

Radiological and Ultrasound Findings in Neonatal Respiratory Pathology: Perspectives in Diagnosis

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ABSTRACT

Background: The evaluation and management of neonatal respiratory pathologies require precise and careful diagnostic approaches, particularly in preterm infants who are at higher risk of respiratory complications. This research compares lung ultrasound (LUS) and chest X-ray for diagnosing and monitoring respiratory conditions in preterm and term neonates.

Methods: We conducted a prospective analysis of the imaging practices for neonatal respiratory pathologies in a cohort of 82 preterm and term infants with a gestational age ranging from 31-41 weeks presenting with respiratory distress syndrome (RDS) diagnostically categorized based on clinical and paraclinical investigations, who were admitted to the neonatal intensive care unit (NICU) immediately after birth.

Results: The most common diagnosis was moderate RDS, which affected 17 neonates, followed by moderate transient tachypnea of the newborn (TTN) in 16 patients, severe RDS in 14 patients and meconium aspiration syndrome (MAS) in 12 patients. Additionally, seven patients presented with mild RDS and six were diagnosed with congenital pneumonia. There were four cases of severe TTN, four cases of mild TTN and only two cases of pneumothorax. This study identified the ultrasound and radiological findings and aimed to highlight the current trend in the evaluation and management of respiratory conditions in preterm and term neonates. The results demonstrate an increasing trend in the use of ultrasound due to its advantages, especially in preterm patients who are at higher risk of respiratory impairment.

Conclusion: The benefits of ultrasound, including absence of radiation and dynamic imaging capabilities, make it a valuable tool for ongoing assessment and management. While X-rays remain an important imaging tool in certain clinical scenarios, their use should be judicious to minimize radiation exposure. These findings support the continued integration of ultrasound in neonatal practice and suggest further research into optimizing imaging protocols to improve long-term outcomes for neonates.

Keywords: lung ultrasound, chest X-ray, diagnosis, neonatal intensive care unit.

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Article received on the 14th of November and accepted for publication on the 22nd of November 2024

INTRODUCTION

The ability of a newborn to adapt to extrauterine life is essential in the development of neonatal respiratory pathology. Neonatal respiratory adaptation is influenced by a multitude of factors, such as developmental insufficiency of surfactant production and function or structural immaturity of the lungs. Other causes of neonatal respiratory pathology can include congenital malformations, infections and fetal growth restriction (1).

Numerous factors can contribute to neonatal respiratory disorders, such as genetic defects, infections acquired before or after delivery, or delayed or inappropriate adaptation to life outside the womb. According to the literature, 6.7% of babies in India and 2.2% of births in Italy are complicated by respiratory diseases. These conditions are the primary reason for both term and preterm neonatal unit admissions. According to one research, 33.3% of all neonatal intensive care unit (NICU) admissions for newborns whose gestational age (GA) is greater than 28 weeks, excluding those who have surgical or congenital defects diseases, with the major admission diagnosis being respiratory disorders (2).

According to another study, clinical symptoms of respiratory distress were seen in 20.5% of all NICU patients. Authors also reported higher rates of NICU admissions for respiratory conditions, potentially as a result of the increased prevalence of cesarean section delivery (3). The clinical presentation of various respiratory pathologies is similar, and establishing a diagnosis requires the support of paraclinical investigations. Until recently, clinicians primarily used chest X-rays to establish a diagnosis; however, lung ultrasonography has recently gained traction as a first-line tool. It can provide valuable information for diagnosis and treatment, as well as for determining the prognosis and disease progression. ■

MATERIALS AND METHODS

The present prospective study was conducted over a two-year period (2022-2023) in the Neonatology Clinic of “Elias” University Emergency Hospital, Bucharest, Romania. The study included 82 neonates with gestational ages ranging from 31 to 41 weeks. The primary focus was

on analyzing the initial diagnoses upon admission to NICU. In the first hours after birth, according to the protocols of the neonatology unit, the newborns were subjected to the following investigations: arterial blood gas analysis, chest X-ray and pulmonary ultrasound; the score of the latter imaging procedure was subsequently calculated.

Statistical methods, including medians, interquartile ranges and the t-independent sample test, were used to assess differences between the two groups.

