

Diagnostic Performance of Lung Ultrasonography for Detecting Infected Pulmonary Consolidation: A CT-Referenced Validation Study

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ABSTRACT

Background: Pulmonary consolidation is a frequent manifestation of lower respiratory tract infection. Although computed tomography (CT) provides high diagnostic sensitivity, its routine use may be limited by ionizing radiation, cost, availability, and the need for patient transportation. Lung ultrasonography (LUS) provides a rapid, radiation-free bedside imaging option for detecting peripheral pulmonary abnormalities.

Objective: To determine the diagnostic performance of lung ultrasonography for detecting infected pulmonary consolidation using multi-slice chest CT as the reference standard.

Methods: This diagnostic validation study included 143 symptomatic patients evaluated in the Department of Radiology, Sindh Institute of Urology and Transplantation, Karachi, from November 2023 to May 2024. Lung ultrasonography was performed using a phased-array 5-MHz transducer and was considered positive when at least one pulmonary consolidation was identified. Multi-slice chest CT served as the reference standard and was interpreted by an experienced radiologist blinded to the ultrasonographic findings. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy were calculated.

Results: The mean age of the participants was 44.27 ± 11.23 years; 97 (67.83%) were male and 46 (32.17%) were female. Lung ultrasonography detected pulmonary consolidation in 48 (33.57%) patients, while CT identified consolidation in 49 (34.27%) patients. Compared with CT, LUS demonstrated a sensitivity of 91.8%, specificity 96.8%, PPV of 93.8%, and NPV of 95.8%. The overall diagnostic accuracy of LUS was 95.10%.

Conclusion: Lung ultrasonography demonstrated high diagnostic performance for detecting infected pulmonary consolidation when compared with CT. Its high sensitivity and specificity, combined with bedside availability and absence of ionizing radiation, supports its role as a useful imaging modality for the initial evaluation and follow-up of appropriately selected patients with suspected pulmonary consolidation.

Keywords: Lung ultrasonography; pulmonary consolidation; pneumonia; computed tomography; diagnostic accuracy; point-of-care ultrasound.

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INTRODUCTION

Lower respiratory tract infections remain an important cause of morbidity and mortality worldwide and impose a substantial burden on healthcare systems. Pneumonia is among the most clinically significant manifestations of lower respiratory tract infection and is characterized by inflammation of the pulmonary parenchyma, frequently resulting in alveolar filling and consolidation. Clinical manifestations commonly include fever, cough, sputum production, dyspnea, pleuritic chest pain, and hypoxemia; however, presentation may be nonspecific, particularly among older adults, immunocompromised individuals, and critically ill patients. Consequently, imaging has an important role in confirming pulmonary involvement,

determining its extent, and identifying complications or alternative causes of acute respiratory symptoms.^{1,2} Chest radiography (CXR) has traditionally been the initial imaging investigation in patients with suspected pneumonia because of its wide availability, relatively low cost, and rapid acquisition. However, conventional radiography has important diagnostic limitations. Small, early, or anatomically obscured areas of consolidation may not be readily identified, while interpretation can be influenced by patient positioning, inadequate inspiration, obesity, and superimposition of thoracic structures.³ These limitations become particularly relevant in emergency departments and intensive care units, where portable

anteroposterior radiographs are frequently obtained under technically challenging conditions. Evidence comparing imaging modalities has demonstrated considerably lower sensitivity of CXR than lung ultrasonography (LUS) for detecting pulmonary consolidation, indicating that a normal or equivocal radiograph cannot reliably exclude clinically relevant pulmonary disease.⁴

Computed tomography (CT) of the chest provides substantially greater anatomical detail and can detect pulmonary abnormalities that may remain occult on conventional radiography. It accurately demonstrates the location and extent of consolidation and can identify associated abnormalities such as ground-glass opacities, pleural effusion, cavitation, abscess formation, and other parenchymal changes. CT therefore plays an important role when initial imaging is inconclusive, disease is complicated, or an alternative diagnosis is suspected.^{2,5} Nevertheless, routine CT examination of every patient with suspected pulmonary infection is neither practical nor desirable. CT involves exposure to ionizing radiation, incurs greater costs, requires dedicated imaging facilities, and may necessitate transportation of acutely ill or unstable patients from the bedside to the radiology department.⁵

