The Use of Lung Ultrasound in Pediatrics: A Review

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ABSTRACT We summarized the role of lung ultrasound for diagnosing and monitoring various pediatric respiratory diseases. We began with an overview of the basics of the tool, followed by describing its use in conditions such as pneumonia, pleural effusion, bronchiolitis, atelectasis, pneumothorax, bronchiectasis, and interstitial lung disease. We highlighted the sensitivity and specificity of lung ultrasound for the various diseases described. Furthermore, we included a comparison of this modality to other commonly used imaging techniques.

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Lung ultrasound (LUS) is an emerging technique that has been increasingly used in recent years. By facilitating fast diagnosis at a patient's bedside, LUS gained popularity, particularly during the coronavirus disease 2019 (COVID-19) pandemic, as it allowed physicians to scan many patients relatively quickly. LUS has a significant advantage in pediatrics since it does not involve exposure to ionizing radiation, thereby also allowing repeating the exam if needed. Moreover, the anatomy of the pediatric chest, which is smaller with less surrounding fat than the adult chest, is favorable for ultrasound imaging. In addition, the use of LUS is relatively easy to learn with a quick learning curve. Its use may be especially important in resource-limited environments and critical care scenarios.

LUNG ULTRASOUND IS GAINING POPULARITY IN THE PEDIATRIC POPULATION AND IS BECOMING AN INCREASINGLY VALUABLE TOOL FOR DIAGNOSIS OF VARIOUS PEDIATRIC RESPIRATORY CONDITIONS.

The first international consensus on the use of LUS in adult population was published in 2012 [1], and neonatal guidelines were available in 2018 [2]. However, unified guidelines for pediatric patients are not yet available [3].

In this review, we presented and summarized the current knowledge regarding the use and efficacy of LUS in the most common pediatric respiratory diseases.

BASIC CONCEPTS OF LUNG ULTRASOUND

A LUS exam may be performed with the patient standing, supine, or lateral decubitus. The imaging is based on the interpretation of artifacts that are generated by the air-to-fluid ratio in the lung parenchyma.

When performing an ultrasound, high-frequency sound waves (usually between 2 and 15 MHz) are transmitted through the body. When these waves encounter different tissues, they reflect back to the ultrasound probe. The lungs themselves contain air, which does not reflect ultrasound waves effectively. As a result, the lungs typically appear hypoechoic (dark) on the ultrasound screen.

A fully aerated lung will present with horizontal hyperechoic reverberations of the pleural lines (known as the A-lines), which are generated by the reverberation of the ultrasound beam between the pleura and the transducer. These lines are a signature of a healthy lung [4]. A-lines are presented in Figure 1.

B-lines are vertical, hyperechoic artifacts that extend from the pleural line to the edge of the screen without fading. They move synchronously with lung sliding and are indicative of increased lung density. These lines may be found in pneumonia, bronchiolitis, or pulmonary edema. A higher number of B-lines is associated with more severe lung involvement [5]. B-lines are presented in Figure 2.

Consolidation is a region of the lung that appears tissue-like on ultrasound imaging, indicating a loss of aeration. It is often described as hepatization of the lung. Air bronchograms are hyperechoic linear or branching structures within the consolidation, representing air-filled bronchi surrounded by fluid-filled alveoli [6]. Hepatization is presented in Figure 3.

Some of the challenges that are more specific to children include the fact that lung boundaries and rib spaces