Given that newborns have a smaller thorax and thinner chest wall, a high-frequency linear probe is recommended because it provides a better picture quality and full lung surface viewing. Prone, lateral, or supine positions were used for lung ultrasonography.

To calculate the pulmonary ultrasound score, which was subsequently used to determine the diagnosis and severity, each hemithorax was divided into anterior, lateral and posterior regions based on the anterior and posterior axillary lines. Each thorax was then divided into three distinct zones: superior anterior, inferior anterior and lateral. Each zone could receive an individual score ranging from 0 to 3 points. The maximum ultrasound score that can be obtained is 18 points.

To enhance visualization of the neonatal lung, a high-frequency linear array transducer (≥ 10 MHz) was used in our unit. Pulmonary ultrasound was performed and interpreted by a clinician with certification in ultrasonography.

Ethical issues

The hospital scientific committees approved the study protocol and all participating patients signed a consent form.

Statistical analysis

The analysis utilized IBM SPSS Statistics version 29.0.1.1 (IBM Corporation, USA, 2024). Descriptive statistics were utilized to define the sample based on patient count, as the sample size was below 100, in conjunction with analytical statistics. Descriptive statistics were calculated to summarize the characteristics of the study population and imaging practices, including minimum, maximum, median and interquartile ranges for the number of ultrasounds and X-rays which were performed. The t-independent sample test was utilized to compare the distributions

of imaging studies between preterm and term groups, given the non-normal distribution of data. A p value of less than 0.05 was considered to be statistically significant. □

RESULTS

The present study included a total of 82 newborns with gestational ages between 31–41 weeks, of whom 55 patients were born preterm and the remaining 27 at term.

Respiratory distress syndrome (RDS)

On X-ray, 27 patients showed hypoaeration, 20 subjects had a ground-glass appearance and 20 patients exhibited an air bronchogram; on ultrasound, 12 patients had white lung, 12 pleural line abnormalities and 34 showed small subpleural consolidations (Figure 1).

Transient tachypnea of the newborn (TTN)

On X-ray, interstitial edema and the "sunburst" sign were observed in 10 patients each and fissures were detected in five subjects; on ultrasound, interstitial edema was seen in 15 patients and symmetric bilateral B-lines were identified in 20 subjects (Figure 2).

Meconium aspiration syndrome (MAS)

On ultrasound, eight patients showed the disappearance of A-lines and eight patients had interstitial syndrome; on X-ray, seven patients had consolidation with an air bronchogram, hyperinflation and pulmonary opacities were observed in three patients each and rib horizontalization was present in one patient (Figure 3).

Pneumothorax

On X-ray, hyperlucency and mediastinal shift were observed in one patient each; on ultrasound, the absence of lung sliding and presence of lung point and A lines without B lines were identified in two patients each (Figure 4).

Congenital pneumonia

On X-ray, four patients showed pleural line abnormalities, six subjects subpleural consolidation and six patients had an air bronchogram, while ultrasound revealed alveolo-reticular opacities in five patients, air bronchogram in four patients and interstitial edema in four patients; on (Figure 5).

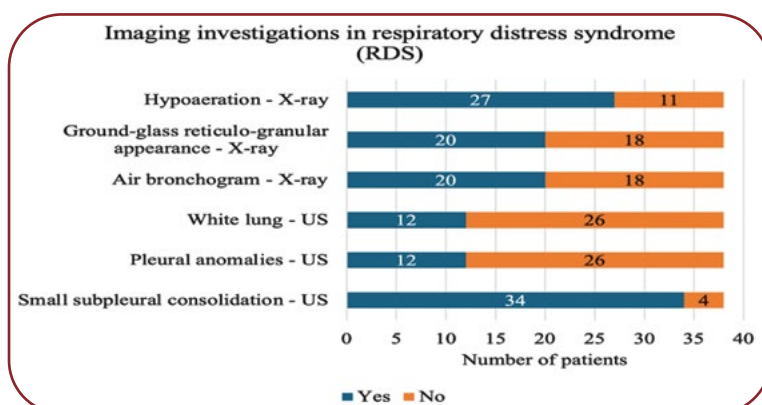


FIGURE 1. Study population distribution according to the results of imaging investigations, including X-ray and ultrasound (US) in respiratory distress syndrome (RDS)

