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Lung ultrasound in the management of mechanical ventilation in pediatric critical care: a narrative review

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Lung ultrasound (LUS) has become an increasingly valuable tool in the
management of critically ill pediatric patients, offering dynamic, radiation-free
bedside evaluation of pulmonary function. This narrative review synthesizes
current evidence on the application of LUS in the context of ventilation in
children and neonates. Key domains include its role in determining the
indication for ventilation, guiding ventilatory adjustments, assessing positive
end-expiratory pressure (PEEP) response, supporting lung recruitment
maneuvers, and aiding in weaning and extubation decisions. The use of LUS in
diagnosing ventilator-associated pneumonia (VAP) is also addressed,
highlighting characteristic sonographic findings and their limitations. The I-
VENT mnemonic is proposed as a practical framework for clinicians to
integrate LUS into ventilatory management. While further research is needed
to standardize protocols and validate scoring systems, current evidence
supports the routine use of LUS in pediatric intensive care as a safe,
accessible, and informative tool for optimizing respiratory support.

KEYWORDS

ultrasonography, lung, respiration, artificial, intensive care units, pediatric, child,
weaning

1 Introduction

Lung ultrasound (LUS) has become an essential bedside tool in pediatric and neonatal
care due to its portability, speed, absence of ionizing radiation, and diagnostic accuracy (1).
In children, the partially ossified chest and reduced subcutaneous tissue provide excellent
acoustic windows for pulmonary imaging (1).

Historically, the lung parenchyma was considered inaccessible to ultrasound due to the
presence of air and the bony thoracic framework, which hinders sound wave propagation.
However, a better understanding of ultrasound artifacts and their correlation with lung
pathology has led to the growing use of LUS in respiratory assessment (2).

LUS has demonstrated high performance in diagnosing pneumonia, ARDS,
bronchiolitis, atelectasis, pleural effusion, and pneumothorax in the pediatric population

(4). Probe selection varies by age and region of interest, with high-frequency linear transducers preferred in neonates and convex or microconvex probes used for deeper lesions in older children (1, 5, 6). A systematic scanning approach—covering anterior, lateral, and posterior zones—is essential for comprehensive evaluation (1, 3, 6).

Despite the growing body of literature on point-of-care lung ultrasound, there is still limited synthesis of its targeted applications in the context of invasive mechanical ventilation in children. This narrative review aims to consolidate current evidence on the use of LUS to guide ventilatory management in pediatric intensive care units (PICUs), including lung recruitment maneuvers, diagnosis of ventilator-associated complications, and optimization of ventilation parameters. By exploring the specific sonographic patterns and their clinical implications, we aim to provide practical insights for integrating LUS into routine respiratory management of critically ill pediatric patients.

2 Lung ultrasound in mechanical ventilation

2.1 Mechanical ventilation indication and LUS score

Lung ultrasound (LUS) scores have been proposed to quantify lung aeration and guide clinical decisions in both adults and children. In adults, a common scoring method evaluates 12 thoracic regions (six per lung), with scores from 0 (normal aeration) to 3 (consolidation). In neonates, six regions are typically assessed, yielding a total score from 0 to 18 (Table 1) (7–9).

In neonates with acute respiratory distress syndrome (ARDS), a LUS score ≥8 is associated with the need for invasive mechanical ventilation (MV), while lower scores may support a trial of non-invasive ventilation (NIV) (10). Additionally, bilateral "white lung" patterns on nasal CPAP have been predictive of NIV failure (11).

LUS also assists in confirming tracheal intubation by detecting bilateral pleural sliding and identifying misplacement (12). In pediatric ARDS, findings include diffuse B-lines, consolidations,

pleural line abnormalities, and effusion. Given disease heterogeneity, semiquantitative scoring systems offer more accuracy than isolated B-line counts (13).

It's important to interpret LUS with age-related differences in mind. Infants under 6 months may display B-lines due to incomplete alveolarization, which typically normalize over time. In these cases, the diagnosis may require other complementary tests and ultrasound changes monitored over time (14).

