Point-of-care Lung Ultrasound in Pediatric Pneumonia

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ABSTRACT

Pneumonia has remained the leading cause of morbidity and mortality in children. Timely diagnosis and prompt treatment can avert many deaths; however, diagnosis of pneumonia in children still remains a challenge. Chest radiography has been widely used worldwide to diagnose pneumonia in children; however, in recent times, lung ultrasound (LUS) is emerging as a useful tool to diagnose pneumonia. The ease of performing LUS, its bedside availability, no exposure to ionizing radiation, and allowance of real-time monitoring of patients make LUS an attractive tool for the intensivists. In this article, we would elaborate the ultrasound equipment, the technique, normal artifacts, and various sonographic patterns of pneumonia in children. The LUS features of various complications of pneumonia like pleural effusion and pneumothorax will also be discussed. This article also summarizes the current evidence of using LUS in the diagnosis of pediatric pneumonia along with the strengths and limitations of this technique.

Keywords: Children, Lung, Lung ultrasound, Pneumonia.

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INTRODUCTION

Globally, pneumonia has remained the leading cause of mortality in children aging less than 5 years. According to the World Health Organization (WHO), 1.4 million children succumb to pneumonia every year, accounting for about one-fifth of the deaths in this age group.¹ In India alone, around 1.27 lakh deaths due to pneumonia were reported in 2018 in children under 5 years of age.² Pneumonia is a curable disease and good outcomes can be visualized in most of the cases of pneumonia after receiving prompt and judicious treatment with antibiotics. But despite the advances in modern medicine, community-acquired pneumonia (CAP) and nosocomial pneumonia—hospital-associated pneumonia (HAP) and ventilator-associated pneumonia (VAP)—continue to remain a big burden to the healthcare systems. One of the reasons for morbidity and mortality associated with pneumonia is delay in diagnosing pneumonia and its severity. Currently, apart from clinical signs and symptoms and laboratory investigations (C-reactive protein (CRP) and leukocytosis), chest X-ray is used to diagnose pneumonia. However, chest X-ray has its own drawbacks i.e., lack of negative predictive value (NPV), poor correlation with signs, nonspecific findings, and inter- and intraobserver variability.^{3–5} Moreover, X-ray exposes children to harmful ionizing radiation. Computed tomography (CT) scan is the preferred modality and is also considered the gold standard in diagnosing pneumonia. It helps in diagnosing lung parenchymal changes and characterization of consolidation. The issues with CT scan in children are logistics, huge cost, and high exposure to radiation. Owing to these concerns, chest X-ray and CT scan are not routinely recommended by the guidelines to diagnose pneumonia in children.^{6,7}

In recent times, ultrasound has been gaining importance in pediatric critical care, neonatology, and pediatric emergency medicine. Previously, lung ultrasound (LUS) was considered to have limited usage as ultrasound waves were seen to be completely reflected by the lung air. However, in the past decade, LUS has been successfully utilized to diagnose a number of lung diseases by using ultrasound artifacts that are formed using an interplay of ultrasonic waves, lung pleura, and parenchymal fluid. Lung ultrasound has been studied extensively and has been proven to

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have a good sensitivity and specificity in diagnosing lung diseases like pleural effusion, interstitial syndrome, consolidation, and pneumothorax in patients of all age groups.^{8–12} Similarly, studies have shown that LUS has a very high sensitivity (96%) and specificity (93%) in diagnosing pneumonia.¹³ In addition, it is now a preferred modality among intensivists as it is noninvasive, easily accessible, portable, affordable, and confers less radiation as compared to chest radiography and CT scan. Furthermore, it also allows real-time monitoring of patients and allows assessment of response to treatment or intervention. The major drawback of LUS is that it is operator-dependent and requires special training of healthcare personnel. In this article, we will discuss the basics, the technique, and the lung ultrasonographic findings in pediatric pneumonia. We will also describe the current evidence in the literature about the accuracy and reliability of ultrasound in diagnosing pneumonia in children.

BASICS OF LUNG ULTRASOUND

Lung ultrasound is the study of the artifacts that arise from the chest wall and the pleura. Structures like skin, subcutaneous fat, and muscles conduct the ultrasound waves and do not generate artifacts. Whereas, the cortex of the ribs blocks and reflects the ultrasound waves, resulting in hyperechoic appearance to the cortex. The lung parenchyma is not visible as it is composed of air;

Fig. 1: Anatomical illustration of the superficial chest wall structures fused with corresponding ultrasound picture

Figs 3A and B: Lung ultrasound examination 12-region method: (A) Divide the anterior, lateral, and posterior part of each hemithorax into upper and lower halves, making up to 12 zones; (B) Keep the probe on the anterior chest in the midclavicular line and examine along this anatomical landmark moving the probe from lung apices to the costophrenic angles. Examine along midaxillary line laterally and along midclavicular line posteriorly

therefore, it scatters and reflects the ultrasound waves. The parietal and the visceral pleura appear as a single hyperechoic shimmering line—pleural line. Figure 1 is an illustration of superficial structures of the chest wall fused with the corroborating ultrasound picture. A number of artifacts are created as the ultrasound waves are reflected by the surface of the lung, which provide important lung's pathophysiology.

