ORIGINAL ARTICLE

DIAGNOSTIC ACCURACY OF LUNG ULTRASOUND PERFORMED BY MIDWIVES IN UNDER FIVE CHILDREN FOR DETECTION OF PNEUMONIA IN RURAL SINDH, PAKISTAN

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PJR July - September 2026; 36(3): 195-201

ABSTRACT

BACKGROUND: Pneumonia is a preventable cause of child mortality if identified and treated early. In settings where access to chest X-ray (CXR) is difficult, the lung ultrasound (LUS) conducted by the community midwives (CMWs) could be beneficial for early detection of pneumonia. **AIM:** This study aimed to determine diagnostic accuracy of LUS performed by CMWs for identification of pneumonia in children under the age of five. **METHODS:** A cross-sectional study was conducted at a District Headquarters Hospital situated in Thatta. Children under five presenting with signs of pneumonia visiting the outpatient department were included. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+ve), negative likelihood ratio (LR-ve), pre and post-test probability, receiver operating characteristic (ROC) curve, and area under the curve (AUC), were calculated using STATA 17. **RESULTS:** A total of 156 children participated with mean age of 29 ± 15 months. Fever was present in 139 (88.5%) children, and the mean respiratory rate was 57 breaths per minute (SD 8), cough was present is 152 (97%) and chest in drawing in 149 (95%). Overall, the test demonstrated a sensitivity of 89.42% and specificity of 38.4%, with PPV of 74.4% and NPV of 64.5%. The area under the ROC curve was 0.63 (95% CI: 0.56-0.71). **CONCLUSION:** LUS can be performed by CMWs, which is a sensitive screening tool for screening pneumonia in children under five in rural settings.

Keywords: Lung ultrasound, Community Midwives, Low resource settings, Community Acquired Pneumonia, Children under five.

Background

Pneumonia remains a leading cause of morbidity and mortality among children under the age of 5, particularly in low-and middle-income countries.[1] In Pakistan, pneumonia accounted for 58,000 deaths among children under the age of 5 years each year.[2] This high prevalence underscores the urgent need for effective, accessible diagnostic tools to combat childhood pneumonia and improve survival.[3]

Early diagnosis of pneumonia is crucial for appropriate treatment, significantly reducing the risk of severe

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Submitted 10 August 2026, Accepted 4 September 2026

complications and death.[4] Late or improper diagnosis can lead to respiratory failure, sepsis, prolonged hospitalization, and increased mortality.[5] In many low-resource settings, the lack of reliable diagnostic tools hampers early detection, making effective pneumonia diagnosis difficult.[6,7]

In primary care settings, physicians typically rely on the World Health Organization (WHO) criteria to diagnose pneumonia in children. However, studies have indicated that these criteria lack sensitivity and specificity, resulting in frequent misdiagnoses and overtreatment.[8-10] Chest X-rays (CXR) can confirm pneumonia, but in resource-limited areas, their use is often limited because in facilities they usually do not have the necessary equipment for x-ray. These limitations result in diagnostic delays and inaccuracies, highlighting the need for alternative, more accessible diagnostic methods for diagnosing pneumonia in children in these settings.

Lung ultrasound (LUS) has emerged as a promising diagnostic tool for pneumonia.[11] LUS is a non-invasive, portable, and low-cost diagnostic tool to detect pneumonia early. Studies have shown that LUS can reliably detect pneumonia, offering comparable accuracy to CXR without the associated risks of radiation exposure.[11] Its portability makes it ideal for use in remote or resource-limited areas.[12] The growing body of evidence supporting LUS underscores its potential to revolutionize pneumonia diagnosis in pediatric populations, particularly in underserved communities.