2.2 Ventilation mode and diaphragm monitoring

LUS and diaphragmatic ultrasound can assist in choosing ventilator modes and optimizing support. LUS scores inversely correlate with lung compliance, suggesting that higher scores may signal reduced aeration or atelectasis (9).

Diaphragm thickening fraction (TF), calculated as the percentage change in diaphragm thickness during inspiration, serves as a marker of respiratory effort. TF between 15%–30% has been associated with shorter ventilation duration and preserved muscle mass in adults (10, 11). In preterm infants, modes such as NIV-NAVA may enhance diaphragm function through improved synchrony, with higher diaphragmatic excursion than other NIV modalities (12, 13).

Anatomical differences in neonates—such as a flatter diaphragm with steeper costal angles—necessitate careful interpretation (14). Diaphragm dysfunction (DD), marked by reduced thickening or excursion, is influenced by ventilation duration and mode. TF <20% is often used to identify dysfunction, and diaphragm thickness may decline by ~2% per day during MV in children (15–17).

2.3 PEEP titration and alveolar recruitment assessment

LUS is valuable for titrating positive end-expiratory pressure (PEEP) and evaluating recruitment responses. Patients with diffuse aeration loss on LUS typically respond better to PEEP, while focal findings increase the risk of overdistension. Trials comparing LUS-guided PEEP to ARDSnet tables show better oxygenation and compliance in the LUS groups, though caution is needed in interpretation (15–18).

Bouhemad et al. proposed a reaeration score based on ultrasound pattern changes across 12 lung zones, correlating with pressure–volume curve analysis. Most reaeration is seen in anterior/lateral zones, while posterior consolidations are less responsive due to gravity and dependent atelectasis (Table 2) (15, 19).

Serial LUS can also guide recruitment maneuvers and prevent unnecessary interventions. However, LUS does not detect hyperinflation or deep parenchymal overdistension. Thus, findings should be interpreted in conjunction with compliance, gas exchange, and clinical data (2, 18).

Despite the lack of standardized protocols in pediatrics, LUS-guided recruitment is feasible—especially in neonates—and helps

TABLE 1 Comparison of adult and neonatal lung ultrasound scoring systems.

Criteria	Adult LUS score (7, 8)	Neonatal LUS score (9)
Regions	6 for each lung (upper and lower parts of the anterior, lateral, and posterior regions)	3 for each lung (upper anterior, lower anterior, and lateral)
Scores	0: normal aeration/A-line pattern (presence of lung sliding with A-lines and, occasionally, an isolated B-line)	
	1: B-pattern (three or more well-spaced B-lines)	
	2: coalescent B-lines (with possible subpleural consolidations)	
	3: tissue-like pattern (complete loss of aeration/ extended consolidations)	
Total Score	0–36	0–18

TABLE 2 Lung ultrasound reaeration score.

1. Ultrasound lung aeration is assessed in each of the 12 lung regions before the intervention.			
N: 5 normal pattern (normal lung aeration)	B1: 5 multiple well-defined either regularly spaced 7-mm apart or irregularly spaced B lines (moderate loss of lung aeration)	B2: 5 multiple coalescent B lines (severe loss of lung aeration)	C: 5 lung consolidation
2. Ultrasound lung aeration is assessed in each of the 12 lung regions after the intervention.			
3. Ultrasound lung reaeration score is calculated as the sum of each score (for each lung region examined) according to the scale below:			

Quantification of reaeration:	**1 point**	**3 points**	**5 points**
	B1 → N	B2 → N	C → N
	B2 → B1	C → B1	
	C → B2		
Quantification of loss of aeration:	**5 point**	**3 points**	**1 points**
	N → C	N → B2	N → B1
		B1 → C	B1 → 2
			B2 → C

minimize radiation exposure. Further research is needed to refine scoring and clinical application.