THE TECHNIQUE OF DOING LUNG ULTRASOUND

Probe Selection

The ultrasound transducer is selected according to the size of the child. Generally, a high-resolution linear or microconvex probe is used with ultrasound frequency range 6–12 MHz (Fig. 2A). If penetration of the linear probe is not enough, like in older or obese children, frequency of the probe can be decreased to microconvex probe (Fig. 2B) or phased array (5–8 MHz) (Fig. 2C).

Technique

Child can be scanned in the upright position, while lying down in the supine position or sitting comfortably in caregiver's lap. Each half

Figs 2A to C: (A) Linear probe; (B) Microconvex probe; (C) Phased array probe

Fig. 4: Ten-region method (preferred in PICU): Whole chest is divided into 10 zones. Area 1 and 2 divided by imaginary line passing through nipple. Area 3 and 4 represent upper and lower axilla whereas area 5 is interscapular area

of chest is divided into three zones—anterior, lateral, and posterior. Subsequently, each zone is further divided into upper and lower half, using an imaginary line that connects the nipples, resulting in total of 12 zones—six on each side. A structured examination is performed subsequently by placing the probe on the upper half of the anterior zone in the intercostal space and then each zone is examined alongside the anatomical landmarks—midclavicular line on the anterior zone, midaxillary line on the lateral zone, and midclavicular line on the posterior zone (Fig. 3). In the pediatric intensive care unit, however, many a times the turning of the sick child is extremely difficult; in that case, the 10-region method can be used, i.e., 10 regions on both sides of the lungs (2 anterior, 2 lateral, i.e., axilla, 1 posteriorly) (Fig. 4). All the 10 areas should be scanned carefully to ensure comprehensive coverage as well as to minimize the possibility of missing lung lesions. The probe should be rotated both parallel and perpendicular to the ribs during lung examination, moving the probe from one intercostal region to another in caudal direction from lung apices to the costophrenic angle till the subdiaphragmatic organs are seen. Dependent areas of the lung should be specifically examined to visualize and exclude the pleural effusion.

LUNG ULTRASOUND BASIC TERMINOLOGY

Pleural Line and Lung Sliding Sign

The first structure that is visualized when the probe is placed on the chest wall is pleural line—a hyperechoic, smooth, crisp, shimmering line that slides back and forth with respiration (Fig. 5A). This movement is due to the movement of the visceral pleura over the parietal pleura with respiration, which gives shimmering or “crawling ant” like look to the pleural line and is called the lung sliding sign. The image can be visualized in the M-mode; superficial parietal layer appears like a sea and the lung parenchyma area deep to it appears granular as the motion of the pleura is reflected all over this granular area. This appearance is known as the “seashore sign” (Fig. 6).

Figs 5A and B: (A) A hyperechoic, smooth, crisp, shimmering line that moves to and fro with inspiration is pleural line; (B) Shows two ribs and the parietal pleura between them forming a bat sign

Fig. 6: Normal lung in B-mode and M-mode. First picture on left side is showing P pleura (visceral and parietal), L lung in B-mode. Middle picture (M-mode) and right picture are showing M-mode appearance of normal lung. A superficial tissue looks like waves (A#) but static. B is like granules of sand (B#) as seen at seashore. This granular appearance, i.e., seashore is because the motion of pleura

Bat Sign

A rib is visualized as a shadow due to the absorption of the ultrasonic waves by the bony rib structure. Two ribs and the parietal pleura between them produce a “bat sign” (the adjacent ribs produce the wings of the bat and the pleural line forms the body of the bat) (Fig. 5B).

ARTIFACTS

A-lines

A-line is a reverberation artifact produced by the reflection of the sound waves when a probe is placed perpendicular to the ribs for scanning (Fig. 7). This occurs when the ultrasonic waves pass through a tissue that is almost completely full of air like normal lung and other pathological states like pneumothorax and asthma. These sound waves are reflected strongly by this tissue-air interface and reverberate or “bounce” back and forth, between the transducer and lung surface to produce A-lines. They are horizontal lines placed constant distances apart.