These limitations have contributed to increasing interest in LUS as a bedside imaging technique for pulmonary and pleural abnormalities. Historically, the lung was considered unsuitable for ultrasonographic examination because normally aerated lung strongly reflects ultrasound waves at the plural-air interface. It is now well established that pathological alterations in the normal air-to-fluid and air-to-tissue relationships generate characteristic sonographic patterns that provide clinically meaningful diagnostic information. International consensus recommendations consequently recognize LUS as a valuable imaging technique across several pulmonary conditions.⁶

Pulmonary consolidation that extends to the pleural surface can be visualized sonographically as a tissue-like or hypoechoic region, often producing an appearance resembling hepatic parenchyma. Additional findings, including pleural-line abnormalities, irregular margins, B-lines, and air or fluid bronchograms, may provide further diagnostic information.⁶ Dynamic air bronchograms are particularly useful because movement of air within bronchi during respiration can support the presence of pneumonic consolidation and assist in differentiating it from some forms of atelectasis. Recent evidence evaluating individual LUS findings has shown that dynamic air bronchograms have particularly high specificity for pneumonia.⁷

LUS also offers several practical advantages over conventional thoracic imaging. It is portable, provides

real-time information, does not expose patients to ionizing radiation, and can be repeated whenever clinically required. These characteristics make it particularly attractive for critically ill patients and individuals requiring serial assessment. Bedside examination can also reduce the logistical difficulties and potential risks associated with transporting unstable patients for CT.^{6,8} Increasing availability of portable ultrasound systems has further expanded the potential application of LUS in emergency departments, intensive care units, inpatient wards, and healthcare environments where access to advanced cross-sectional imaging may be limited.⁶

Accumulating evidence supports the diagnostic capability of LUS for pneumonia. A recent systematic review and meta-analysis involving 29 studies and 6,702 participants reported pooled sensitivity and specificity of approximately 92% and 94%, respectively, with an area under the receiver operating characteristic curve of 0.97.⁸ These findings are consistent with earlier meta-analyses demonstrating high diagnostic performance of LUS in adults with suspected pneumonia.⁹ More recent CT-referenced comparisons have similarly suggested that pulmonary ultrasonography can provide greater sensitivity than conventional chest radiography for detecting community-acquired pneumonia.¹⁰ Collectively, these findings indicate that LUS may have an important role in the initial evaluation of appropriately selected patients while potentially reducing dependence on radiographic examinations involving ionizing radiation. ([PubMed](#))

Despite these advantages, LUS has recognized limitations. Its ability to demonstrate pulmonary consolidation depends substantially on the anatomical relationship of the abnormality to the pleural surface. Lesions surrounded by normally aerated lung may remain inaccessible to ultrasound. Furthermore, image acquisition and interpretation are operator dependent, and diagnostic performance may vary according to examiner expertise, scanning protocol, patient characteristics, disease setting, and the sonographic criteria applied.^{6,9} Recent evidence in critically ill populations also demonstrates that although LUS may provide higher sensitivity than CXR, heterogeneity and operator-related factors remain important considerations.¹¹ Therefore, CT continues to provide a more comprehensive assessment of the thorax, particularly for centrally located lesions and complex pulmonary pathology. ([PubMed](#))

The clinical usefulness of LUS ultimately depends on whether it can identify infected pulmonary consolidation with sufficient diagnostic reliability when compared directly with an established reference imaging modality. Measures including sensitivity, specificity, positive predictive value, negative

predictive value, and overall diagnostic accuracy provide an objective framework for evaluating such performance. Local validation is particularly important because results obtained in specialized international settings may not necessarily be reproduced across different patient populations, operators, and healthcare environments.

In a high-volume tertiary care setting, a reliable bedside method for detecting infected pulmonary consolidation could facilitate rapid assessment while reducing unnecessary radiation exposure and the need for patient transportation. However, its diagnostic performance should be established through direct comparison with CT rather than inferred solely from previous studies. Therefore, the present study aimed to determine the diagnostic performance of lung ultrasonography for detecting infected pulmonary consolidation using multi-slice chest CT as the reference standard.

