;65:693–704.
7. Kurepa D, Zaghloul N, Watkins L, Liu J. Neonatal lung ultrasound exam guidelines. J Perinatol. 2018;38:11–22.
8. Liu J, Cao HY, Wang XL, Xiao LJ. The significance and the necessity of routinely performing lung ultrasound in the neonatal intensive care units. J Matern Fetal Neonatal Med. 2016;29:4025–30.
9. Liu J, Guo G, Kurepa D, Volpicelli G, Sorantin E, Lovrenski J, et al. Specification and guidelines for technical aspects and scanning parameter settings of neonatal lung ultrasound examination. J Matern Fetal Neonatal Med. 2022;35:1003–16.
10. Corsini I, Parri N, Gozzini E, Coviello C, Leonardi V, Poggi C, Giacalone M, Bianconi T, Tofani L, Raimondi F, Dani C. Lung ultrasound for the differential diagnosis of respiratory distress in neonates. Neonatology. 2019;115:77–84.
11. Liu J, Lovrenski J, Hlaing AY, Kurepa D. Neonatal lung diseases: lung ultrasound or chest X-ray. J Matern Fetal Neonatal Med. 2021;34:1177–82.
12. Gao YQ, Qiu RX, Liu J, Zhang L, Ren XL, Qin SJ. Lung ultrasound completely replaced chest X-ray for diagnosing neonatal lung diseases: a 3-year clinical practice report from a neonatal intensive care unit in China. J Matern Fetal Neonatal Med. 2020;35:3565–72.
13. Loi B, Vigo G, Baraldi E, Raimondi F, Carnielli VP, Mosca F, De Luca D. Lung ultrasound to monitor extremely preterm infants and predict bronchopulmonary dysplasia. A multicenter longitudinal cohort study. Am J Respir Crit Care Med. 2021;203:1398–409.
14. Gizzi C, Moretti C, Agostino R. Weaning from mechanical ventilation. J Matern Fetal Neonatal Med. 2011;24(Suppl 1):61–3.
15. Razak A, Faden M. Neonatal lung ultrasonography to evaluate need for surfactant or mechanical ventilation: a systematic review and meta-analysis. Arch Dis Child Fetal Neonatal Ed. 2020;105:164–71.
16. Liu J, Fu W, Qin SJ. Lung ultrasound to guide the administration of exogenous pulmonary surfactant in respiratory distress syndrome of newborn infants: a retrospective investigation study. Front Pediatr. 2022;10:952315.
17. El Shahed AI, Dargaville PA, Ohlsson A, Soll R. Surfactant for meconium aspiration syndrome in term and late preterm infants. Cochrane Database Syst Rev. 2014;12:CD002054.
18. Deshpande S, Suryawanshi P, Ahya K, Maheshwari R, Gupta S. Surfactant therapy for early onset pneumonia in late preterm and term neonates needing mechanical ventilation. J Clin Diagn Res. 2017;11:SC09-SC12.
19. Qiu RX, Liu X, Wang JL, Cai C, Zeng JA, Liu HC, Cheng R, Li ZK, Liu J. Clinical effect of exogenous pulmonary surfactant in the treatment of severe neonatal infectious pneumonia: a multicenter prospective clinical trial. CJCP. 2019;21:327–31.
20. Alkan S, Ozer EA, Ilhan O, Sutcuoglu S, Tatli M. Surfactant treatment for neonatal respiratory disorders other than respiratory distress syndrome. J Matern Fetal Neonatal Med. 2015;28:131–3.
21. Sweet DG, Carnielli V, Greisen G, Hallman M, Ozek E, Te Pas A, Plavka R, Roehr CC, Saugstad OD, Simeoni U, Speer CP, Vento M, Visser GHA, Halliday HL. European consensus guidelines on the management of respiratory distress syndrome - 2019 update. Neonatology. 2019;115:432–50.
22. Rodriguez-Fanjul J, Jordan I, Balaguer M, Batista-Muñoz A, Ramon M, Bobillo-Perez S. Early surfactant replacement guided by lung ultrasound in preterm newborns with RDS: the ULTRASURF randomised controlled trial. Eur J Pediatr. 2020;179:1913–20.
23. Gortner L, Schüller SS, Herting E. Review demonstrates that less invasive surfactant administration in preterm neonates leads to fewer complications. Acta Paediatr. 2018;107:736–43.