Fig. 7: A-lines—A is distance between skin and pleura, A# is distance between pleura and first A-line. Distance between two A-lines is equal to point A. As we move away from probe, A-lines fade (line 3 is fainter than 2)

- A-lines are normal finding if present with normal lung sliding sign, and suggest normal lung parenchyma.
- A-lines with absent lung sliding sign suggest pneumothorax.^{14,15}

B-lines

B-line is an artifact that occurs when sound waves encountering a mixture of air and water below the pleural line [as in pulmonary edema, pneumonia, lung contusion, acute respiratory distress syndrome (ARDS), etc.]. In this case, the air and water interface causes reverberation artifact within the lung, giving rise to discrete laser-like vertical hyperechoic structures that arise vertically from the pleural line, extend to the bottom of the ultrasound screen without fading, erasing the A-lines, and move synchronously with respiration and lung sliding (Fig. 8). B-lines are also called "lung rockets." A single B-line can be a normal finding. However, more than three lines in a single intercostal view is significant and is pathological. A confluent B-line is when the entire intercostal space is occupied with B-lines and it's not possible to distinguish or count the B-lines. It occurs due to increased interstitial fluid, which causes thickening of the interlobular septae, resulting in confluent B-lines on LUS.^{10,16}

- Generalized B-lines are seen in ARDS and lung edema.¹⁷
- Localized B-lines are seen in pneumonia and lung contusion.
- When two or more intercostal spaces are filled with confluent B-lines in a scanning area, it is termed as alveolar-Interstitial syndrome (AIS).

Figs 8A and B: B-lines—(A) represents B-lines whereas (B) is showing normal lung

Z-lines are short, ill-defined, vertical comet tail artifacts arising from the pleural line but not reaching the bottom of the screen and are not B-lines (Fig. 9). These are found in normal persons as well as in those with pneumothorax. They are less echogenic than the pleural line, usually taper off at after 2–4 cm; they do not erase A-lines and do not move with lung sliding.

LUNG ULTRASOUND FINDINGS IN CASE OF PNEUMONIA IN CHILDREN

Consolidation

- Consolidation with air bronchograms is the most typical finding on LUS in pneumonia.^{18,19} Consolidation is an isoechoic structure that looks like tissue on ultrasound and occurs due to loss of aeration.^{20,21} Lung is a hypoechoic structure on LUS. In translobar consolidation, a tissue-like sign is visualized in which the lung appears like a solid viscera, such as liver. Inflammatory and purulent fluid fills up the alveoli giving a homogeneous solid appearance to the lungs, similar to the liver (Fig. 10B). In case of nontranslobar consolidation, the border of the consolidated area, where consolidated lung meets the aerated lung, appears shredded and is called the shred sign (Fig. 11B).
- Another important finding in pneumonia is air in the bronchi—air bronchogram. Air in the consolidated area remains in the small bronchi, and these echogenic air bubbles lined up in a bronchus give the sonographic appearance of air bronchogram. These air bubbles can be seen moving in the bronchi with respiration and are termed as dynamic air bronchograms (Figs 12A and B). Collapsed lung or atelectatic segments can mimic consolidation on LUS.^{22,23} The presence of dynamic air bronchogram confers the patency of bronchi, hence rules out the collapse or atelectasis.²⁴
- Other key features are (a) abnormal pleural line (thickened or irregular) over the consolidated area, (b) subpleural consolidations, (c) A-lines are erased by B-lines, (d) increased B-lines or alveolar interstitial syndrome-like pattern is present in nonconsolidated area due to inflammatory edema, and (e) pleural effusion (echo-free or hypoechoic fluid space between the visceral and parietal pleura).^{25–27}
- Lung pulse, which represents movement of the pleura due to transmissions of cardiac pulsations, can also be seen in case of

Figs 9A and B: Z lines—Z lines (vertical arrows) are comet-tail artifacts arising from the pleural line, ill-defined, short (2–4 cm), less echoic than the pleural line, not erasing the A-lines (horizontal arrows)

Figs 10A and B: (A) Chest X-ray of a 7-year-old child showing B/L pneumonia; (B) Lung ultrasound shows tissue-like sign—homogeneous solid appearance of the lungs, similar to liver

Figs 11A and B: (A) Chest X-ray of 10 months old with pneumonia; (B) Lung ultrasound shows irregular border between the consolidated area and the aerated lung is termed as the shred sign

collapse or collapse with consolidation. This picture or presence of single B-line rules out pneumothorax.²⁸ It is demonstrated in the M-mode as a regular motion artifact via the seashore sign pattern to the level of the pleura (Fig. 13).

A recent meta-analysis done on 795 children with suspected pneumonia reported a higher sensitivity of 96% (95% CI: 94–97%) but lower specificity of 93% (95% CI: 90–96%) of LUS in diagnosing pneumonia in children²⁹ as compared to adult studies (sensitivity and specificity of 94 and 96%, respectively).²¹ Small and thin chest wall allowing better visualization of lung parenchyma in children is responsible for higher sensitivity. Another systemic review and meta-analysis conducted by Orso et al. showed 94% sensitivity and 94% specificity of LUS in diagnosing pneumonia in children with the likelihood ratio of 13.4% and area under the operating curve as 0.98, which indicates good diagnostic accuracy of LUS.³⁰ However, noninfective processes like segmental atelectasis and collapse that are commonly seen in bronchiolitis and asthma in children are misinterpreted as pneumonia, and account for lower specificity. Hence, it becomes imperative to differentiate between bronchiolitis, viral, and bacterial pneumonia. According to the literature, the LUS findings in bronchiolitis or viral pneumonia are subcentimeter subpleural consolidations (<1 cm), no dynamic air bronchograms, and pleural line changes (irregularity or thickening), with single, few B-lines.^{31–33} Baigi et al. used LUS for diagnosing