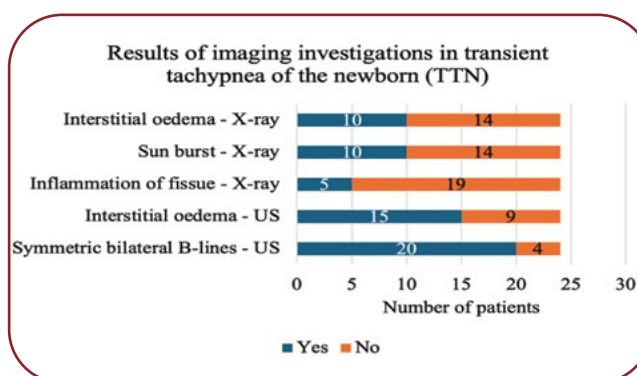


FIGURE 2. Study population distribution according to the results of imaging investigations, including X-ray and ultrasound (US) in transient tachypnea of the newborn (TTN)

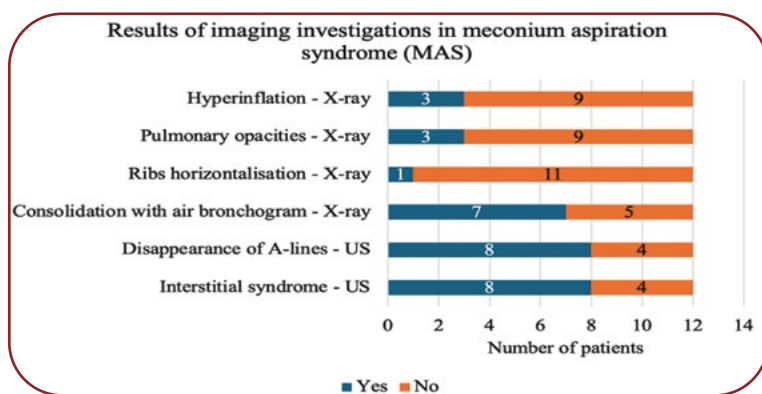


FIGURE 3. Study population distribution according to the results of imaging investigations, including X-ray and ultrasound (US), in meconium aspiration syndrome (MAS)

Number of ultrasounds in preterm and term newborns

The data has been represented as mean $\pm$ SD of number of ultrasounds which were performed per group of patients (term and premature new-

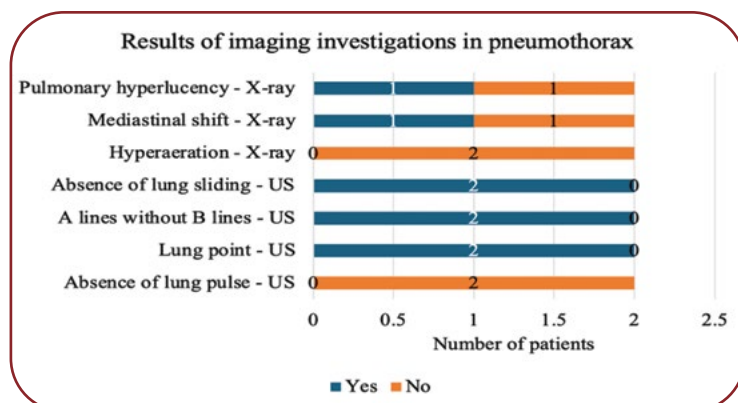


FIGURE 4. Study population distribution according to the results of imaging investigations, including X-ray and ultrasound (US), in pneumothorax

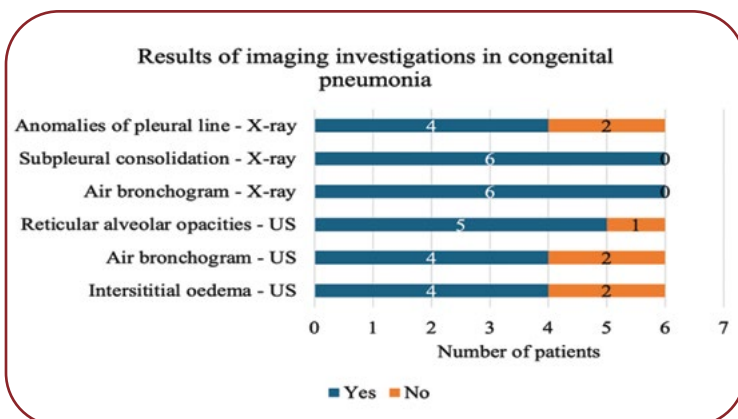


FIGURE 5. Study population distribution according to the results of imaging investigations, including X-ray and ultrasound (US), in congenital pneumonia