Community midwives (CMW) play a pivotal role in primary healthcare delivery, particularly in low-resource settings where they often serve as the first point of contact for healthcare services.[13] Their extensive reach within communities and established trust with families make them well-positioned to expand their roles to include diagnostic tasks.[14] Task-shifting, which involves training midwives to perform additional healthcare functions, has been successfully implemented in various healthcare domains.[15] Empowering CMWs to use LUS for pneumonia diagnosis could significantly improve early detection and management. Therefore, the primary objective of this study is to evaluate the diagnostic accuracy of LUS performed by CMWs in the early identification of pneumonia in children under 5 years. To our knowledge the literature on establishing the diagnostic accuracy of LUS for pneumonia done by CMW is scarce. Therefore, we aim to determine diagnostic accuracy and reliability of LUS performed by CMW for identification of pneumonia using chest x-ray as a reference standard at a low-resource setting of Thatta, Pakistan.

Methods

Study Design

This was a cross-sectional study conducted from October 2023 to March 2024. We used Standard for Reporting Diagnostic Accuracy Studies (STARD) for reporting this study.[16]

Setting

We conducted this study at a district headquarter (DHQ) hospital located within the catchment area of the Global Network for Maternal and Newborn Health Registry (MNHR) in Thatta, Sindh province, Pakistan. This secondary care hospital includes both in-patient and out-patient areas and various departments such as Obstetrics and Gynecology, Surgery, Emergency, Pediatrics, and Radiology.

Sample Size Calculation

The sample size was calculated based on the estimation of the area under curve (AUC) of ROC curve, which serves as the primary measure of diagnostic accuracy in this study. An expected AUC of 0.98 was used, derived from a published meta-analysis evaluating LUS for the diagnosis of childhood pneumonia.[17] The prevalence of pneumonia in children was assumed to be 15%, based on global estimates from low- and middle-income countries.[18] A precision level of ± 0.06 and a 95% confidence level were set for the calculation. Using an online AUC sample size calculator, the required sample size was determined to be 140 participants. Accounting for an anticipated 10% dropout rate, the final adjusted sample size was set at 156 participants.

Study Participants

We used convenient sampling techniques to select participants. Children under five years of age who presented with clinical signs suggestive of pneumonia, such as cough, fever, fast breathing, or chest in drawing, as defined by WHO, were included in the study. Physicians at the hospital adhere to WHO guidelines for diagnosing and treating pneumonia in children.[19] Children with danger signs such as convulsions,

cyanosis, severe respiratory distress were excluded. Additionally, children with known metabolic disorders or chronic conditions such as kidney disease, type 1 diabetes, known asthma, bronchiectasis, cardiac disorders, or those requiring mechanical ventilation were also excluded.

CXR reporting

Infants underwent a CXR while lying supine. The x-ray images were sent to the radiologist through Picture Archiving and Communication System (PACS). The radiologist was not aware of the clinical and test results. The radiologist, who reported CXRs, was a consultant pediatric radiologist working at the Aga Khan University Hospital, having a greater than 10 years' experience in the field. On CXR, pneumonia was recognized as "consolidation", "infiltrate", or "pneumonia" or "pleural effusion" by the attending pediatric radiologist.

Training of CMW

LUS training for identifying pneumonia on ultrasound was conducted by a pediatric radiologist, at Aga Khan University to three CMWs who already had previous experience of conducting ultrasounds for basic obstetrics. This training consisted of several sessions within a span of 10 working days, beginning with basic lung anatomy and ultrasound landmarks. Each sonographer then observed 5 normal LUS cases and 2 cases of suspected pneumonia. The images of these cases were reviewed by the expert radiologist, who approved the midwives to perform the ultrasound. Once the CMWs had a basic theoretical knowledge of the ultrasound they were trained on the field for another week. Finding a hypo-echogenic region with ill-defined boundaries and compact underlying artifacts perpendicular to the pleural line, known as B lines, was the criterion used to identify pneumonia on LUS.[20]

LUS examination

GE logiq portable ultrasound machine was used with small linear 10-20 MHZ probe. The patient was positioned in supine, lateral decubitus, or sitting positions. The machine was placed on the right side for easy handling. A standard 6-point LUS examination was performed. The technique began from the lung apices and proceeded in a descending manner to the diaphragm, covering all six lung zones: anterior, lateral, and posterior regions of both lungs in sagittal and transverse sections. The depth was adjusted to ensure visibility of at least one A-line in the distant field.