pneumonia in patients with clinical bronchiolitis and demonstrated that on including consolidation size >1 cm as the criteria to diagnose pneumonia, specificity of LUS increased.³⁴ Similarly, Lissaman et al. studied that 44% of the patients with subcentimetric lesions on LUS recovered without antibiotics, further emphasizing viral etiology in patients' LUS findings of lesions <1 cm.³⁵ The alveolar interstitial pattern is also generally accepted to represent viral pneumonias.^{18,32} However, there not sufficient direct microbiological evidence to link alveolar-interstitial syndrome (AIS) to specific pathogen. The LUS finding of typical consolidation and dynamic air bronchograms and presence of pleural effusion favors the presence of bacterial pneumonia.³⁶

Alveolar-interstitial syndrome can be due to cardiogenic pulmonary edema or fluid overload and due to ARDS or interstitial pneumonia. In ARDS, there is nonhomogeneous distribution of B-lines, along with subpleural consolidations, irregular thickened pleura, absence or reduction of lung sliding sign, and "spared areas" of normal lung (Fig. 14B); however, in cardiogenic pulmonary edema, B-lines are uniformly spread with smooth pleural line (Fig. 14D). Lung ultrasound shows 93% accuracy in diagnosing alveolar interstitial syndrome, using CT scan as a reference, which is 100% accurate.¹⁰

Ultrasound also aids in diagnosing the complications of pneumonia—pleural effusion, empyema, and pneumothorax.

Pleural Effusion

The consolidated area may be surrounded by pleural effusion of various degrees. Ultrasound is more efficient than a normal physical examination CXR in diagnosing pleural effusion. Even minimal pleural effusion (about 5 mL), which is not obvious on a chest X-ray, can be detected using LUS. Pleural effusion is seen as a hypoechoic or anechoic fluid in the pleural space (Figs 15A and B); however, exudates and septations can be seen in case of old hemothorax or empyema (Figs 15C to E and 16B). In case of moderate to large pleural effusions, lung floating or lung flapping sign can be appreciated (Fig. 17). Figure 18B shows the LUS of a girl with empyema with exudates and septations in the pleural space. Amount of pleural fluid can be monitored using serial LUSs, and LUS allows safe USG-guided drainage of the pleural fluid for the diagnostic as well as therapeutic purpose. In adults, the quantity of

Figs 12A and B: Air bubbles in a bronchus of a consolidated area form the air bronchogram. The movement of these air bubbles with respiration is termed as dynamic air bronchograms

Figs 13A and B: Pulse sign (movement of the pleura due to transmissions of cardiac pulsations seen in collapse or collapse with consolidation) seen in M-mode as a regular motion artifact via the seashore sign pattern to the level of the pleura

the pleural fluid can be assessed using the formula: volume (mL) = distance between the base of the lung and the pleura in mm $\times$ 20. Studies have shown that LUS has a sensitivity of 93% and specificity of 97 % in detecting pleural effusions.^{8,37}

Pneumothorax

Lung ultrasound has 95% sensitivity and 100% NPV in diagnosing pneumothorax.¹⁴ In a pneumothorax, the air separates the visceral and parietal pleura and prevents the visualization of visceral pleura. Hence, lung sliding is absent. The M-mode can be used to confirm a lack of sliding sign. The resultant M-mode tracing in a pneumothorax will display a pattern of parallel horizontal lines above and below the pleural line, indicating the lack of movement. This pattern is termed as a "barcode" and is often called the "stratosphere sign." The NPV for lung sliding is reported as 99.2–100%, indicating that the presence of sliding effectively rules out a pneumothorax.^{12,38} However, lung sliding is abolished in a variety of conditions other than pneumothorax, including ARDS, pulmonary fibrosis, and very large consolidations. Hence, combination of this with other signs improves the accuracy of the diagnosis of pneumothorax. A-lines

will be present in a patient with a pneumothorax, but comet tail artifacts or "B-lines," these reverberation artifacts are lost due to air accumulating within the pleural space.

Lung Point

It is point where sudden appearing of sliding occurs in an area of no sliding sign with A pattern. It is the most pathognomonic sign in diagnosing pneumothorax. The "lung-point sign" can be noticed at the border of a pneumothorax. It is the point at which visceral and parietal pleura start to separate. The "lung-point sign" is 100% specific for pneumothorax^{11,39} (Fig. 18B). The location of the lung point aids in determining the size of the pneumothorax. If the lung point is found laterally or posteriorly, it points toward large pneumothorax.