Figure 1. A-lines

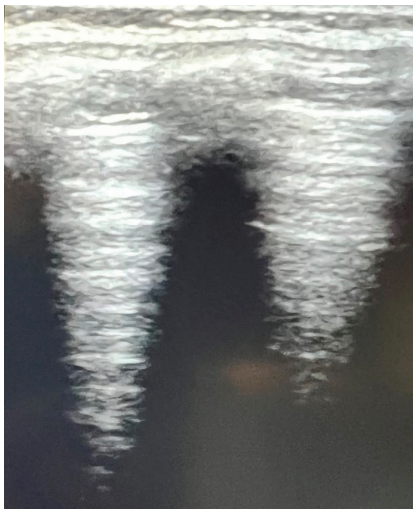


Figure 2. B-lines

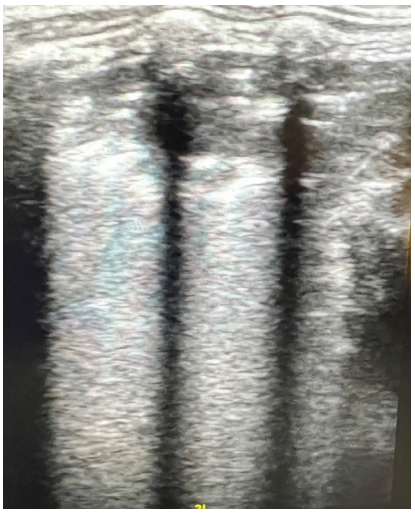
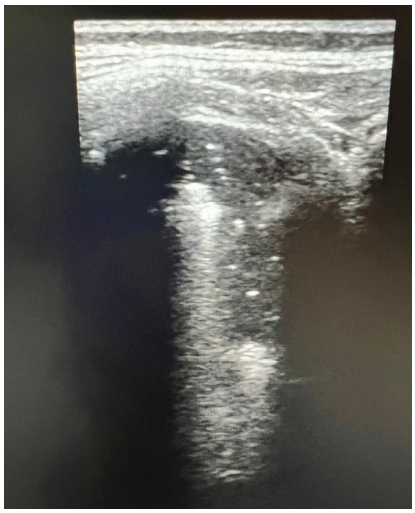


Figure 3. Lung hepatization



are more compact, which makes it challenging to get a clear view of the lung parenchyma. Another challenge is that children have faster and more irregular respiratory patterns than adults, making it harder to capture clear, still images. Also, as in any exam in pediatric patients, cooperation may be harder to achieve.

PNEUMONIA

Pneumonia is the most common reason for hospitalization and the leading cause of death in patients under 5 years old. Therefore, the use of LUS for the diagnosis of pneumonia is of special importance

Pneumonia may be seen in LUS as consolidations, B-lines, and pleural irregularities as well as air bronchogram [7]. Like other diagnostic tools LUS is unable to distinguish between the different pathogens [8].

Similarly, Yilmaz and colleagues [9] found that LUS was at least as useful as chest X-ray (CXR), with LUS findings compatible with pneumonia in 95.3% of cases compared to 88.5% for CXR. Claes and co-authors [10] in a monocentric prospective study also highlighted the high sensitivity (98%) and specificity (92%) of LUS in detecting lung consolidation in 143 children aged 0–16 years with suspected of pneumonia.

Meta-analyses further support these findings. In a systemic review and meta-analysis of 22 studies and a total of 2470 patients, Yan et al. [11] reported pooled sensitivity and specificity of 0.95 and 0.90, respectively, four clinical signs, including pulmonary consolidation, positive air bronchogram, abnormal pleural line, and pleural effusion were most frequently observed using LUS in diagnosing pediatric pneumonia, indicating its reliability and diagnostic value. Yang et al. [12] confirmed that LUS has a higher sensitivity than CXR for detecting pneumonia in children, with a sensitivity of 0.95 compared to 0.92 for CXR.

LUS is also useful as a follow-up tool in pediatric pneumonia. Omran and colleagues [13] demonstrated that in infants younger than one year, LUS was superior to CXR in diagnosing pneumonia and served as a safe follow-up tool, supporting decisions regarding hospital discharge. This research found that 5 days after the initial diagnosis, consolidation patch disappeared in 26.5% infants, diminished in size in 55.1%, remained at the same size in 4.1%. It increased in size in 14.3% of the infants. In addition, Ginsburg and co-authors [14] showed that serial LUS examinations in children with chest-indrawing pneumonia often reflected the clinical course, indicating its potential utility in monitoring disease progression and resolution. By day 14, 100% of the patients who were clinically cured showed improvement in their LUS. LUS also has a role in diagnosing complications such as lung abscess [15].

PLEURAL EFFUSION

Pleural effusion appears as an anechoic (echo-free) or hypoechoic area between the parietal and visceral pleura that changes shape with respiration. Fine strands present within the fluid indicate exudates. The volume of pleural fluid can be estimated based on the extent of the echo-free space.

According to the British Thoracic Society (BTS) guidelines, LUS has a higher sensitivity for detecting pleural effusion compared to clinical examination or CXR, including lateral decubitus films [16].

The BTS guidelines, as well as a review article, recommend the use of LUS to confirm the presence of pleural fluid collections, help distinguish between different forms of pleural effusion, and guide thoracocentesis or drain placement, thereby increasing the safety of these procedures and reducing life-threatening complications [16,17].