The three trained midwives performed all the ultrasounds in the community with a mean procedure time, from setup to video recording to diagnosis, of 8.4 ± 2.2 min. A final diagnosis was achieved for all the participants. The ultrasound assessment took longer when findings of lung consolidation were present versus when ultrasound reading was normal; and when the child was less than or equal to 12 months versus when the child was older than 12 months. There was no difference in procedure time with gender. The midwives were aware of the child's symptoms but not the final diagnosis or laboratory/x-ray findings, they documented LUS findings and presence or absence of pneumonia.

Data collection methods

Children under 5 years who are presented to a hospital emergency room or outpatient department with cough, fever, rapid breathing, and chest in drawing were examined by a physician and referred for a CXR followed by a LUS. Immediately, after the CXR, LUS was performed by midwives. The child was sent back to the treating physicians who provided treatment based on the clinical signs and CXR. The CMWs were blinded to the findings from CXR. Written informed consent was obtained from parents of each participant before enrolling in the study.

Data analysis

Mean and standard deviation (SD) were calculated for quantitative variables including age, respiratory rate, and temperature, while frequencies and percentages were calculated for qualitative variables including gender and clinical signs and symptoms. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), positive likelihood ratio (LR+ve), negative likelihood ratio (LR-ve), for LUS, compared to CXR, were calculated. The receiver operating charac-teristic (ROC) curve was created, with the area under the curve (AUC) reported with a 95% confidence interval. p-value less than 0.05 was considered as significant. The data were analyzed using STATA version 17.

Ethical considerations

The study was approved by the National Bioethics Committee. Additionally, the study district health office of the study site also provided approved the study.

Informed consent was obtained from the parents or caretakers of the children prior to enrollment in this study.

Results

A total of 156 children participated in the study. The mean age of the children was 29 ± 15 months. The proportion of males was 54%, Reported symptoms among the participants included cough, severe chest in-drawing, fast breathing, and fever. Other less frequently observed symptoms were poor feeding or sucking, lethargy, and diarrhea. Rare symptoms included apnea, cold touch, and bulging fontanelle. (Tab.1) provides the characteristics of the participants.

The diagnostic performance of the test was evaluated across multiple variables. Overall, the sensitivity was 89.42% (81.9-94.6) and specificity was 38.4% (25.3-53.0). The PPV reached 74.4% (65.8-81.8), while the NPV was 64.5% (45.4-80.8). The LR+ve and LR-ve were at 1.45 and 0.28, respectively. Based on a pretest probability of 66.67%, the posttest probability after a positive test was 74.4%. Among males, sensitivity was measured at 91.17% and specificity at 52.94%. The PPV and NPV were 88.57% and 60%, respectively. LR+ve was 1.94, and LR-ve was 0.17. The pretest probability for this subgroup was 80%, increasing to a posttest probability of 88.57%. While, in females, sensitivity and specificity were 86.11% and 31.43%, respectively. The PPV was 56.36%, and the NPV reached 68.75%. LR+ve and LR-ve were 1.26 and 0.44. A pretest probability of 50.7% resulted in a posttest probability of 56.36%. The detailed sensitivity, specificity, PPV, NPV, Likelihood ratios and pre/post-test probabilities stratified based on symptoms at presentation are given in (Tab.2).

Characteristics	Frequency	Percentage
Age (Month) Mean ± SD	29 ± 14	15.0
Gender		
Male	85	54.1
Female	72	45.9
Weight (gm) of children (mean ± SD)	5457	3109.0
Temperature (F) of children (mean ± SD)	99	5.0
Respiratory rate of children (mean ± SD)	57	8.0
Fever	139	88.5
Lethargy	81	51.9
Severe chest in-drawing	149	94.9
Poor feeding suck	110	70.1
Apnea	3	1.9
Unable to feed	18	11.5
Persistent vomiting	23	14.6
Bulging fontanelle	20	12.8
Mother's age (mean ± SD)	30	4.0
Heart rate of children (mean ± SD)	121	23.0
Length/Height of children (mean ± SD)	73	15.0
Fast breathing	148	94.8
Diarrhea	33	21.1
Cold to touch	16	10.2
Cough	152	97.4