24. Shepherd EG, De Luca D. New imaging tools allow bronchopulmonary dysplasia to enter the age of precision medicine. Am J Respir Crit Care Med. 2020;202:924–6.

25. Tingay DG, Pereira-Fantini PM, Oakley R, McCall KE, Perkins EJ, Miedema M, et al. Gradual aeration at birth is more lung protective than a sustained inflation in preterm lambs. Am J Respir Crit Care Med. 2019;200:608–16.
26. Tingay DG, Sett A, Jobe AH. Lung ultrasound in early preterm life: a window into the future? Am J Respir Crit Care Med. 2021;203:1338–9.
27. de Villiers MR, de Villiers PJ, Kent AP. The Delphi technique in health sciences education research. Med Teach. 2005;27:639–43.
28. Jones J, Sanderson C, Black N. What will happen to the quality of care with fewer junior doctors? A Delphi study of consultant physicians' views. J R Coll Physicians Lond. 1992;26:36–40.
29. Linstone HA, Turoff M. The Delphi method techniques and applications. Boston: Addison-Wesley; 1975.
30. Moore CM. Group techniques for idea building. Thousand Oaks: Sage Publications; 1987.
31. Okoli C, Pawlowski SD. The Delphi method as a research tool: an example, design considerations and applications. Inf Manag. 2004;42:15–29.
32. Akins RB, Tolson H, Cole BR. Stability of response characteristics of a Delphi panel: application of bootstrap data expansion. BMC Med Res Methodol. 2005;5:37.
33. Santaguida P, Dolovich L, Oliver D, Lamarche L, Gilsing A, Griffith LE, Richardson J, Mangin D, Kastner M, Raina P. Protocol for a Delphi consensus exercise to identify a core set of criteria for selecting health related outcome measures (HROM) to be used in primary health care. BMC Fam Pract. 2018;19:152.
34. Shang Z. Use of Delphi in health sciences research: a narrative review. Medicine (Baltimore). 2023;102:e32829.
35. Rubino F, Puhl RM, Cummings DE, Eckel RH, Ryan DH, Mechanick JI, et al. Joint international consensus statement for ending stigma of obesity. Nat Med. 2020;26:485–97.
36. Sun DQ, Targher G, Byrne CD, Wheeler DC, Wong VW, Fan JG, et al. An international Delphi consensus statement on metabolic dysfunction-associated fatty liver disease and risk of chronic kidney disease. Hepatobiliary Surg Nutr. 2023;12:386–403.
37. Lazarus JV, Mark HE, Anstee QM, Arab JP, Batterham RL, Castera L, et al. Advancing the global public health agenda for NAFLD: a consensus statement. Nat Rev Gastroenterol Hepatol. 2022;19:60–78.
38. Rocha G, Rodrigues M, Guimarães H. Respiratory distress syndrome of the preterm neonate-placenta and necropsy as witnesses. J Matern Fetal Neonatal Med. 2011;24:148–51.
39. Perri A, Fattore S, Prontera G, Patti ML, Sbordone A, Tana M, D'Andrea V, Vento G. Lung ultrasound in the early diagnosis and management of the mild form of meconium aspiration syndrome: a case report. Diagnostics (Basel). 2023;13:719.
40. Ma HR, Yan WK, Liu J. Diagnostic value of lung ultrasound for neonatal respiratory distress syndrome: a meta-analysis and systematic review. Med Ultrason. 2020;22:325–33.
41. Liu J, Wang Y, Fu W, Yang CS, Huang JJ. The diagnosis of neonatal transient tachypnea and its differentiation from respiratory distress syndrome using lung ultrasound. Medicine (Baltimore). 2014;93:e197.
42. Vergine M, Copetti R, Brusa G, Cattarossi L. Lung ultrasound accuracy in respiratory distress syndrome and transient tachypnea of the newborn. Neonatology. 2014;106:87–93.
43. Liu J, Qiu RX, Ren XL, Li JJ, Xia RM, Chi JH. The differentiation diagnosis of respiratory distress syndrome and transient tachypnea of the newborn by lung ultrasound. Chest. 2019;155(4s):A1-232A.
44. Ibrahim M, Omran A, Abdallah NB, Ibrahim M, El-Sharkawy S. Lung ultrasound in early diagnosis of neonatal transient tachypnea and its differentiation from other causes of neonatal respiratory distress. J Neonatal Perinatal Med. 2018;11:281–7.
