

WHAT'S NEW IN INTENSIVE CARE



# What's new in lung ultrasound in the critically ill or injured child

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Lung ultrasonography (LUS) is a well-established technique in adult critical care, but remains insufficiently recognized in children and infants. The purpose of this short review is to describe the rapidly growing field of point-of-care LUS in critically ill and injured children.

LUS interpretation is based on the analysis of dynamic artifacts, mostly related to the air–fluid ratio and lung density. All LUS patterns originate from the pleural line because LUS, as a surface technique, is not able to detect consolidation in the deep lung far from the surface. Although not scientifically demonstrated, because of their small lung volume, children—and specifically infants—may be more suitable for in-depth analysis of the lung parenchyma and identification of deep alveolar consolidations, atelectasis and interstitial infiltrates. Similarly, the use of linear probes in infants and curvilinear probes in older children is preferred. LUS semiology is well characterized and identifies normal lung patterns (e.g., batwing sign, pleural line, seashore sign, A-lines), interstitial syndrome/pulmonary edema (e.g., B-lines), lung consolidation (e.g., tissue-like sign, tree-like and linear dynamic air bronchograms, shred sign, lung pulse) and pleural effusion (e.g., fluid, PLAPS [posterolateral alveolar and/or pleural syndrome] point, quad sign) [1]. LUS can be easily performed by clinicians at the bedside, and recent data suggest that the use of this radiation-free point-of-care ultrasonography (POCUS) technique reduces both cumulative radiation and number of chest X-rays (CXR) [2, 3]. In a controlled study including 191 children, Jones et al. showed that LUS could replace CXR for diagnosis of community-acquired pneumonia (CAP).

The authors demonstrated a significant (38%) reduction in CXR, with no missed CAP diagnosis by either experienced or novice ultrasonologists [4]. In critically ill adults, LUS has shown diagnostic accuracy comparable to CXR (using CT scan as gold standard). Based on these clinically meaningful experiences, a panel of experts provided evidence-based recommendations for the use of bedside LUS for adults in emergency and critical care settings [5]. The POCUS working group of the European Society of Paediatric and Neonatal Intensive Care (ESPNIC) is currently establishing practice and educational recommendations, providing specific guidelines for LUS use in neonatal and pediatric intensive care.

