Indonesian Journal of Global Health Research
Volume 8 Number 1, February 2026
e-ISSN 2715-1972; p-ISSN 2714-9749
http://jurnal.globalhealthsciencegroup.com/index.php/IJGHR

DIAGNOSTIC ROLE OF LUNG ULTRASOUND IN PNEUMONIA

Putu Gita Indraswari[1,2]*, I Desak Putu Agung Krisdanti[1,2], Faradilla Novita Anggreini[1,3]
[1]Faculty of Medicine, Universitas Udayana, Jl. P.B. Sudirman, Dangin Puri Klod, Denpasar Barat, Denpasar, Bali 80232, Indonesia
[2]Department of Pulmonology and Respiratory Medicine, RS Universitas Udayana, Jl. Rumah Sakit Universitas Udayana, Jimbaran, Kuta Selatan, Badung, Bali 80361, Indonesia
[3]Department of Radiology, RSUD Prof. I.G.N.G. Ngoerah, Diponegoro, Dauh Puri Klod, Denpasar Barat, Denpasar, Bali 80113, Indonesia
*gitaindraswariputu@unud.ac.id

ABSTRACT
Pneumonia remains a leading cause of morbidity and mortality worldwide, particularly among hospitalized and critically ill patients. Diagnosis is traditionally based on clinical evaluation and chest radiography; however, overlapping clinical features with other respiratory diseases and limited access to radiographic imaging may result in diagnostic delays or inaccuracies. Lung ultrasonography has increasingly been recognized as a useful bedside imaging modality due to its portability, lack of ionizing radiation, and favorable diagnostic performance. This review aims to describe the underlying mechanism of lung ultrasonography, outline characteristic ultrasonographic findings in pneumonia, and evaluate its diagnostic value, including advantages and limitations, in clinical practice. A narrative literature review was conducted using electronic databases including PubMed, Scopus, Google Scholar, and ScienceDirect. Peer-reviewed articles, meta-analyses, clinical studies, guidelines, and authoritative textbooks related to lung ultrasound and adult pneumonia were included than published since 2021-2024. Data were analyzed descriptively, focusing on ultrasonographic features and diagnostic accuracy parameters. Lung ultrasound reveals a spectrum of findings corresponding to disease severity, including focal B-lines and pleural irregularities in early pneumonia, followed by lung consolidation characterized by shred sign, air bronchograms, and tissue-like (hepatization) appearance in advanced stages. Evidence from meta-analyses consistently demonstrates high diagnostic accuracy, with sensitivity and specificity generally exceeding 85–90%, often surpassing chest radiography. Lung ultrasonography is a reliable and practical imaging modality for the diagnosis of pneumonia. Given its high diagnostic accuracy and clinical advantages, lung ultrasound should be considered an important adjunct or alternative to conventional imaging, particularly in emergency, intensive care, and resource-limited settings.

Keywords: bedside imaging; diagnostic accuracy; lung ultrasonography; pneumonia; pulmonary consolidation

How to cite (in APA style)
Indraswari, P. G., Krisdanti, I. D. P. A., & Anggreini, F. N. (2026). Diagnostic Role of Lung Ultrasound in Pneumonia . *Indonesian Journal of Global Health Research*, *8*(1), 787–792. https://doi.org/10.37287/ijghr.v8i1.1453.

INTRODUCTION

Pneumonia remains a significant cause of morbidity and mortality worldwide. It is among the eight leading causes of death globally, with mortality rates reaching approximately 23% among patients admitted to intensive care units. In Indonesia, pneumonia was listed among the top ten causes of hospitalization in 2020 (Perhimpunan Dokter Paru Indonesia, 2022). The diagnosis of pneumonia is established based on clinical history, physical examination, and supportive diagnostic investigations. However, diagnosing pneumonia continues to be clinically challenging. The clinical presentation of pneumonia often overlaps with other respiratory conditions, and chest radiography as a standard imaging modality cannot always be performed due to patient condition or logistical limitations. These challenges may lead to diagnostic uncertainty, resulting in both underdiagnosis and overdiagnosis of pneumonia, which can adversely affect clinical outcomes (Perhimpunan Dokter Paru Indonesia, 2022).