METHODOLOGY

This diagnostic validation study was conducted in the Department of Radiology, Sindh Institute of Urology and Transplantation (SIUT), Karachi, Pakistan, over a period of six months, from 26 November 2023 to 25 May 2024. A total of 143 patients presenting with clinical features suggestive of lower respiratory tract infection and suspected infected pulmonary consolidation were included. Participants were enrolled according to the predefined eligibility criteria using non-probability consecutive sampling. Patients of either gender aged 18–65 years presenting with symptoms suggestive of lower respiratory tract infection were considered eligible. Patients with previously diagnosed pulmonary malignancy, pulmonary tuberculosis, major chest wall abnormalities interfering with ultrasonographic assessment, or other conditions specified in the study exclusion criteria were excluded to minimize potential diagnostic confounding.

After enrollment, relevant demographic and clinical information was recorded on a predefined data collection form. All participants underwent lung ultrasonography (LUS) followed by multi-slice computed tomography (CT) of the chest, with CT used as the reference standard for determining the presence or absence of infected pulmonary consolidation. The diagnostic assessment was performed according to the standardized study protocol to allow direct comparison between the index and reference tests.

Lung ultrasonography was performed using a phased-array 5-MHz transducer. Patients were examined systematically to evaluate accessible regions of both lungs, with scanning performed through appropriate intercostal acoustic windows. The pleural line and underlying lung parenchyma were assessed for sonographic evidence of consolidation. Pulmonary

consolidation was identified as a subpleural tissue-like or hypoechoic area demonstrating loss of the normal aerated lung pattern, with associated sonographic features such as air bronchograms where present. To diagnostic classification, LUS was considered positive when at least one pulmonary consolidation was detected and negative when no consolidation was demonstrated.

Following LUS assessment, patients underwent multi-slice CT examination of the chest according to the institutional imaging protocol. CT images were evaluated for evidence of pulmonary consolidation and served as the reference standard against which LUS findings were compared. To minimize interpretation bias, CT examinations were interpreted by an experienced radiologist who was blinded to the lung ultrasonography findings. A CT examination demonstrating pulmonary consolidation was categorized as positive, whereas the absence of consolidation was categorized as negative.

The findings of LUS and CT were subsequently cross tabulated in a 2×2 diagnostic table and categorized as true positive, false positive, true negative, or false negative. A true-positive result was defined as pulmonary consolidation detected on both LUS and CT; a true-negative result indicated absence of consolidation on both modalities. A false-positive result represented consolidation detected on LUS but not confirmed on CT, while a false-negative result represented consolidation demonstrated on CT but not detected by LUS. These categories were used to calculate the diagnostic performance of lung ultrasonography.

Data was entered and analyzed using IBM SPSS Statistics version 22.0. Continuous variables, including age, were summarized using mean and standard deviation, whereas categorical variables, including gender and imaging findings, were presented as frequencies and percentages. The diagnostic performance of LUS was determined by calculating sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy, with multi-slice CT considered the reference standard. Diagnostic performance was additionally assessed after stratification according to relevant demographic characteristics, including age and gender, to evaluate potential variation in test performance across patient subgroups. A p -value ≤ 0.05 was considered statistically significant where inferential testing was applicable.

The study was conducted after approval of the dissertation/research protocol by the relevant institutional authorities at the Sindh Institute of Urology and Transplantation. Eligible participants were informed about the study procedures, and written

Diagnostic Performance of Lung Ultrasonography for Detecting Infected Pulmonary Consolidation: A CT-Referenced Validation Study

informed consent was obtained before enrollment. Patient confidentiality was maintained throughout data collection, analysis, and reporting, and information obtained during the study was used solely for research purposes.

RESULTS

A total of 143 patients with clinical suspicion of infected pulmonary consolidation were included in the study. The mean age of the study participants was 44.27 ± 11.23 years. Of the total participants, 97 (67.83%) were male and 46 (32.17%) were female. Lung ultrasonography (LUS) identified pulmonary consolidation in 48 (33.57%) patients, whereas multi-slice computed tomography (CT), used as the reference standard, demonstrated pulmonary consolidation in 49 (34.27%) patients.