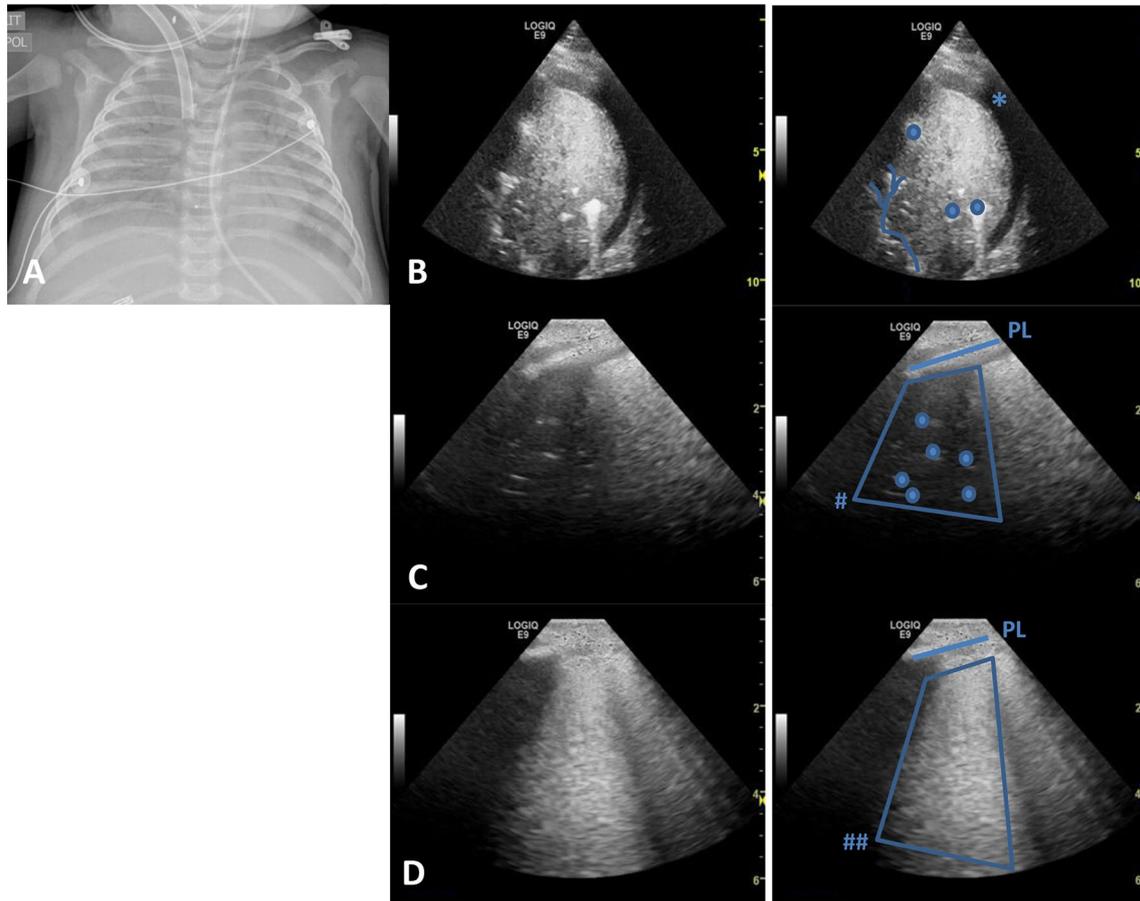
Although the LUS technique is currently recognized for use early in the initial evaluation of the severely ill or injured child, it has been shown to be suitable for point-of-care diagnostic and therapeutic intervention in several pulmonary conditions.

1. Community-acquired and ventilator-associated (VAP) pneumonia. LUS semiology of pneumonia is characterized by dynamic tree-like or linear bronchograms associated with tissue-like sign, shred sign, and lung pulse (Fig. 1). A recent meta-analysis evaluating LUS in pediatric CAP showed pooled sensitivity and specificity for CAP diagnosis of 96% and 93%, respectively, with an area under the receiver operating curve of 0.98 [6]. Reliability was found to be higher in the hands of expert users, although studies provided evidence of good diagnostic accuracy when performed by a novice. The prevalence of pneumonia without pleural involvement in children is unknown and may impact the accuracy of LUS diagnosis. Unlike studies in adults, no pediatric LUS studies have focused on VAP diagnosis and treatment monitoring.

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**Fig. 1** A 4-month-old boy with malignant pertussis-related acute respiratory distress syndrome (ARDS) on high-frequency oscillatory ventilation and veno-arterial extracorporeal life support (ECLS). **a** Chest X-ray showing bilateral diffuse opacities and bronchograms suggestive of pneumonia. On LUS, whole left lung in transverse view **(b)** demonstrated diffuse subpleural tissue-like consolidation (hash), with dynamic tree-like and linear (degree sign) bronchograms, along with pleural effusion (asterisk). Lung recruitment obtained with an increase in continuous distending pressure from 10 cm H<sub>2</sub>O **(c)** to 20 cm H<sub>2</sub>O **(d)** induced the reappearance of confluent B lines (double hash) instead of poorly delineated (shred sign) subpleural condensations (hash), suggesting posterior lobe re-aeration. *PL* pleural line

2. Acute viral bronchiolitis. A patchwork of LUS patterns is described, including alveolar consolidation, atelectasis, interstitial infiltrate and peribronchial thickening, with multiple sliding B lines in the most severe cases [7, 8]. Although frequently found on CXR, static pulmonary overdistension is not identifiable with a single LUS exam, and may need dynamic evaluation of re-aeration, such as during optimal positive end-expiratory pressure (PEEP) setup during non-invasive ventilation. The study performed by Caiulo et al. in infants with acute severe and moderate viral bronchiolitis showed that LUS was more likely to identify lung abnormalities than CXR [7]. Interestingly, a weak correlation exists between subpleural lung consolidation, identified by LUS, and severity score or oxygen requirement in infants with

bronchiolitis hospitalized in pediatric wards, suggesting that some LUS artifacts may have prognostic value [8]. In a recent single-center prospective study involving 47 infants with acute viral bronchiolitis admitted to the intensive care unit, we showed that the severity of bronchiolitis did not correlate with LUS-based score, but with the number of affected intercostal spaces [9].