OTHER PRACTICAL APPLICATIONS OF LUNG ULTRASOUND IN PNEUMONIA

- Monitoring treatment response and assessing new complications while on treatment of pneumonia: Daily bedside LUSs can be done in order to monitor the response to treatment in case of pneumonia (resolution of tissue like sign or shred sign, drainage of pneumothorax/pleural effusion after placing chest drain). Lung ultrasound also helps to identify and act on any new complications, such as any new lung infection, VAP, fluid overload, and pneumothorax, which can occur while on treatment, manifested in the form of acute deterioration of the clinical status after an initial response to treatment (Fig. 19).
- Monitoring the fluid in the lungs: Positive fluid balance has shown to increase the length of hospital stay, days on mechanical ventilator, and mortality.⁴⁰ As mentioned before, more than three B-lines in an intercostal space is indicative of increased extravascular lung water. Hence, it helps the clinician to identify fluid overload and initiate diuretic therapy in order to achieve negative balance and remove the extra fluid in the lungs. Figures 20 and 21 mention two cases, one of bronchiolitis and the other one of multi-inflammatory syndrome, which showed extensive B-lines and respiratory status improved after initiating the diuretics along with fluid restriction.

Figs 14A to D: (A) Chest X-ray picture of a 4-year-old boy with ARDS B/L infiltrates and air bronchogram; (B) Corresponding lung USG picture showing nonhomogeneous distribution of B-lines, along with subpleural consolidations, absence or reduction of lung sliding sign, “spared areas” of normal lung. This ultrasound picture can be compared with the normal lung (C) and cardiogenic pulmonary edema (D) where B-lines are uniformly spread with sooth pleural line, no spared areas

Figs 15A to F: Pleural effusion—(A) hypoechoic or anechoic fluid representing transudate, (C, D, F) pictures representing exudates with septae, D# showing decrease in septae after conservative treatment of exudative effusion with septae secondary to Staphylococci infection as shown in pic D, (B) M-mode of pleural effusion, used to estimate the expiratory depth, (E) hemothorax, starry sky appearance

Figs 16A and B: (A) Chest X-ray of a 14-year-old girl with *Pseudomonas empyema* left lung; (B) Lung USG showing exudates and septations seen in the pleural space suggestive of empyema

Figs 17A and B: (A) Chest X-ray of a 12-year-old boy with pneumonia and B/L pleural Effusion; (B) Lung USG shows hypoechoic clear fluid in the pleural effusion with floating lung in the fluid

Figs 18A and B: (A) Chest X-ray of a 2-year-old male child with acute bronchopneumonia and right pneumothorax; (B) Lung USG (M-mode) shows lung point—the junction of normal lung (seashore sign) and pneumothorax lung (barcode sign)

Figs 19A to E: A 12-year-old female case of bronchopleural fistulae (A) secondary to H1N1 infection. On 12th day there was reappearance of fever with chest X-ray showing radio-opaque (B) fluid in the right side of chest. CT scan axial picture (D) showing necrotic lung with fluid in pleura. Ultrasound lung (C) showing extensive loculations that are better seen than CT scan. Linear probe (E) was kept posteriorly on the right side

Figs 20A and B: (A) Chest X-ray of a case of small VSD presented with features of cough and cold without clinical features of congestive cardiac failure. Initial impression was acute bronchiolitis; (B) USG lung showed extensive B-lines. Furosemide was given in infusion for 24 hours, after which respiratory status improved indicating pulmonary edema as dominating pathology than viral bronchiolitis. Above figure also indicates that as compared to chest X-ray ultrasound is more sensitive to show fluid in lung

Figs 21A to F: A case of multi-inflammatory syndrome secondary to COVID-19 in a 6-year-old child. 12 hours after IVIG child developed respiratory distress. (A) Chest X-ray done at the time of appearance of respiratory distress showing slight increase in bronchovascular markings in expiratory and underexposed film. Lung USG showing B-lines that further reduced over next 12 hours after giving diuretics (B-lines decreasing from C to F)

WHAT IS BETTER—LUNG ULTRASOUND OR CHEST X-RAY FOR DIAGNOSING PEDIATRIC PNEUMONIA?

Several studies till date have reported that LUS is a robust modality to diagnose pneumonia in children as compared to chest X-ray. Copetti et al. reported that lung USG is as reliable as chest X-ray in

diagnosing pneumonia in children, with additional advantage that lung USG can be performed at patient's bedside without exposing the child to harmful ionizing radiation.⁴¹ Lung ultrasound has also been reported to be a better modality to detect very small subcentimeter consolidations that can be missed on the chest X-ray. A study done on 143 children with pneumonia showed that 70% of the children had negative chest X-ray for consolidation, whereas