Table 1. Baseline characteristics and imaging findings of the study population (n=143)

Variable	Finding
Total participants	143
Age, years (Mean $\pm$ SD)	44.27 ± 11.23
Male	97 (67.83%)
Female	46 (32.17%)
LUS positive for consolidation	48 (33.57%)
LUS negative for consolidation	95 (66.43%)
CT positive for consolidation	49 (34.27%)
CT negative for consolidation	94 (65.73%)

Comparison of LUS' findings with CT demonstrated close agreement between the two imaging modalities. Based on the reported diagnostic indices, LUS correctly identified most patients with CT-confirmed pulmonary consolidation and correctly excluded consolidation in most CT-negative patients. The resulting diagnostic performance was characterized by a **sensitivity of 91.8%** and **specificity of 96.8%**. The corresponding **PPV was 93.8%** and **NPV was 95.8%**, while the **overall diagnostic accuracy was 95.10%**.

Table 2. Diagnostic performance of lung ultrasonography for infected pulmonary consolidation using CT as the reference standard.

Diagnostic parameter	Value (%)
Sensitivity	91.8
Specificity	96.8
Positive predictive value (PPV)	93.8
Negative predictive value (NPV)	95.8
Overall diagnostic accuracy	95.10

The high sensitivity indicates that LUS detected approximately nine out of every ten patients with CT-confirmed consolidation. More importantly, the specificity of **96.8%** demonstrates a low probability of incorrectly classifying patients without CT evidence of consolidation as positive. Similarly, the high NPV (**95.8%**) indicates strong performance of a negative LUS examination for excluding CT-detectable consolidation in this study population.

Diagnostic performance was also evaluated after stratification according to age and gender. The dissertation analysis demonstrated that the diagnostic performance of LUS remained favorable across the evaluated demographic subgroups, indicating that the overall findings were not attributable exclusively to a single age or gender category.

Table 3. Summary interpretation of LUS diagnostic performance compared with CT.

Measure	Result	Interpretation
Sensitivity	91.8%	High ability to detect CT-positive consolidation
Specificity	96.8%	High ability to exclude CT-negative cases
PPV	93.8%	High probability of CT confirmation after positive LUS
NPV	95.8%	High probability of absence of CT consolidation after negative LUS
Accuracy	95.10%	High overall diagnostic performance

Figure 1. Detection of pulmonary consolidation by LUS and CT

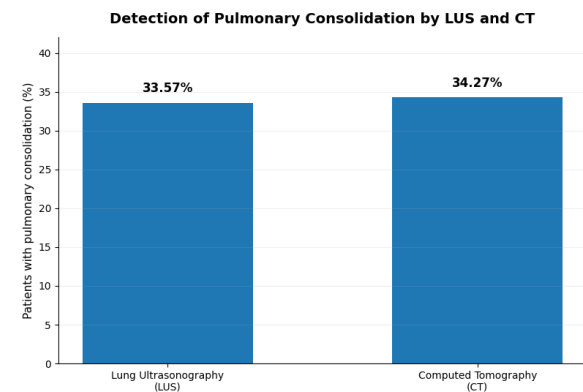


Figure 1. Comparison of the proportion of patients with pulmonary consolidation detected by lung ultrasonography (LUS) and computed tomography (CT). Detection rates were closely comparable between LUS (33.57%) and CT (34.27%).

Figure 2. Diagnostic performance profile of lung ultrasonography

Diagnostic Performance of Lung Ultrasonography for Detecting Infected Pulmonary Consolidation: A CT-Referenced Validation Study

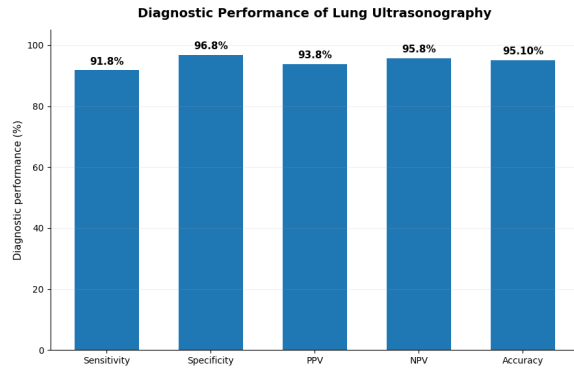


Figure 2. Diagnostic performance of lung ultrasonography for detecting infected pulmonary consolidation using computed tomography as the reference standard. LUS demonstrated consistently high sensitivity, specificity, predictive values, and overall diagnostic accuracy.