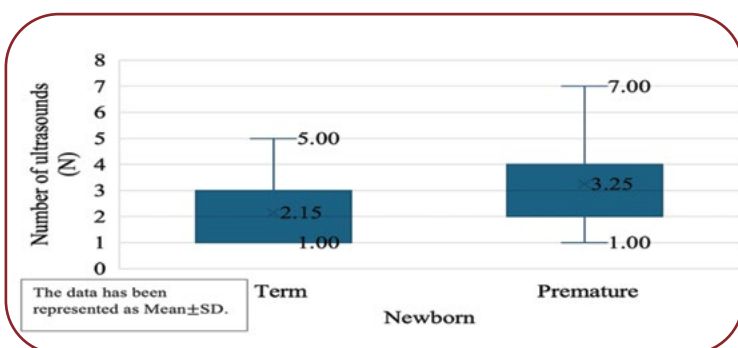


FIGURE 6. Boxplots of number of ultrasounds performed in term and premature newborns

borns). The mean number of ultrasounds was 2.15 ± 0.98 ($n=27$ patients) in term newborns and significantly lower (3.25 ± 1.57) in premature newborns ($n=55$) ($t(80)=3.33$, $p<0.001$) (Figure 6) (Table 1).

TABLE 1. Number of ultrasounds in preterm and term newborns

Number of ultrasounds	Number of premature patients	Number of term patients
Minimum	1	1
Quartile 1	2	1.5
Median	3	2
Quartile 3	4	3
Maximum	7	5

TABLE 2. Number of X-ray in preterm and term newborns

Number X-ray	Number of premature patients	Number of term patients
Minimum	0	0
Quartile 1	0	0
Median	1	0
Quartile 3	1	1
Maximum	3	2

Number of X-rays in preterm and term newborns

The data has been represented as mean $\pm$ SD of number of chest X-rays which were performed per group of patients (term and premature newborns). The mean number of chest X-rays was 0.33 ± 0.55 in term newborns ($n=27$ patients) and significantly lower (0.89 ± 0.78) in premature newborns ($n=55$ patients) ($t(80)=3.30$, $p<0.001$) (Figure 7) (Table 2). $\square$

DISCUSSION

In the studied cohort, we drew comparisons between radiological and ultrasound findings concerning neonatal respiratory pathologies. These findings align with the existing literature, confirming that respiratory pathology remains the leading cause of admission to NICU for both preterm and term neonates. The present study also included graphical analyses using boxplots to visualize the distribution of imaging studies, including lung ultrasound (US) and chest X-ray (RX), which were performed in preterm and term neonates. The boxplots depicted the range, median and interquartile ranges of the number of imaging studies, providing a clear representation of the variability and central tendencies within each group. These graphical tools helped emphasize the differences in imaging practices, particularly the greater reliance on US in preterm infants compared to term infants.

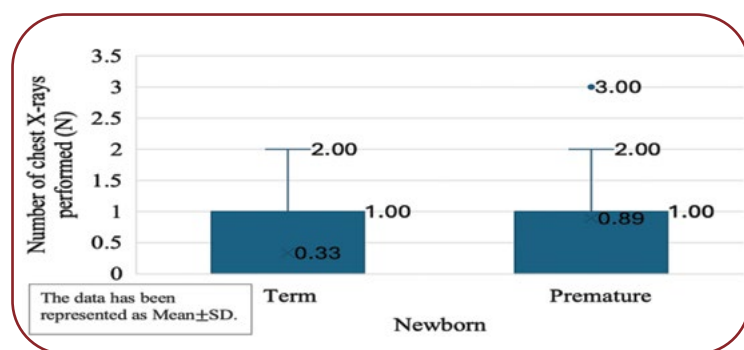


FIGURE 7. Boxplots of number of X-rays performed in term and premature newborns

The results demonstrate an increasing trend in the use of US due to its advantages, especially in preterm patients who are at higher risk of respiratory impairment.