lung USG demonstrated good performance—98% sensitivity, 92% specificity, and a very high NPV of 99%. Lung ultrasound could pick up consolidations as small as 9.4 mm.¹³ Lung ultrasonography can also pick up small effusions, which can be difficult to pick up on chest radiograph. Caiulo et al. reported lung USG is better than chest X-ray in detecting pleural effusion in complicated pneumonia, as LUS picked up pleural effusion in 16 cases of pneumonia in children, whereas chest X-ray was able to pick effusion in only 3 cases out of 102 patients.⁴² In case of pneumothorax, sensitivity of a lung USG (90%) is higher than chest X-ray (49%) in diagnosing pneumothorax.⁴³ Lung ultrasound is also more useful than chest X-ray in diagnosing pneumothorax as it allows prompt diagnosis of pneumothorax at bedside in critical situation like cardiac arrest, detects radio-occult pneumothorax, and quantifies the extension of pneumothorax. On comparing chest X-ray with CT scan, which is the gold standard in diagnosing pneumonia, Kurian et al. found that performance of LUS is similar to CT scan in identifying pleural effusion, consolidation of lung parenchyma, necrosis, or abscess in case of complicated pneumonia. Hence, LUS can be used to do initial workup of a child with complicated pneumonia and CT scan can be limited to those cases with discrepant clinical findings.⁴⁴ Sensitivity of lung USG in detecting pneumothorax is similar to CT chest and it does not require transport of critically sick patient to the scanning room ensuring less exposure to ionizing radiation.

Lung ultrasound is also better than chest X-ray in differentiating bronchiolitis and viral pneumonias than chest X-ray. A study conducted on patients clinically diagnosed with bronchiolitis, LUS could detect 47 out of 52 children, whereas chest X-ray could pick up only 38 out of 52 children with bronchiolitis.³³ A randomized control trial (RCT) done on 191 children reported 38.8% reduction in performing chest radiography in children admitted to emergency department with pneumonia with LUS in the study group. Remarkably, no cases of pneumonias were missed in patients in the study arm.¹⁹ Other advantages of using lung USG over chest X-ray are that LUS does not expose the patient to harmful ionizing radiation, which is not the case with chest radiography. Also, LUS can be performed at bedside and its repeatable, reproducible. Real-time ultrasound monitoring can be done to monitor the treatment response without additional radiation exposures. A number of studies have been conducted that follow-up ultrasounds between 5 and 8 days from the date of commencement of treatment and saw a decrease or disappearance of subpleural parenchymal consolidations, along with clinical improvement and decrease in the inflammatory markers.^{42,45,46} However, LUS has its own limitations. It can miss deep-seated consolidations. Also, routine features like hyperinflation, cardiac size, airway size, and position, which are clearly evident on chest radiograph, cannot be studied with LUS.²³

LUNG ULTRASOUND TRAINING

Lung ultrasound also can be learnt with brief training. Shah et al. conducted a study where USG was performed on 200 patients after 1 hour of focused training sessions of the emergency clinicians and found that doctors were able to diagnose pneumonia with high specificity (89%) with likelihood ratio of 7.8%.¹⁸ Other studies have also assessed the reliability of LUS by demonstrating substantial interobserver agreement between several clinicians on the interpretation of LUS images with kappa values of 0.55–0.93.^{19,47} A number of other studies have shown that even 10–30 minutes of brief ultrasound training has been sufficient for the pediatricians and emergency physicians to

identify lung pathology on lung ultrasonography.^{48,49} Hence, LUS training to clinicians and emergency physicians can not only help us identify pneumonia in children but also can guide us about the development of complications of pneumonia and monitor the treatment response.

CONCLUSION

To summarize, LUS if performed using a structured approach, after focused training, is an accurate and reliable tool to detect consolidations and other features of pneumonia in children with added advantages of no exposure to harmful radiations. In settings where chest radiograph is not available, LUS can prove to be a beneficial tool to identify pneumonia, whereas in the settings where both the modalities are available, ultrasound can reduce to need for repeated chest radiographs. However, the LUS interpretation should be guided by comprehensive clinical examination and microbiological results.