BRONCHIOLITIS

Clinical assessment is the gold standard for the diagnosis of bronchiolitis. LUS can identify specific lung abnormalities associated with bronchiolitis, such as B-lines, subpleural consolidations, and pleural line abnormalities. These findings correlate well with clinical severity and can help predict the need for interventions such as oxygen therapy. A prospective study that evaluated 92 infants found that higher a LUS score is associated with increased clinical severity and longer hospital stays [18]. A prospective study of 76 patients found that LUS scores can help predict the need for respiratory support, such as continuous positive airway pressure [19]. Another prospective study with 106 infants found that in some patients normal CXR but abnormal LUS findings were consistent with clinical bronchiolitis [20]. Disappearance of these abnormalities correlates with clinical improvement at discharge [20]. It should be noted that these studies used the same protocol for the performance of LUS.

LUNG ULTRASOUND HAS HIGH SENSITIVITY AND SPECIFICITY FOR DIAGNOSING NUMEROUS PEDIATRIC RESPIRATORY CONDITIONS INCLUDING PNEUMONIA PLEURAL EFFUSION, LUNG ABNORMALITIES ASSOCIATED WITH BRONCHIOLITIS, NEONATAL PULMONARY ATELECTASIS, AND PNEUMOTHORAX.

ATELECTASIS

LUS can accurately diagnose neonatal pulmonary atelectasis with high sensitivity and specificity. In a study involving 80 neonates with neonatal atelectasis, LUS was compared to CXR and high-resolution computed tomography (HRCT). LUS showed a sensitivity of 100%, significantly outperforming CXR, which had a sensitivity of 75% [21]. The main ultrasound findings in atelectasis include large areas of lung consolidation with clearly demarcated borders, air bronchograms, pleural line abnormalities, and the absence of A-lines.

In a prospective study that evaluated 40 children with congenital heart disease who were scheduled for elective surgery, LUS was effective in monitoring changes such as atelectasis, particularly in the inferoposterior lung regions. This evaluation can be crucial during perioperative management, where positive end-expiratory pressure can be adjusted based on LUS findings to reduce atelectatic areas [22].

In a prospective study that evaluated 40 children with neuromuscular disease, LUS was a useful adjunct to CXR, reducing the need for ionizing radiation. Although the sensitivity of LUS in this population was 57%, its specificity was 82%, making it a valuable tool for early identification of pulmonary atelectasis [23]. In addition, LUS has been validated against magnetic resonance imaging for diagnosing anesthesia-induced atelectasis in 14 children, showing high sensitivity (88%) and specificity (89%) [24].

The European Society of Pediatric and Neonatal Intensive Care also supports the use of point-of-care ultrasound for detecting atelectasis in critically ill neonates and children, highlighting its diagnostic accuracy and utility in guiding respiratory interventions [25].

PNEUMOTHORAX

The most common tool for diagnosis of pneumothorax in clinical practice is CXR, although HRCT is considered the gold standard. However, considering that HRCT is time consuming and requires more resources, it is less suitable for initial diagnosis. The diagnosis of pneumothorax using LUS is based mainly on the absence of lung sliding (lung sliding is the dynamic movement observed at the pleural line, the interface between the visceral and parietal pleura, visualized as a shimmering or sliding motion of the pleural line during respiration), which is highly indicative of pneumothorax [26]. In critically ill neonates, LUS has shown 100% sensitivity and specificity for detecting pneumothorax [26]. Similarly, in children presenting with acute chest pain, LUS demonstrated high sensitivity (92.3–100%) and specificity (100%) for pneumothorax detection [27]. It is recommended for both diagnosis and procedural guidance [27].

BRONCHIECTASIS

The role of LUS in diagnosing pediatric bronchiectasis is limited. Bronchiectasis is characterized by the abnormal dilation of the bronchi and bronchioles, which results in airway damage. LUS does not provide detailed imaging of the airways and does not penetrate deeply enough to provide detailed images of the airway structures within the lung tissue itself. HRCT is considered the gold standard for diagnosing bronchiectasis due to its ability to provide detailed images of the bronchial anatomy and detect characteristic features such as bronchial dilation and wall thickening. LUS can identify some secondary fea-

tures of bronchiectasis, such as consolidations and pleural abnormalities, but it lacks the resolution to visualize bronchial wall changes and airway dilatation directly [4]. However, LUS does have a role in identifying pulmonary exacerbations in patients with cystic fibrosis [28].