Recent updates of the American Thoracic Society and Infectious Diseases Society of America guidelines acknowledge the growing role of lung ultrasonography as an adjunctive imaging

modality in the diagnostic evaluation of pneumonia, particularly in settings where chest radiography or computed tomography is unavailable, impractical, or delayed. Lung ultrasonography offers several advantages, including bedside applicability, absence of ionizing radiation, and favorable diagnostic accuracy compared with conventional chest imaging, This review aims to elucidate the mechanism of lung ultrasonography, describe its characteristic findings in pneumonia, and evaluate its diagnostic value, including its advantages and limitations in clinical practice.

METHOD

Study Design

This study was conducted as a narrative literature review aimed at analyzing the role of lung ultrasonography in the diagnosis of pneumonia. The review focused on the mechanism of lung ultrasound, characteristic ultrasonographic findings in pneumonia, and its diagnostic accuracy compared to conventional imaging modalities.

Data Sources and Search Strategy

Relevant literature was identified through electronic database searches including PubMed, Scopus, Google Scholar, and ScienceDirect. The search was conducted using combinations of the following keywords: “lung ultrasound,” “lung ultrasonography,” “pneumonia,” “diagnostic accuracy,” “B-lines,” “lung consolidation,” and “BLUE protocol.” Additional articles were identified through manual searching of reference lists from relevant studies and clinical guidelines.

Inclusion and Exclusion Criteria

Articles were included if they: 1) Discussed the application of lung ultrasound in adult patients with pneumonia since 2021-2024; 2) Reported ultrasonographic findings, diagnostic performance, or comparative analysis with chest radiography or computed tomography; 3) Were published in peer-reviewed journals or authoritative clinical textbooks; 4) Were written in English or Indonesian.
Studies were excluded if they focused exclusively on pediatric populations, non-infectious pulmonary diseases without relevance to pneumonia, or lacked clear diagnostic outcome data.

Data Extraction and Analysis

Data were extracted independently by reviewing the full text of selected articles. Extracted information included study design, population characteristics, lung ultrasound techniques, ultrasonographic findings, diagnostic performance parameters (sensitivity, specificity, predictive values, and likelihood ratios), as well as reported advantages and limitations of lung ultrasound. The findings were synthesized descriptively to provide a comprehensive overview of the diagnostic value of lung ultrasonography in pneumonia.

Ethical Considerations

As this study was based solely on previously published literature, no ethical approval or informed consent was required.