3. Acute respiratory distress syndrome (ARDS) and atelectasis. Lung dependent atelectasis is frequently involved in intrapulmonary shunt-related hypoxemia, a major concern in critically ill children. Atelectasis is typically identified by LUS as bright echogenic branching, roughly parallel to the lung surface. Focal B lines (vertical, laser-like lines erasing A lines) can be found in the dependent lung area. A recent con-

trolled study showed good agreement between magnetic resonance imaging and LUS in children with anesthesia-induced atelectasis [10]. In adults, LUS was shown to differentiate focal and diffuse ARDS [11]. In addition, LUS has been tested for diagnosing ARDS in settings where CXR is unavailable, and the so-called Kigali modification of the Berlin ARDS definition was proposed [12]. The typical LUS semiology of ARDS is characterized by B lines, spared areas, pleural thickening and subpleural consolidation [11]. The B-line pattern does not allow differentiation between interstitial infiltrates and cardiogenic lung edema, and cardiac US is needed to help in differentiating the two conditions. LUS is likely to display similar findings in ARDS in both infants and children, and may offer opportunities for diagnosing additional and deeper lesions due to the broader US window in younger patients. Among other scenarios, LUS can be employed for assessing alveolar recruitment strategies using optimal driving pressure (as shown in Fig. 1) and may represent an exciting new field of research. LUS assessment of PEEP-induced recruitment was previously validated using re-aeration scores and CT scans as reference in adults with ARDS [13, 14]. Although no specific studies on LUS diagnosis of pediatric or neonatal ARDS have been published, we recently showed that LUS-based scores were able to predict the need for surfactant replacement therapy in a prospective study involving 133 extremely preterm infants [15].

4. Pneumothorax and chest drainage. LUS is a widely accepted method for the diagnosis of pneumothorax and for performing US-guided chest drainage. The detection of a lung point that corresponds to the loss of pleural sliding definitively confirms pneumothorax diagnosis. In a recent prospective multicenter study in neonates, LUS demonstrated sensitivity, specificity, and positive and negative predictive values of 100% in the diagnosis of pneumothorax. The LUS was performed in acutely desaturating patients in an average of 5 min (compared to 12 min for CXR) [16]. A meta-analysis of adult studies showed that LUS had higher diagnostic accuracy than conventional radiology for the diagnosis of pneumothorax [17].

In summary, the pace of clinical research in the field of pediatric LUS has accelerated over the past few years, and similar to the use of LUS in adults, the technique is quickly becoming a standard of care in the management of pulmonary-related conditions in critically ill or injured children. The time has come to investigate the incorporation of LUS into diagnostic and treatment algorithms for

various lung diseases encountered in pediatric and neonatal intensive care.