DISCUSSION

The present study demonstrated that lung ultrasonography (LUS) has high diagnostic performance for detecting infected pulmonary consolidation when multi-slice computed tomography (CT) is used as the reference standard. Among 143 patients, LUS demonstrated a sensitivity of 91.8%, specificity of 96.8%, positive predictive value (PPV) of 93.8%, negative predictive value (NPV) of 95.8%, and overall diagnostic accuracy of 95.10%. These findings indicate that LUS can reliably identify most patients with CT-confirmed pulmonary consolidation while maintaining a relatively low rate of false-positive findings. The combination of high sensitivity and specificity is clinically relevant because an imaging technique intended for early bedside assessment should be capable of both recognizing disease and excluding it when absent.

The sensitivity observed in the present study is consistent with the overall performance reported in previous systematic reviews and meta-analyses. Llamas-Álvarez et al. evaluated LUS for pneumonia in adults and reported pooled sensitivity and specificity of approximately 92% and 93%, respectively.¹¹ Similarly, Long et al. reported pooled sensitivity of 88% and specificity of 86% for LUS in the diagnosis of adult pneumonia.¹² The sensitivity of 91.8% in our study therefore closely corresponds with pooled international estimates, while the 96.8% specificity is somewhat higher. Differences in specificity across studies may reflect variations in patient selection, prevalence and severity of disease, operator experience, scanning protocols, diagnostic criteria, and the reference standard used.

More recent evidence has further supported the diagnostic capability of LUS. Desai et al., in a systematic review and meta-analysis involving 29 studies and 6,702 participants, reported pooled

sensitivity and specificity of approximately 92% and 94%, respectively, with an area under the receiver operating characteristic curve of 0.97.¹³ These estimates closely resemble the findings of the present study and provide strong external support for the observed diagnostic performance. The slightly greater specificity in our population may be related to the use of CT as the reference standard and the requirement for recognizable sonographic consolidation rather than reliance on nonspecific pulmonary artifacts alone.

The high PPV (93.8%) observed in this study suggests that most LUS-positive consolidations were confirmed on CT. Conversely, the NPV of 95.8% indicates that a negative LUS examination substantially reduced the probability of CT-demonstrable consolidation in this study population. Similar findings have been described in previous diagnostic studies. Parlamento et al. demonstrated that LUS could identify pneumonia in patients presenting to an emergency department with acute pleuritic pain and reported better diagnostic performance than conventional chest radiography.¹⁴ Cortellaro et al. also reported that LUS performed well in emergency department patients with suspected pneumonia and could provide diagnostically useful information at initial bedside assessment.¹⁵ Collectively, these observations reinforce the potential value of LUS where rapid clinical decision-making is required.

One important explanation for the high diagnostic performance of LUS is the characteristic sonographic appearance of pulmonary consolidation. When inflammatory consolidation reaches the visceral pleura, replacement of normally aerated alveoli by inflammatory material creates an acoustic window through which the affected lung becomes directly visualizable. Consolidated lung typically develops a tissue-like or hepatized appearance, frequently accompanied by air bronchograms. Dynamic air bronchograms can provide additional evidence supporting pneumonic consolidation and may assist in differentiating pneumonia from obstructive atelectasis. Lichtenstein et al. demonstrated that dynamic air bronchograms have high specificity for pneumonia in patients with alveolar consolidation.¹⁶ This physiological and anatomical basis explains why LUS performs particularly well for peripheral consolidations that extend to the pleural surface.