RESULT

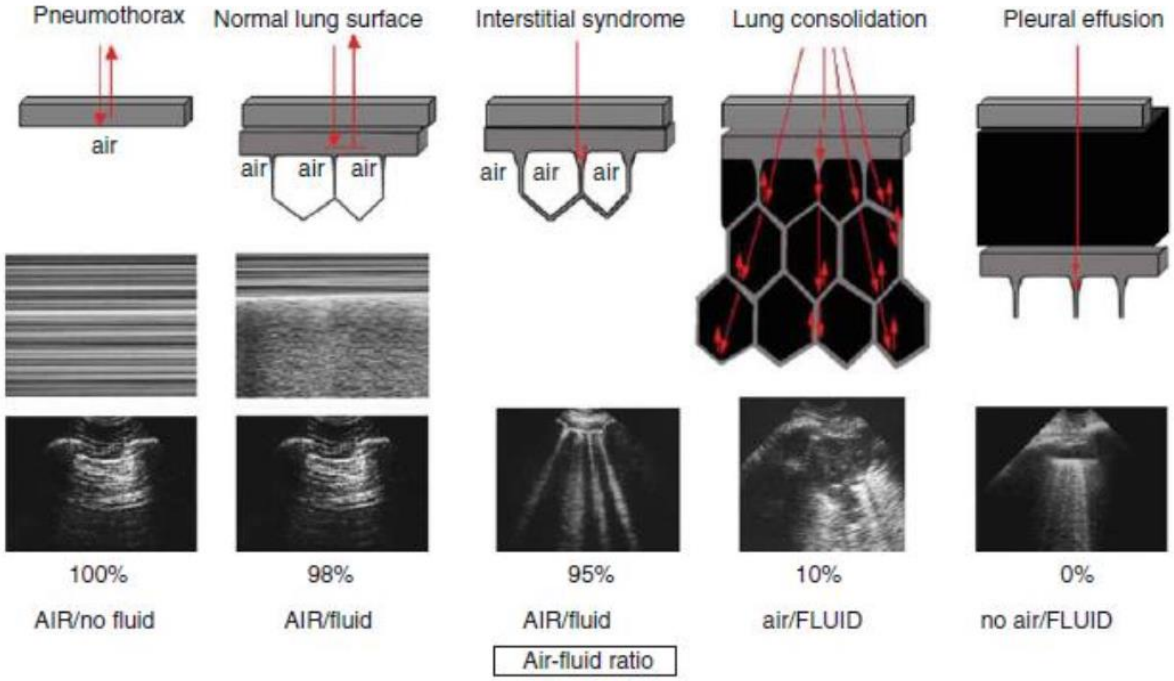
Mechanism of Lung Ultrasonography

Ultrasonography operates by generating high-frequency acoustic waves, typically within the range of 2 to 18 megahertz. These waves are produced through the piezoelectric properties of ceramic materials embedded within the ultrasound transducer. When an electrical current is applied, the piezoelectric elements undergo rapid mechanical deformation, producing oscillatory vibrations that propagate as ultrasonic waves. The emitted waves result from the inverse piezoelectric effect, whereas echoes reflected from tissue interfaces are detected by the transducer and converted back into electrical signals via the direct piezoelectric effect. These signals are subsequently processed and displayed as grayscale images based on the amplitude of the returning echoes (Elhidsi, 2023).

As ultrasonic waves propagate through biological tissues, they may be reflected, refracted, scattered, transmitted, or absorbed, depending on tissue composition and acoustic impedance. Lung

ultrasonography fundamentally differs from imaging of solid organs because pulmonary tissue contains air, which constitutes a strong acoustic reflector. Consequently, lung ultrasound does not rely on direct visualization of pulmonary anatomy but rather on the interpretation of characteristic artifacts generated by the interaction between ultrasound waves, the pleural surface, and intrapulmonary air (Elhidsi, 2023).

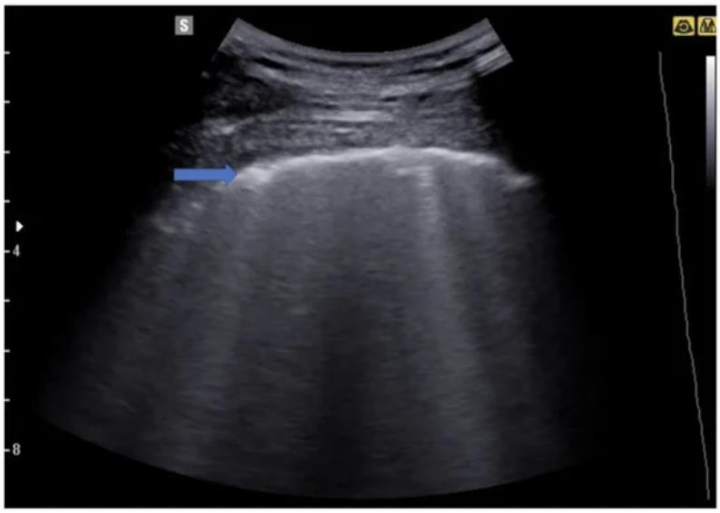
Image formation in lung ultrasonography is primarily governed by pronounced acoustic impedance gradients between air and fluid. Air effectively acts as an acoustic barrier, resulting in near complete reflection of ultrasound waves, whereas fluid facilitates efficient sound transmission. Variations in the air to fluid ratio produce distinct ultrasonographic patterns that correlate with specific pulmonary pathologies. In pleural effusion, the air to fluid ratio approaches zero; in interstitial syndrome, the ratio is markedly elevated at approximately 0.95; in chronic obstructive pulmonary disease or asthma, air predominates with a ratio of approximately 0.98; while in lung consolidation, the ratio is substantially reduced to around 0.1 (Lichtenstein, 2015).