45. Raimondi F, Yousef N, Rodriguez Fanjul J, De Luca D, Corsini I, Shankar-Aguilera S, Dani C, Di Guardo V, Lama S, Mosca F, Migliaro F, Sodano A, Vallone G, Capasso L. A multicenter lung ultrasound study on transient tachypnea of the neonate. Neonatology. 2019;115:263–8.
46. Shari HMM, Naghibi S, Mahdavi E, Khademi G. Diagnostic utility of chest X-rays in neonatal respiratory distress: determining the sensitivity and specificity. Int J Pediatr. 2014;2:65–72.
47. Roggini M, Pepino D, D'Avanzo M, Andreoli GM, Ceccanti S, Capocaccia P. Respiratory distress in newborn: evaluation of chest X-rays. Minerva Pediatr. 2010;62:217–9.
48. Liu J, Chen XX, Li XW, Chen SW, Wang Y, Fu W. Lung ultrasonography to diagnose transient tachypnea of the newborn. Chest. 2016;149:1269–75.
49. Oktem A, Yigit S, Oğuz B, Celik T, Haliloğlu M, Yurdakok M. Accuracy of lung ultrasonography in the diagnosis of respiratory distress syndrome in newborns. J Matern Fetal Neonatal Med. 2021;34:281–6.
50. Nobile S, Sette L, Esposito C, Riitano F, Di Sipio MC, Sbordone A, Vento G, Perri A. Diagnostic accuracy of lung ultrasound in neonatal diseases: a systematised review. J Clin Med. 2024;13:3107.
51. Wu J, Wang Y, Zhao A, Wang Z. Lung ultrasound for the diagnosis of neonatal respiratory distress syndrome: a meta-analysis. Ultrasound Q. 2020;36:102–10.
52. Ma HR, Liu J, Yan WK. Accuracy and reliability of lung ultrasound to diagnose transient tachypnoea of the newborn: evidence from a meta-analysis and systematic review. Am J Perinatol. 2022;39:973–9.
53. Huang P, Chen D, Liu X, Zhang X, Song X. Diagnostic value of bedside lung ultrasound and 12-zone score in the 65 cases of neonatal respiratory distress syndrome and its severity. Biomed Eng Online. 2024;23:29.
54. Fei Q, Lin Y, Yuan TM. Lung ultrasound, a better choice for neonatal pneumothorax: a systematic review and meta-analysis. Ultrasound Med Biol. 2021;47:359–69.
55. Sharma D, Farahbakhsh N. Role of chest ultrasound in neonatal lung disease: a review of current evidences. J Matern Fetal Neonatal Med. 2019;32:310–6.
56. Rodríguez-Fanjul J, Balcells C, Aldecoa-Bilbao V, Moreno J, Iriondo M. Lung ultrasound as a predictor of mechanical ventilation in neonates older than 32 weeks. Neonatology. 2016;110:198–203.
57. Szymański P, Kruczek P, Hożejowski R, Wais P. Modified lung ultrasound score predicts ventilation requirements in neonatal respiratory distress syndrome. BMC Pediatr. 2021;21:17.
58. Raimondi F, Migliaro F, Sodano A, Ferrara T, Lama S, Vallone G, Capasso L. Use of neonatal chest ultrasound to predict noninvasive ventilation failure. Pediatrics. 2014;134:e1089-94.
59. Brat R, Yousef N, Klifa R, Reynaud S, Shankar Aguilera S, De Luca D. Lung ultrasonography score to evaluate oxygenation and surfactant need in neonates treated with continuous positive airway pressure. JAMA Pediatr. 2015;169:e151797.
60. De Luca D, Bonadies L, Alonso-Ojembarrena A, Martino D, Gutierrez-Rosa I, Loi B, Dasani R, Capasso L, Baraldi E, Davis A, Raimondi F. Quantitative lung ultrasonography to guide surfactant therapy in neonates born late preterm and later. JAMA Netw Open. 2024;7:e2413446.
61. Zini T, Miselli F, Berardi A. Noninvasive monitoring strategies for bronchopulmonary dysplasia or post-prematurity respiratory disease: current challenges and future prospects. Children. 2023;10:1753.