Table 1: Characteristics and clinical signs and symptoms of participants

Variable	Sensitivity	Specificity	PPV	NPV	LR+VE	LR-VE	Pretest Probability	Post test Probability (Positive test)
Overall	89.4	38.4	74.4	64.5	1.4	0.3	66.7	74.4
Male	91.2	52.9	88.6	60.0	1.9	0.2	80.0	88.6
Female	86.1	31.4	56.4	68.7	1.3	0.4	50.7	56.4
Fever	76.1	37.2	76.1	61.5	1.2	0.6	69.1	76.1
Severe Chest in drawing	88.9	38.0	73.9	63.3	1.4	0.3	66.4	73.9
Poor Suck	87.0	36.4	76.1	54.5	1.4	0.4	70.0	76.1
Cough	89.1	37.3	73.8	63.3	1.4	0.3	66.4	73.8
Lethargy	72.3	37.9	72.3	68.7	1.2	0.7	64.2	72.3

Table 2: Diagnostic test performance metrics and post-test probability calculations

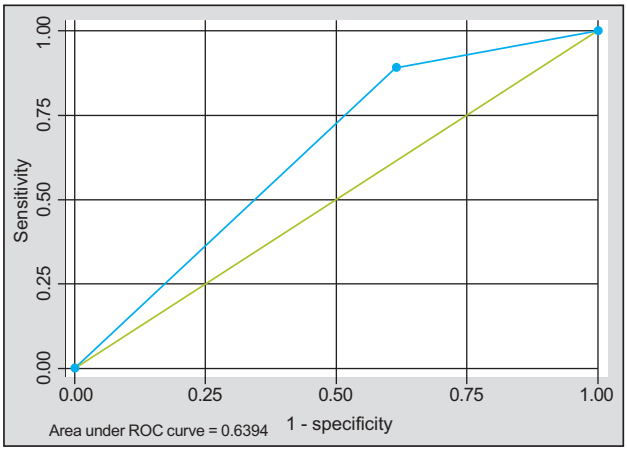

Figure 1: The ROC Curve showing the AUC for LUS

The area under the ROC curve was 0.63 (95% CI: 0.56-0.71); which indicates fair discrimination, that is, the LUS test has a fair ability to distinguish between children with and without pneumonia as shown in (Fig.1).

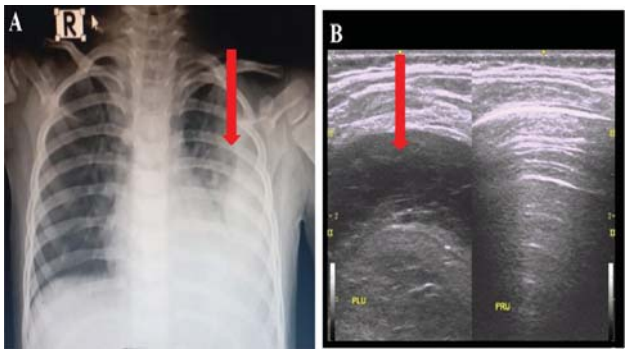

Figure 2: a) X-ray shows left sided moderate pleural effusion with possible underlying consolidation. (R=Right side of the patient) **b)** Ultrasound of the left lung of same patient shows separated pleural effusion along with left lung consolidation while right lung is normal. (PLU=Posterior Left Upper Quadrant and PRU=Posterior Right Upper Quadrant)

Discussion

This study investigated the diagnostic accuracy of LUS performed by CMW at a rural setting compared with CXR reported by radiologist of a tertiary hospital for diagnosis of pneumonia in under five children in rural setting of Pakistan. We found that the sensitivity was 89.42% (95% CI: 81.9 - 94.6) indicating a low rate missed pneumonia cases but low specificity was 38.4%, (95% CI: 25.3 - 53.0), suggesting frequent false positives. The LUS correctly identified only 38.4% of them as not having the disease. The ROC curve showed an AUC of 0.63 (95% CI: 0.56-0.71) indicating a moderate discriminative ability of the LUS, by midwives.