Picture 1. Ultrasonographic Findings Based on the Air-Fluid Ratio (Lichtenstein, 2015).

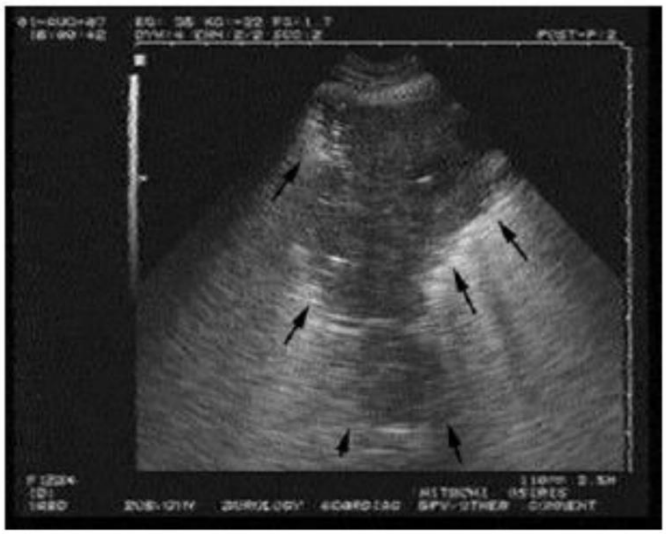
Lung Ultrasonography in Pneumonia

Pneumonia presents with a wide spectrum of ultrasonographic appearances depending on the extent of pulmonary involvement, particularly the degree of interstitial inflammation and alveolar consolidation. These variations reflect the progressive replacement of air within the lung parenchyma by fluid, inflammatory cells, or exudative material. In the early stage of pneumonia, lung ultrasound may demonstrate focal or localized abnormalities. These typically appear as focal B-lines, reflecting interstitial thickening and inflammation. Small pneumonic lesions may also manifest as subpleural hypoechoic areas, indicating limited involvement of the peripheral lung parenchyma. At this stage, lung aeration is usually still partially preserved (Marini et al., 2021).



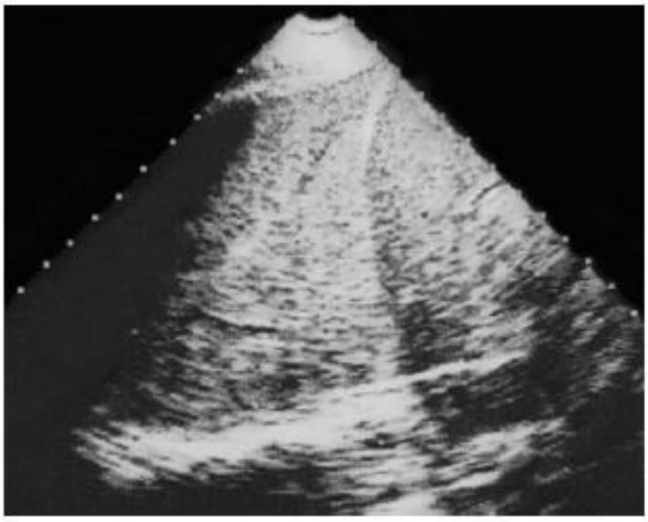
Picture 2. Ultrasound image of a patient with mild COVID-19 pneumonia showing an irregular pleural line (blue arrow), representing an early sign of pulmonary involvement, accompanied by the presence of focal B-lines Boccatonda et al., 2023).

As the disease progresses, alveolar involvement becomes more evident, leading to the development of consolidation. The transition between normally aerated lung and consolidated tissue is visualized as an irregular hyperechoic margin known as the shred sign, which reflects the heterogeneous interface between healthy and diseased lung parenchyma. Within these areas, residual air trapped in the bronchi appears as hyperechoic punctate or branching structures, representing air bronchograms (Marini et al., 2021).