62. Lee J. Lung ultrasound as a monitoring tool. Tuberc Respir Dis (Seoul). 2020;83(Supple 1):S12–6.
63. Abushady NM, Awad HAS, Kamel DR, Fouda EM, Ahmed NT, Dawoud MO. Role of lung ultrasound in the assessment of recruitment maneuvers in ventilated preterm neonates with respiratory distress syndrome and its correlation with tracheal IL-6 levels: a randomised controlled trial. J Neonatal Perinatal Med. 2021;14:369–74.
64. Sant'Anna G, Shalish W. Weaning from mechanical ventilation and assessment of extubation readiness. Semin Perinatol. 2024;48:151890.
65. Szymański P, Puskarz-Gąsowska J, Hożejowski R, Stefańska M, Błaż W, Sadowska-Krawczenko I, et al. Prognostic relevance of the lung ultrasound score: a multioutcome study in infants with respiratory distress syndrome. Am J Perinatol. 2024;41(S 01):e2862–9.
66. Sangsari R, Saeedi M, Maddah M, Mirnia K, Goldsmith JP. Weaning and extubation from neonatal mechanical ventilation: an evidenced-based review. BMC Pulm Med. 2022;22:421.
67. Masry A, Nimeri NAMA, Koobar O, Hammoudeh S, Chandra P, Elmalik EE, Khalil AM, Mohammed N, Mahmoud NAM, Langtree LJ, Bayoumi MAA. Reintubation rates after extubation to different non-invasive ventilation modes in preterm infants. BMC Pediatr. 2021;21:281.
68. Niyogi SG, Kumar B, Puri GD, Negi S, Mishra AK, Singh Thingnam SK. Utility of lung ultrasound in the estimation of extravascular lung water in a pediatric population-a prospective observational study. J Cardiothorac Vasc Anesth. 2022;36(8 Pt A):2385–92.
69. Yu LF, Xu CK, Zhao M, Niu L, Huang XM, Zhang ZQ. Bedside cardiopulmonary ultrasonography evaluates lung water content in very low-weight preterm neonates with patent ductus arteriosus. World J Clin Cases. 2021;9:1827–34.
70. Mayr U, Lukas M, Habenicht L, Wiessner J, Heilmaier M, Ulrich J, Rasch S, Schmid RM, Lahmer T, Huber W, Herner A. B-lines scores derived from

lung ultrasound provide accurate prediction of extravascular lung water index: an observational study in critically ill patients. J Intensive Care Med. 2022;37:21–31.
71. Huang D, You C, Mai X, Li L, Meng Q, Liang Z. Lung ultrasound-guided fluid resuscitation in neonatal septic shock: a randomised controlled trial. Eur J Pediatr. 2024;183:1255–63.
72. Rodriguez-Fanjul J, Balcells C, Aldecoa-Bilbao V, Moreno J, Iriondo M. Lung ultrasound as a predictor of mechanical ventilation in neonates older than 32 weeks. Neonatology. 2016;110:198–203.
73. De Martino L, Yousef N, Ben-Ammar R, Raimondi F, Shankar-Aguilera S, De Luca D. Lung ultrasound score predicts surfactant need in extremely preterm neonates. Pediatrics. 2018;142:e20180463.
74. Luo K, Wang H, Huang F, Tang J. Optimal timing and cut-off range of lung ultrasound in predicting surfactant administration in neonates: a meta-analysis and systematic review. PLoS ONE. 2023;18:e0287758.
75. Raschetti R, Yousef N, Vigo G, Marseglia G, Centorrino R, Ben-Ammar R. Echography-guided surfactant therapy to improve timeliness of surfactant replacement: a quality improvement project. J Pediatr. 2019;212:137–43.
76. Capasso L, Pacella D, Migliaro F, Salomè S, Grasso F, Corsini I, De Luca D, Davis PG, Raimondi F. Can lung ultrasound score accurately predict surfactant replacement? A systematic review and meta-analysis of diagnostic test studies. Pediatr Pulmonol. 2023;58:1427–37.
77. Demi L, Wolfram F, Klersy C, De Silvestri A, Ferretti VV, Muller M, et al. New international guidelines and consensus on the use of lung ultrasound. J Ultrasound Med. 2023;42:309–44.
78. Gardelli G, Feletti F, Nanni A, Mughetti M, Piraccini A, Zompatori M. Chest ultrasonography in the ICU. Respir Care. 2012;57:773–81.
79. Garg S, Sinha S. Noninvasive ventilation in premature infants: based on evidence or habit. J Clin Neonatol. 2013;2:155–9.

Publisher's Note