The performance observed in our study also compares favorably with conventional chest radiography. Although chest radiography remains widely used as an initial investigation for suspected pneumonia, its diagnostic sensitivity can be limited, particularly for small lesions, early disease, technically inadequate examinations, or consolidations obscured by the diaphragm, mediastinum, or other thoracic structures. Self et al. demonstrated substantial discordance

between chest radiography and CT for pulmonary opacities in emergency department patients, highlighting the possibility of both false-negative and false-positive radiographic interpretations.¹⁷ In a systematic review, Hansell et al. found that LUS had greater accuracy than conventional respiratory assessment methods, including chest radiography, for detecting consolidation and other pleural-pulmonary abnormalities.¹⁸ Thus, LUS may provide important additional information when clinical suspicion remains high despite an inconclusive radiograph.

Nevertheless, the present results should not be interpreted as demonstrating equivalence between LUS and CT for comprehensive thoracic evaluation. CT remains substantially capable of depicting the entire lung parenchyma and identifying centrally located lesions, subtle ground-glass abnormalities, cavitation, small nodules, mediastinal abnormalities, and complex pulmonary pathology. Garin et al. emphasized the additional diagnostic contribution of CT in community-acquired pneumonia, particularly when clinical and conventional radiographic findings are discordant.¹⁹ In contrast, ultrasound requires a lesion to reach or closely approach the pleural surface to become sonographically visible. A consolidation surrounded by normally aerated lung may therefore remain undetected. This limitation provides a plausible explanation for the false-negative LUS examinations observed in the present study.

The high overall accuracy of 95.10% should also be considered in relation to operator dependence. Unlike CT, where images can be acquired using standardized protocols and subsequently interpreted by different radiologists, LUS acquisition and interpretation occur dynamically and are influenced by examiner skill. Chavez et al., in a systematic review and meta-analysis, demonstrated high diagnostic accuracy of LUS for adult pneumonia but also identified heterogeneity related to study setting, operator expertise, and methodological characteristics.²⁰ Similarly, Alzahrani et al. reported favorable diagnostic performance while emphasizing variation in scanning techniques and diagnostic definitions between studies.²¹ Standardized scanning protocols and adequate operator training are therefore important prerequisites before the results observed in controlled diagnostic studies can be generalized to routine clinical practice.

Another clinically important advantage of LUS is the absence of ionizing radiation. This characteristic is particularly relevant in patients who require repeated imaging, including those undergoing serial monitoring of pulmonary disease. Ultrasound can be repeated at the bedside without cumulative radiation exposure and can demonstrate changes in the size and sonographic characteristics of consolidation during treatment.

Reissig et al. demonstrated that LUS was useful not only for diagnosing community-acquired pneumonia but also for monitoring disease evolution.²² This provides an important distinction from CT: although CT offers superior anatomical detail, repeated CT examinations solely to monitor uncomplicated consolidation may expose patients to avoidable radiation.

Bedside availability represents another major advantage. Transporting critically ill or unstable patients to CT facilities may require considerable logistical support and may expose patients to risks associated with intrahospital transfer. LUS can instead be performed immediately at the bedside and integrated with the clinical examination. Mongodi et al. demonstrated the value of quantitative LUS in assessing lung aeration in critically ill patients and highlighted its potential for serial bedside evaluation.²³ These properties are particularly relevant in high-volume tertiary hospitals and resource-constrained environments where rapid access to CT may be limited.

However, not all published evidence has demonstrated uniformly excellent LUS performance. Diagnostic accuracy may decline in patients with obesity, subcutaneous emphysema, chest wall dressings, limited mobility, or lesions that do not contact the pleural surface. Furthermore, the diagnostic performance reported in studies conducted by experienced operators may not be reproduced by clinicians with limited thoracic ultrasound training. Orso et al. found generally high sensitivity and specificity in their meta-analysis but also demonstrated heterogeneity among included studies.²⁴ Such findings emphasize that LUS should be considered a complementary diagnostic modality rather than an unconditional substitute for CT.

The present study has several strengths. CT was used as the reference standard, allowing direct assessment of LUS against a highly sensitive anatomical imaging modality. Blinded CT interpretation reduced the potential for review bias, while consecutive recruitment of symptomatic patients provided a clinically relevant study population. The study also provides local evidence from a tertiary-care institution in Pakistan, where a rapid, portable, and radiation-free imaging modality may have considerable practical value. The close agreement between our diagnostic estimates and those reported in international meta-analyses supports the external plausibility of the findings.