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#### References

1. Ord HL, Griksaitis MJ (2018) 15-minute consultation: using point of care ultrasound to assess children with respiratory failure. *Arch Dis Child Educ Pract Ed*. <https://doi.org/10.1136/archdischild-2017-313795> (**Epub ahead of print**)
2. Ambroggio L, Sucharew H, Rattan MS, O'Hara SM, Babcock DS, Clohessy C et al (2016) Lung ultrasonography: a viable alternative to chest radiography in children with suspected pneumonia? *J Pediatr* 176(93–98):e7. <https://doi.org/10.1016/j.jpeds.2016.05.033>
3. Escourrou G, De Luca D (2016) Lung ultrasound decreased radiation exposure in preterm infants in a neonatal intensive care unit. *Acta Paediatr* 105(5):e237–e239. <https://doi.org/10.1111/apa.13369>
4. Jones BP, Tay ET, Elikashvili I (2016) Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: a randomized controlled trial. *Chest* 150(1):131–138. <https://doi.org/10.1016/j.chest.2016.02.643>
5. International Liaison Committee on Lung Ultrasound (ILC-LUS) for the International Consensus Conference on Lung Ultrasound (ICC-LUS), Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G et al (2012) International evidence-based recommendations for point-of-care lung ultrasound. *Intensive Care Med* 38(4):577–591. <https://doi.org/10.1007/s00134-012-2513-4>
6. Pereda MA, Chavez MA, Hooper-Miele CC, Gilman RH, Steinhoff MC, Ellington LE et al (2015) Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. *Pediatrics* 135(4):714–722. <https://doi.org/10.1542/peds.2014-2833>
7. Caiulo VA, Gargani L, Caiulo S, Fisicaro A, Moramarco F, Latini G et al (2011) Lung ultrasound in bronchiolitis: comparison with chest X-ray. *Eur J Pediatr* 170(11):1427–1433. <https://doi.org/10.1007/s00431-011-1461-2>
8. Basile V, Di Mauro A, Scalini E, Comes P, Lof I, Mostert M et al (2015) Lung ultrasound: a useful tool in diagnosis and management of bronchiolitis. *BMC Pediatr*. <https://doi.org/10.1186/s12887-015-0380-1>
9. Taveira M, Yousef N, Miatello J, Roy C, Claude C, Boutillier B et al (2018) Can a simple lung ultrasound score predict length of ventilation for infants with severe acute viral bronchiolitis? *Arch Fr Pediatr* 25(2):112–117. <https://doi.org/10.1016/j.arcped.2017.11.005>
10. Acosta CM, Maidana GA, Jacovitti D, Belaunzarán A, Cereceda S, Rae E et al (2014) Accuracy of transthoracic lung ultrasound for diagnosing anesthesia-induced atelectasis in children. *Anesthesiology* 120(6):1370–1379. <https://doi.org/10.1097/ALN.0000000000000231>
11. Corradi F, Brusasco C, Pelosi P (2014) Chest ultrasound in acute respiratory distress syndrome. *Curr Opin Crit Care* 20(1):98–103. <https://doi.org/10.1097/MCC.0000000000000042>
12. Riviello ED, Kiviri W, Twagirumugabe T et al (2016) Hospital incidence and outcomes of the acute respiratory distress syndrome using the Kigali Modification of the Berlin Definition. *Am J Respir Crit Care Med* 193:52–59. <https://doi.org/10.1164/rccm.201503-0584OC>
13. Haddam M, Zieleskiewicz L, Perbet S, Baldovini A, Guerville C, Arbelot C et al (2016) Lung ultrasonography for assessment of oxygenation response to prone position ventilation in ARDS. *Intensive Care Med* 42(10):1546–1556. <https://doi.org/10.1007/s00134-016-4411-7>

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14. Bouhemad B, Brisson H, Le-Guen M, Arbelot C, Lu Q, Rouby J-J (2011) Bedside ultrasound assessment of positive end-expiratory pressure-induced lung recruitment. *Am J Respir Crit Care Med* 183(3):341–347. <https://doi.org/10.1164/rccm.201003-0369OC>
  15. De Martino L, Yousef N, Ben-Ammar R, Raimondi F, Shankar-Aguilera S, De Luca D (2018) Lung ultrasound score predicts surfactant need in extremely preterm neonates. *Pediatrics* 142(2):e20180463. <https://doi.org/10.1542/peds.2018-0463>
  16. Raimondi F, Rodriguez Fanjul J, Aversa S, Chirico G, Yousef N, De Luca D et al (2016) Lung ultrasound for diagnosing pneumothorax in the critically ill neonate. *J Pediatr* 175:74–78. <https://doi.org/10.1016/j.jpeds.2016.04.018>
  17. Alrajab S, Youssef AM, Akkus NI et al (2013) Pleural ultrasonography versus chest radiography for the diagnosis of pneumothorax: review of the literature and meta-analysis. *Crit Care* 17:R208. <https://doi.org/10.1186/cc13016>