INTERSTITIAL LUNG DISEASE

LUS may also be useful in detecting interstitial syndromes, which are characterized by the presence of multiple diffuse bilateral B-lines, pleural irregularities, and subpleural consolidations. These findings have been shown to correlate well with HRCT findings in children with systemic juvenile idiopathic arthritis-associated interstitial lung disease (ILD) [29]. In addition, LUS has demonstrated high sensitivity and specificity in detecting pulmonary interstitial involvement secondary to systemic connective tissue diseases with sensitivity and specificity of 99.3% and 96.4%, respectively [30].

LUNG ULTRASOUND MAY BE USEFUL IN DETECTING PEDIATRIC INTERSTITIAL SYNDROMES; HOWEVER, IT HAS A LIMITED ROLE FOR DIAGNOSIS IN BRONCHIECTASIS.

The interpretation of LUS in ILD can be challenging because of the overlapping signs with other conditions, particularly pleural effusions or pneumonia, which may also produce B-lines or other artifacts. Furthermore, LUS may miss subtle interstitial abnormalities and diffuse bilateral lung involvement. This situation can lead to misinterpretation or missed diagnoses, making HRCT the method of choice for the diagnosis and follow up of ILD.

SUMMARY

Pediatric LUS is a pivotal diagnostic tool, offering insights into most pediatric respiratory conditions with commendable efficacy. Its non-invasive nature, the lack of exposure to ionizing radiation, and real-time visualization capabilities make it particularly advantageous in assessing lung pathologies in children, with research proving its sensitivity and specificity in most common respiratory diseases. It is becoming a routine tool for both diagnosis and follow-up in various respiratory situations in the pediatric patient.

A major issue regarding the current use of LUS in pediatrics is the lack of standardization. Standardization is essential to ensure accurate and consistent diagnosis and management of respiratory conditions, provide clear guidelines for clinicians, improve the accuracy of diagnosis, and enhance training and competency for healthcare providers. Clear standardization of LUS would also allow more accurate multicenter studies.

The implementation of artificial intelligence (AI) in pediatric LUS has potential to improve its use by automating image analysis and offering more consistent and accurate readings, as well as better standardization. AI may also assist in identifying subtle patterns that may be difficult for the human eye to detect.

LUS should be integrated into pediatric care settings where non-invasive, real-time diagnostic tools are essential, particularly in emergency, intensive care, and outpatient clinics. Given its portability, safety, and ability to provide immediate results, LUS may be used as first assessment in patients where respiratory conditions such as pneumothorax, pneumonia, or pleural effusion are suspected.

Disclosure

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Capsule

Graft-versus-host disease prophylaxis with cyclophosphamide and cyclosporin

Allogeneic peripheral-blood stem-cell transplantation (SCT) from a matched related donor after myeloablative conditioning is the preferred curative treatment for patients with high-risk blood cancers. The combination of a calcineurin inhibitor and an antimetabolite remains standard care for graft-versus-host disease (GVHD) prophylaxis for these patients. **Curtis** and colleagues randomly assigned adults who were undergoing SCT from a matched related donor after myeloablative or reduced-intensity conditioning to receive either post-transplantation cyclophosphamide–cyclosporin (experimental prophylaxis) or cyclosporin–methotrexate (standard prophylaxis). The primary endpoint was GVHD-free, relapse-free survival. Among 134 patients who underwent randomization, 66 were assigned to receive experimental prophylaxis and 68 to receive standard prophylaxis. GVHD-free, relapse-free survival was significantly longer with experimental prophylaxis (median 26.2 months; 95% confidence interval [95%CI] 9.1 to not reached) than with standard prophylaxis (median 6.4 months; 95%CI 5.6–8.3; $P < 0.001$ by a log-rank test). GVHD-free, relapse-free survival at 3 years was 49% (95%CI 36–61) with experimental prophylaxis and 14% (95%CI 6–25) with standard prophylaxis (hazard ratio [HR] for GVHD, relapse, or death, 0.42; 95%CI 0.27–0.66). The cumulative incidence of grade III to IV acute GVHD at 3 months was 3% (95%CI 1–10) in the experimental-prophylaxis group and 10% (95%CI 4–19) in the standard-prophylaxis group. At 2 years, overall survival was 83% and 71%, respectively (HR for death 0.59; 95%CI 0.29–1.19). The incidence of serious adverse events was similar in the two groups in the first 100 days after SCT.

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