REFERENCES

1. World Health Organisation. Maternal, newborn, child and adolescent health. Available from https://www.who.int/maternal_child_adolescent/news_events/news/2011/pneumonia/en/. Accessed April 21, 2020.
2. UNICEF. One child dies of pneumonia every 39 seconds, agencies warn. Available from <https://www.unicef.org/press-releases/one-child-dies-pneumonia-every-39-seconds-agencies-warn>. Accessed April 21, 2020.
3. Johnson J, Kline JA. Intraobserver and interobserver agreement of the interpretation of pediatric chest radiographs. *Emerg Radiol* 2010;17(4):285–290. DOI: 10.1007/s10140-009-0854-2.
4. Levinsky Y, Mimouni FB, Fisher D, et al. Chest radiography of acute paediatric lower respiratory infections: experience versus interobserver variation. *Acta Paediatr* 2013;102(7):310–314. DOI: 10.1111/apa.12249.
5. Hagaman JT, Panos RJ, Rouan GW, et al. Admission chest radiograph lacks sensitivity in the diagnosis of community-acquired pneumonia. *Am J Med Sci* 2009;337(4):236–240. DOI: 10.1097/MAJ.0b013e31818ad805.
6. Stuckey-Schrock K, Hayes BL, George CM. Community-acquired pneumonia in children. *Am Fam Physician* 2012;86(7):661–667.
7. Haq IJ, Battersby AC, Eastham K, et al. Community acquired pneumonia in children. *BMJ* 2017;356:686. DOI: 10.1136/bmj.j686.
8. Lichtenstein D, Hulot JS, Rabiller A, et al. Feasibility and safety of ultrasound-aided thoracentesis in mechanically ventilated patients. *Intensive Care Med* 1999;25(9):955–958. DOI: 10.1007/s001340050988.
9. Lichtenstein DA, Lascols N, Meziere G, et al. Ultrasound diagnosis of alveolar consolidation in the critically ill. *Intensive Care Med* 2004;30(2):276–281. DOI: 10.1007/s00134-003-2075-6.
10. Lichtenstein D, Mézière G, Biderman P, et al. The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. *Am J Respir Crit Care Med* 1997;156(5):1640–1646. DOI: 10.1164/ajrccm.156.5.96-07096.
11. Lichtenstein D, Mezière G, Biderman P, et al. The "lung point": an ultrasound sign specific to pneumothorax. *Intensive Care Med* 2000;26(10):1434–1440. DOI: 10.1007/s001340000627.
12. Lichtenstein DA, Mezière G, Lascols N, et al. Ultrasound diagnosis of occult pneumothorax. *Crit Care Med* 2005;33(6):1231–1238. DOI: 10.1097/01.CCM.0000164542.86954.B4.
13. Claes AS, Clapuyt P, Menten R, et al. Performance of chest ultrasound in pediatric pneumonia. *Eur J Radiol* 2017;88:82–87. DOI: 10.1016/j.ejrad.2016.12.032.
14. Lichtenstein DA, Menu Y. A bedside ultrasound sign ruling out pneumothorax in the critically ill. *Chest* 1995;108(5):1345–1348. DOI: 10.1378/chest.108.5.1345.