Certain limitations should nevertheless be acknowledged. The study was conducted at a single tertiary-care center, which may restrict generalizability to other institutions and patient populations. LUS is inherently operator dependent,

and the results may reflect the experience of the radiologists performing the examinations. The technique is also less suitable for consolidations that do not extend to the pleural surface. Additionally, the study primarily assessed the presence or absence of infected pulmonary consolidation rather than evaluating the diagnostic performance of individual sonographic signs or quantifying lesion size and distribution. Future multicenter studies incorporating standardized scanning protocols, assessment of interobserver agreement, and evaluation across different levels of operator experience would further clarify the reproducibility and broader applicability of LUS.

Overall, the findings of this study are strongly aligned with the existing evidence supporting LUS as an accurate imaging technique for pulmonary consolidation. The observed 91.8% sensitivity, 96.8% specificity, and 95.10% overall accuracy compare favorably with published international data.^{11–13} The principal clinical value of LUS lies not in replacing CT in every patient, but in providing a rapid, bedside, repeatable, and radiation-free method for identifying peripheral pulmonary consolidation. CT should remain available when LUS findings are negative despite persistent clinical suspicion, when lesions may be centrally located, or when detailed assessment of complications and alternative thoracic pathology is required.

CONCLUSION

Lung ultrasonography demonstrated high diagnostic performance for detecting infected pulmonary consolidation when compared with computed tomography, with a sensitivity of 91.8%, specificity of 96.8%, and overall diagnostic accuracy of 95.10%. These findings support LUS as a dependable, rapid, radiation-free, and readily repeatable imaging modality for the assessment of suspected peripheral pulmonary consolidation. Its bedside applicability may be particularly valuable when rapid evaluation or serial imaging is required. However, CT remains important when LUS findings are inconclusive, clinical suspicion persists despite a negative examination, or detailed assessment of centrally located lesions and associated thoracic abnormalities is required.

RECOMMENDATIONS

Lung ultrasonography may be incorporated into the initial assessment of appropriately selected patients with suspected pulmonary consolidation, particularly in emergency, inpatient, and critical-care settings. Standardized scanning protocols and adequate operator training should be encouraged to improve reproducibility. Larger multicenter studies evaluating interobserver agreement and performance across

different levels of operator experience are recommended.

LIMITATIONS

The study was conducted at a single tertiary-care institution, which may limit the generalizability of the findings. LUS is operator dependent, and its ability to detect consolidation is influenced by lesion location and accessibility to the pleural surface. Centrally located lesions surrounded by normally aerated lung may not be visualized. The study also primarily evaluated the presence or absence of consolidation rather than the diagnostic performance of individual sonographic signs.

ETHICAL APPROVAL

The study was conducted after approval of the research protocol by the relevant institutional authorities at the Sindh Institute of Urology and Transplantation (SIUT), Karachi, Pakistan. All study procedures were performed in accordance with institutional ethical requirements.

INFORMED CONSENT

Written informed consent was obtained from all participants before enrollment in the study. Patient confidentiality and anonymity were maintained throughout data collection, analysis, and reporting.

CONFLICT OF INTEREST

The authors declare **no conflict of interest**.

FUNDING

The study received **no external funding**.

DATA AVAILABILITY

The data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to institutional and ethical requirements.

AUTHORS' CONTRIBUTIONS

K.H.: Conceptualization, study design, data collection, literature review, and manuscript preparation.

S.S.: Supervision, study methodology, radiological assessment, and critical revision of the manuscript.

K.A.A.: Radiological assessment, interpretation of findings, and manuscript review.

M.R.A.: Methodological input, interpretation of imaging findings, and critical review.

A.L.: Data interpretation, literature review, and manuscript revision.

M.B.: Data organization, literature review, and manuscript preparation.

All authors reviewed and approved the final version of the manuscript.

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Diagnostic Performance of Lung Ultrasonography for Detecting Infected Pulmonary Consolidation: A CT-Referenced Validation Study

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