Prone positioning (PP) represents an additional strategy to improve oxygenation and regional aeration through postural recruitment. Performing LUS in the prone position is feasible and can be used to monitor its effects. Although oxygenation improvement after PP does not correlate with a specific sonographic pattern, studies show increased LUS scores in dependent regions after approximately 3 h of PP, with associated rises in the PaO_2/FiO_2 ratio. However, this effect may diminish after prolonged sessions (>6 h) (20–23).

2.4 Patient-ventilator asynchrony

Patient–ventilator asynchrony (PVA) is a mismatch between patient effort and ventilator response. Diaphragm ultrasound can help identify PVA by correlating muscle movement with airway pressure, often more feasibly than invasive monitoring or waveform analysis (11, 24, 25).

2.5 Weaning and extubation prediction

LUS and diaphragm ultrasound are increasingly used to assess readiness for weaning. In adults, a LUS score <13 after spontaneous breathing trial (SBT) predicts extubation success, while >17 indicates failure (9, 26). A rise in B-lines during SBT may also signal fluid overload and weaning risk.

In neonates, LUS score ≤6 before and ≤7 after nCPAP removal predicted successful weaning (25, 26). TF <23.2% and diaphragmatic excursion <6.2 mm have been associated with

weaning failure in children, though thresholds vary by age and condition (27–31).

Several factors influence LUS predictive value, including timing relative to SBT, ventilatory support settings, and zone count (6–14) used during assessment.

3 Diagnosis of ventilator-associated pneumonia

Ventilator-associated pneumonia (VAP) is the most common hospital-acquired infection in pediatric intensive care, contributing to significant morbidity, mortality, and prolonged mechanical ventilation. Its reported incidence varies from 3% to 32% in children and up to 20% in neonates, depending on definitions and diagnostic methods used (32, 33). While adult criteria integrate clinical, radiologic, and microbiological findings, pediatric and neonatal populations lack standardized diagnostic frameworks. In neonates, particularly, radiographic and clinical signs are often nonspecific and overlap with other conditions such as RDS or sepsis, making the diagnosis especially challenging (34–37).

This diagnostic uncertainty may result in delayed treatment, increased antibiotic use, and prolonged ventilation. In this context, lung ultrasound (LUS) has emerged as a valuable tool for early, radiation-free, and bedside diagnosis of VAP. Studies report sensitivity and specificity above 90% for pneumonia detection using LUS in children, often exceeding the performance of chest radiography (35–37).

Typical sonographic findings in VAP include subpleural consolidations, often with dynamic air bronchograms, pleural effusions, and B-lines. Although these signs support the diagnosis of pneumonia, their interpretation must consider the clinical context, as similar patterns may be seen in atelectasis, ARDS, or bronchiolitis (37, 38).

To enhance diagnostic consistency, structured scoring systems have been proposed. One of the most studied is the VPLUS score, which assigns 1 point for the presence of two or more subpleural consolidations, 2 points for at least one dynamic air bronchogram, and 1 point for purulent tracheal secretions. A total score of 2 or more indicates a high probability of VAP. Two expanded versions—VPLUS-EAgram and VPLUS-EAquant —add microbiological data such as Gram stain or quantitative cultures, increasing diagnostic specificity to above 95% when scores reach 3 (38). For neonates, a Multiparametric Score was developed to integrate clinical, ultrasound, and microbiological criteria. On day 1, the score includes clinical signs such as temperature instability, changes in secretions, and respiratory deterioration (1 point each), along with ultrasound findings: subpleural consolidations over 0.5 cm, dynamic air bronchograms, and pleural effusion (2 points each). On day 3, a positive bacterial culture from tracheal aspirate adds 1 additional point. A total score above 4 on day 1 or above 5 on day 3 has shown excellent diagnostic performance (AUC >0.9) (37).

Despite its advantages, LUS is not without limitations. Findings such as consolidations and B-lines are not exclusive to pneumonia

and may occur in atelectasis, ARDS, and bronchiolitis (37). Additionally, subcutaneous emphysema—a recurrent condition in Pediatric Intensive Care Units—may also compromise the quality of the ultrasound window in critically ill patients.