15. Piette E, Daoust R, Denault A. Basic concepts in the use of thoracic and lung ultrasound. *Curr Opin Anaesthesiol* 2013;26(1):20–30. DOI: 10.1097/ACO.0b013e32835afd40.
16. Martelius L, Heldt H, Lauerma K. B-lines on pediatric lung sonography: comparison with computed tomography. *J Ultrasound Med* 2016;35(1):153–157. DOI: 10.7863/ultra.15.01092.
17. Dietrich CF, Mathis G, Blaivas M, et al. Lung B-line artefacts and their use. *J Thorac Dis* 2016;8(6):1356–1365. DOI: 10.21037/jtd.2016.04.55.
18. Shah VP, Tunik MG, Tsung JW. Prospective evaluation of point-of-care ultrasonography for the diagnosis of pneumonia in children and young adults. *JAMA Pediatr* 2013;167(2):119–125. DOI: 10.1001/2013.jamapediatrics.107.
19. Jones BP, Tay ET, Elikashvili I, et al. Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: a randomized controlled trial. *Chest* 2016;150(1):131–138. DOI: 10.1016/j.chest.2016.02.643.
20. Benci A, Caremani M, Menchetti D, et al. Sonographic diagnosis of pneumonia and bronchopneumonia. *Eur J Ultrasound* 1996;4(3):169–176. DOI: 10.1016/S0929-8266(96)00195-4.
21. Chavez MA, Shams N, Ellington LE, et al. Lung ultrasound for the diagnosis of pneumonia in adults: a systematic review and meta-analysis. *Respir Res* 2014;15(1):50. DOI: 10.1186/1465-9921-15-50.
22. Riccabona M. Ultrasound of the chest in children (mediastinum excluded). *Eur Radiol* 2008;18(2):390–399. DOI: 10.1007/s00330-007-0754-3.
23. Tomà P, Owens CM. Chest ultrasound in children: critical appraisal. *Pediatr Radiol* 2013;43(11):1427–1434. DOI: 10.1007/s00247-013-2756-4.
24. Lichtenstein D, Mezière G, Seitz J. The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. *Chest* 2009;135(6):1421–1425. DOI: 10.1378/chest.08-2281.
25. Stadler JAM, Andronikou S, Zar HJ. Lung ultrasound for the diagnosis of community-acquired pneumonia in children. *Pediatr Radiol* 2017;47(11):1412–1419. DOI: 10.1007/s00247-017-3910-1.
26. Ho MC, Ker CR, Hsu JH, et al. Usefulness of lung ultrasound in the diagnosis of community-acquired pneumonia in children. *Pediatr Neonatol* 2015;56(1):40–45. DOI: 10.1016/j.pedneo.2014.03.007.
27. Mohamed A, Kamel O, Ghazy M. Accuracy of lung ultrasonography in diagnosis of community acquired pneumonia as compared to chest X-ray in pediatric age group. *Egypt J Hospital Med* 2018;72(8):4977–4983.
28. Ord HL, Griksaitis MJ. Fifteen-minute consultation: using point of care ultrasound to assess children with respiratory failure. *Arch Dis Child Educ Pract Ed* 2019;104(1):2–10. DOI: 10.1136/archdischild-2017-313795.
29. Pereda MA, Chavez MA, Hooper-Miele CC, et al. Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. *Pediatrics* 2015;135(4):714–722. DOI: 10.1542/peds.2014-2833.
30. Orso D, Ban A, Guglielmo N. Lung ultrasound in diagnosing pneumonia in childhood: a systematic review and meta-analysis. *J Ultrasound* 2018;21(3):183–195. DOI: 10.1007/s40477-018-0306-5.
31. Basile V, Di Mauro A, Scalini E, et al. Lung ultrasound: a useful tool in diagnosis and management of bronchiolitis. *BMC Pediatr* 2015;15(1):63. DOI: 10.1186/s12887-015-0380-1.
32. Tsung JW, Kessler DO, Shah VP. Prospective application of clinician performed lung ultrasonography during the 2009 H1N1 influenza a pandemic: distinguishing viral from bacterial pneumonia. *Crit Ultrasound J* 2012;4(1):16. DOI: 10.1186/2036-7902-4-16.
33. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound in bronchiolitis: comparison with CXR. *Eur J Pediatr* 2011;170(11):1427–1433. DOI: 10.1007/s00431-011-1461-2.
34. Biagi C, Pierantoni L, Baldazzi M, et al. Lung ultrasound for the diagnosis of pneumonia in children with acute bronchiolitis. *BMC Pulm Med* 2018;18(1):191. DOI: 10.1186/s12890-018-0750-1.
35. Lissaman C, Kanjanaptom P, Ong C, et al. Prospective observational study of point-of-care ultrasound for diagnosing pneumonia. *Arch Dis Child* 2019;104(1):12–18. DOI: 10.1136/archdischild-2017-314496.
36. Najgrodzka P, Buda N, Zamojska A, et al. Lung ultrasonography in the diagnosis of pneumonia in children-A metaanalysis and a review of pediatric lung imaging. *Ultrasound Q* 2019;35(2):157–163. DOI: 10.1097/RUQ.0000000000000411.
37. Lichtenstein D, Goldstein I, Mourgeon E, et al. Comparative diagnostic performances of auscultation, chest radiography and lung ultrasonography in ARDS. *Anesthesiology* 2004;100(1):9–15. DOI: 10.1097/00000542-200401000-00006.
38. Blaivas M, Lyon M, Duggal S. A prospective comparison of supine chest radiography and bedside ultrasound for the diagnosis of traumatic pneumothorax. *Acad Emerg Med* 2005;12(9):844–849. DOI: 10.1197/j.aem.2005.05.005.
39. De Luca C, Valentino M, Rimondi M, et al. Use of chest sonography in acute-care radiology. *J Ultrasound* 2008;11(4):125–134. DOI: 10.1016/j.jus.2008.09.006.
40. Flori HR, Church G, Liu KD, et al. Positive fluid balance is associated with higher mortality and prolonged mechanical ventilation in pediatric patients with acute lung injury. *Critic Care Res Pract* 2011. 854142. DOI: 10.1155/2011/854142.
41. Copetti R, Cattarossi L. Ultrasound diagnosis of pneumonia in children. *Radiol Med* 2008;113(2):190–198. DOI: 10.1007/s11547-008-0247-8.
42. Caiulo VA, Gargani L, Caiulo S, et al. Lung ultrasound characteristics of community-acquired pneumonia in hospitalized children. *Pediatr Pulmonol* 2013;48(3):280–287. DOI: 10.1002/ppul.22585.
43. Volpicelli G. Sonographic diagnosis of pneumothorax. *Intensive Care Med* 2011;37(2):224–232. DOI: 10.1007/s00134-010-2079-y.
44. Kurian J, Levin TL, Han BK, et al. Comparison of ultrasound and CT in the evaluation of pneumonia complicated by Parapneumonic effusion in children. *AJR Am J Roentgenol* 2009;193(6):1648–1654. DOI: 10.2214/AJR.09.2791.
45. Omran A, Eesai S, Ibrahim M, et al. Lung ultrasound in diagnosis and follow up of community acquired pneumonia in infants younger than 1-year old. *Clin Respir J* 2018;12(7):2204–2211. DOI: 10.1111/crj.12790.
46. Ianniello S, Piccolo CL, Buquicchio GL, et al. First-line diagnosis of paediatric pneumonia in emergency: lung ultrasound (LUS) in addition to chest-X-ray (CXR) and its role in follow-up. *Br J Radiol* 2016;89(1061):20150998. DOI: 10.1259/bjr.20150998.
47. Ambroggio L, Sucharew H, Rattan MS, et al. Lung ultrasonography: a viable alternative to chest radiography in children with suspected pneumonia? *J Pediatr* 2016;176:93–98.e7. DOI: 10.1016/j.jpeds.2016.05.033.
48. Bedetti G, Gargani L, Corbisiero A, et al. Evaluation of ultrasound lung comets by hand-held echocardiography. *Cardiovasc Ultrasound* 2006;4(1):34. DOI: 10.1186/1476-7120-4-34.
49. Monti JD, Younggren B, Blankenship R. Ultrasound detection of pneumothorax with minimally trained sonographers: a preliminary study. *J Spec Oper Med* 2009;9(1):43–46.