Picture 3. Shred sign (Lichtenstein, 2015)

With further progression, the consolidated lung loses its normal air content and acquires an echotexture similar to that of the liver, a phenomenon referred to as hepatization or tissue like sign. This occurs when alveoli are filled with exudate, inflammatory cells, blood, or fluid. As a result, normal A-lines disappear due to the loss of air–tissue interfaces, indicating advanced alveolar consolidation Marini et al., 2021).



Picture 4. *Tissue like sign* (Lichtenstein, 2015)

DISCUSSION

Diagnostic Value of Lung Ultrasound In Pneumonia

A comprehensive meta-analysis involving 29 studies with a total of 6,702 participants demonstrated the high diagnostic performance of lung ultrasound (LUS) in adult patients with pneumonia. The pooled sensitivity, specificity, and positive predictive value were 92% (95% CI: 91–93%), 94% (95% CI: 94–95%), and 93% (95% CI: 89–96%), respectively. In addition, the pooled positive and negative likelihood ratios were 16 (95% CI: 14–19) and 0.08 (95% CI: 0.07–0.09), indicating excellent diagnostic power. These findings suggest that lung ultrasound provides highly reliable diagnostic performance and may play an important role in future diagnostic algorithms for adult pneumonia (Desai et al., 2024)

Consistent with these results, another meta-analysis reported that lung ultrasound outperformed chest radiography in the diagnosis of pneumonia, with a sensitivity of 88% and specificity of 86% (Sistani and Parooie, 2021). Supporting these international findings, a study conducted at RSUP Ngoerah using the BLUE protocol demonstrated a sensitivity of 86.8% (95% CI: 74.7–94.5%) and a specificity of 70.6% (95% CI: 44.0–89.7%). Confirmed diagnostic accuracy in this cohort reached 82.8%, with a positive predictive value of 90.2% (95% CI: 78.6–96.7%) and a negative predictive value of 63.2% (95% CI: 38.4–83.7%) (Indraswari et al., 2024).

Further reinforcing the diagnostic reliability of lung ultrasound, Tarnoki et al (2024) reported a sensitivity of 90.0% (95% CI: 81.3–96.2%) and a specificity of 90.8% (95% CI: 79.9–97.7%). The corresponding positive and negative likelihood ratios were 9.45 (95% CI: 3.73–23.94) and 0.12 (95% CI: 0.06–0.24), respectively, yielding a diagnostic odds ratio of 79.74 (Tarnoki et al., 2024). Overall, these findings consistently indicate that lung ultrasound possesses superior diagnostic accuracy compared to chest radiography for the detection of pneumonia.

Advantages and Limitations of Lung Ultrasound in Diagnosing Pneumonia

Lung ultrasound offers several important advantages in the evaluation of pneumonia. It is a low-cost, radiation-free imaging modality, making it safe for repeated use and particularly suitable for vulnerable populations such as children and pregnant women. Its high availability and portable nature allow bedside assessment in emergency departments, intensive care units, and resource-limited settings. Despite its advantages, lung ultrasound has several limitations. The technique is operator-dependent, requiring adequate training and experience for accurate interpretation. Lung ultrasound is also limited in its ability to detect deep or centrally located lung lesions that do not extend to the pleural surface. Image acquisition may be challenging in patients with obesity, subcutaneous emphysema, or extensive chest wall deformities (Tarnoki et al., 2024).

CONCLUSION

Lung ultrasonography is based on the interaction between ultrasound waves and air–fluid interfaces within the lung, producing characteristic artifacts that reflect underlying pulmonary pathology. Pneumonia presents with a wide spectrum of ultrasonographic appearances depending on the extent of pulmonary involvement, particularly the degree of interstitial inflammation and alveolar consolidation. Evidence consistently shows that lung ultrasound has high diagnostic accuracy for pneumonia. Its advantages include bedside applicability, absence of radiation, and cost-effectiveness. Despite limitations related to operator dependency and reduced detection of deep lung lesions, lung ultrasound remains a reliable and practical imaging modality for the diagnosis of pneumonia.

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