Moreover, LUS only detects lesions that reach the pleural surface and lie within intercostal windows, limiting its ability to evaluate apical, central, or subdiaphragmatic consolidations. In adults, this may result in up to 8% of lesions being missed (38); in children, this limitation is less pronounced but still relevant (37). Operator experience also influences diagnostic performance, especially when distinguishing subtle findings.

Nevertheless, compared with chest radiography, LUS demonstrates superior sensitivity and specificity for detecting consolidations and effusions, and allows serial monitoring of disease progression and complications (37, 38). It also enables dynamic evaluation of treatment response, guiding drainage of effusions, and identifying complications such as empyema. The integration of color Doppler can help differentiate inflammatory consolidations, which typically show preserved perfusion, from atelectasis, where vascular flow is often reduced or absent (37).

In summary, LUS is a powerful diagnostic tool for ventilator-associated pneumonia in pediatric and neonatal intensive care. Through the recognition of key findings and use of structured diagnostic scores, it enhances bedside clinical decision-making and reduces dependence on radiation-based imaging in this vulnerable population.

4 Practical summary: the I-VENT mnemonic

To facilitate the structured application of lung ultrasound in the management of mechanically ventilated pediatric patients, we propose the I-VENT mnemonic, which encompasses the key domains covered in this review:

I—Indication for ventilation: LUS scores can aid in identifying the need for mechanical ventilation, particularly in neonates with ARDS or those at risk of NIV failure.

V—Ventilation adjustment: LUS supports titration of ventilatory parameters, including detection of overdistension and atelectasis, as well as optimization of modes such as SIMV or NIV-NAVA.

E—Effusion and edema detection: LUS enables bedside detection of pleural effusions and interstitial syndromes, guiding fluid management and differential diagnoses.

N—Non-aerated areas: Consolidations, atelectatic regions, and regional heterogeneity can be identified, supporting decisions on positioning, recruitment, and antibiotic therapy.

T—Thoracic sliding and tube position: Visualization of pleural sliding confirms correct tracheal intubation, rules out selective intubation, and helps exclude pneumothorax.

This framework may serve as a practical bedside checklist and an educational tool to reinforce the comprehensive use of LUS throughout the continuum of ventilatory support.

5 Discussion

This narrative review highlights the growing and multifaceted role of lung ultrasound (LUS) in the management of mechanically ventilated pediatric patients. From guiding the indication for ventilation to optimizing PEEP, assessing recruitment, predicting weaning success, and diagnosing complications such as ventilator-associated pneumonia, LUS offers a dynamic, radiation-free, bedside tool that enhances clinical decision-making.

The pediatric and neonatal populations, with their unique anatomical characteristics and vulnerability to radiation, particularly benefit from the incorporation of LUS into routine care. Despite the promising results, certain limitations must be acknowledged, including reduced sensitivity for consolidations not adjacent to the pleura and challenges in standardizing protocols across age groups and clinical scenarios. Moreover, the absence of universally accepted pediatric-specific diagnostic criteria for conditions such as VAP underscores the importance of combining LUS findings with clinical judgment.

Future research should aim to validate existing scoring systems, establish evidence-based protocols, and integrate LUS training into pediatric critical care curricula. With ongoing advancements in portable ultrasound technology and increasing clinician familiarity, LUS is poised to become a cornerstone of respiratory management in pediatric intensive care units worldwide.

Author contributions

NL: Writing – original draft, Writing – review & editing, Methodology, Conceptualization. VA: Writing – original draft, Methodology, Conceptualization. MM: Conceptualization, Writing – original draft, Methodology. PGPM: Conceptualization, Writing – original draft. LZB: Conceptualization, Validation, Supervision, Writing – review & editing. RdHP: Supervision, Conceptualization, Investigation, Writing – review & editing, Validation.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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