Prior studies and meta-analyses have consistently shown high diagnostic accuracy of LUS for pediatric pneumonia, with sensitivities and specificities exceeding 90% when performed by experienced clinicians.[21] Moreover, Lorio et al reported LUS sensitivity of 96.5%, specificity of 95.6%, LR+ve of 22.2, and LR-ve of 0.04 in children, noting LUS detected some pneumonias missed by CXR.[22] In resource-limited settings, promising results have also been reported. For example, study from Nepal demonstrated LUS sensitivity of 89%, and specificity of 86%.[23] These findings suggest the potential utility of LUS even in low-resource contexts, when performed by trained healthcare providers. However, the lower specificity in our study may be due to LUS being performed by midwives with no prior experience, following a short, 10-day training. This limited training likely reduced diagnostic precision, particularly in differentiating pneumonia from other respiratory conditions such as bronchiolitis or asthma. Furthermore, midwives were blinded to clinical presentations, limiting the contextual interpretation typically essential in point-of-care ultrasound.

Another known limitation of LUS is its reduced ability to detect deep lung consolidations that do not about the pleural, potentially contributing to missed cases. Additionally, the basic ultrasound equipment used may have limited resolution and features necessary for accurate imaging, further affecting diagnostic accuracy.[12, 24]

Despite these limitations, the study has several notable strengths. It is the first to evaluate the feasibility of LUS by CMWs in a rural Pakistani context, highlighting the potential of task-sharing in diagnostic imaging. Training non-physician health workers to perform LUS could bridge diagnostic gaps in low-resource settings where access to radiography is limited. While CMWs have been previously trained for obstetric scans,[25] their application in diagnosing pediatric pneumonia is novel and promising. However, generalizability is limited by the single-site rural setting and brief training duration. Future studies should explore structured, competency-based training, integration of clinical data with imaging, and improved equipment to optimize diagnostic performance.

Conclusion

LUS performed by trained midwives demonstrates high sensitivity but limited specificity, indicating its potential role as a screening and triage tool for pediatric pneumonia in rural, resource-constrained settings. The high sensitivity supports its use in early identification and referral of suspected cases. These findings provide preliminary evidence to inform context-specific integration of LUS into community-level child health services, alongside appropriate training and supervision. This study lays foundational evidence for scaling up LUS through targeted training and integration into community-level healthcare.

DECLARATIONS

CONSENT FOR PUBLICATION: Consent for publication was obtained during the written informed consent, and all the authors approved the study to be published.

DATA AVAILABILITY: The datasets used and/or analysed during the current study are available from the corresponding author upon reasonable request (Corresponding author email: shiyam.sunder@ aku.edu)

CONFLICT OF INTEREST: The authors declare that they have no competing interests.

FUNDING STATEMENT: This study was funded by the National Institute of Child Health and Human Development (NICHD). The NICHD did not have any role in the design, conduct, analysis or reporting of the study.

ACKNOWLEDGEMENTS: We acknowledge Mr. Zaheer Habib and Mr. Zahid Soomro his efforts in coordination and administrative work.

AUTHOR CONTRIBUTORS: WM, SS and SST designed the study concept. WM and SST wrote the protocol. EM, RG performed critical review and revision of the protocol. JM and HS performed analysis and interpretation of result, alongside manuscript drafting. WM, SST, EM, RG, and SS did the proof-reading, editing and performed final review critical review and revision of initial draft. All authors read the manuscript for consented for its publication.

ETHICAL APPROVAL: This study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki and the institutional guidelines governing research involving human participants. Ethical approval for the study protocol was obtained from the National Bioethics committee. The research procedures, data collection, and handling of participant information adhered strictly to the regulations and standards set forth by the Committee.

Because all participants in this study were children under the age of five, written informed consent was obtained from their parents or legal guardians prior to inclusion. Parents/guardians were provided with detailed information regarding the study objectives, procedures, potential risks and benefits, and their right to withdraw their child at any time without any consequences. Routine medical care was provided as usual. Confidentiality of all participant information was ensured throughout the study, and all data were anonymized prior to analysis.

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