The analysis indicates that preterm newborns require more frequent US examinations than term neonates, which reflects a higher need for ultrasound monitoring in preterm infants, largely due to their increased risk of respiratory complications. Ultrasound is preferred for its advantages, such as the absence of radiation and its ability to provide real-time imaging, which supports dynamic assessment and timely management of neonatal respiratory issues.

Preterm infants tend to undergo more X-rays than term ones, which is driven by clinical instability and the frequent occurrence of respiratory complications in this group of patients. However, X-ray use remains limited overall, thus highlighting concerns about radiation exposure and a preference for ultrasound, which is a safer and less invasive imaging method.

According to our results, ultrasonography should remain the main diagnosis and surveillance method for newborn respiratory disorders, especially in preterm infants. The use of X-rays should be carefully considered, taking into account the risks of radiation exposure. Future research should explore the relationship between different imaging techniques and long-term outcomes to improve neonatal care protocols.

In a study conducted by Ma *et al*, which included a systematic review and meta-analysis of nine studies totalizing 703 patients, the diagnostic accuracy of lung ultrasound (LUS) for the neonatal respiratory distress syndrome (NRDS) was evaluated. The authors found a significant variability among studies in terms of LUS techniques,

timing relative to chest X-rays (CXR), study design and diagnostic criteria. Their findings indicate that the transthoracic ultrasound approach is highly effective for diagnosing neonatal respiratory distress syndrome, with a sensitivity of 99% and specificity of 97%, surpassing both the transabdominal approach and chest X-ray. The pooled sensitivity and specificity of LUS were 0.99 and 0.95, respectively, with an area under the curve of 0.99, which demonstrated a high diagnostic accuracy. The authors concluded that LUS was a promising non-invasive bedside tool for diagnosing NRDS and an effective alternative to traditional imaging methods (4).

In a study conducted by J. Liu, in 2023, on 275 newborns, including both premature and full-term infants, the authors found that 42.5% had primary RDS and the remaining 57.5% secondary RDS. Lung ultrasound identified three distinct patterns of lung involvement: ground-glass opacity, snowflake-like consolidations and snowflake-like signs with complications. The study suggests that RDS can be effectively classified into mild, moderate and severe grades based on LUS findings. Severe RDS is associated with extensive lung involvement or complications like pneumothorax and pulmonary hemorrhage (5).

In order to assist treatment choices by giving clear insights into the severity and course of RDS, the literature emphasizes LUS as an efficient and trustworthy technique for detecting RDS in both preterm and full-term neonates (5).

In a meta-analysis conducted by Silviera *et al*, 1,686 studies were reviewed, of which only 23 were selected, involving a total of 2,245 newborns. All selected studies used chest X-rays to diagnose neonatal RDS, with 91% also utilizing it to assess disease severity. While 30% of studies suggested that chest X-rays were irreplaceable, 43% found that alternative methods were superior for assessing severity, monitoring progress, predicting the need for surfactant therapy, anticipating continuous positive airway pressure (CPAP) failure and aiding in differential diagnoses. Despite the continued use of chest X-rays in clinical practice, the results of Silviera's study suggest they may not fully reflect global practices, particularly in resource-limited settings where managing neonatal RDS early remains crucial for newborn survival (6).

In another study assessing the reliability of lung sonography in neonates with respiratory distress, interpretations were compared among physicians with different levels of experience. A retrospective analysis of 465 lung sonograms from 114 neonates was conducted and four observers independently evaluated the scans. The Cohen κ coefficient demonstrated high interobserver agreement between experienced and less experienced interpreters ($\kappa_1 = 0.94$, $\kappa_2 = 0.72$, $\kappa_3 = 0.81$). For RDS and transient tachypnea, agreement remained strong. The study concludes that lung sonography is a reliable diagnostic tool, even with varying levels of interpreter experience (7).

Transient tachypnea of the newborn is a primary cause of respiratory distress in neonates. This generally benign and self-resolving condition arises from delayed clearance of the fetal lung fluid after birth. Transient tachypnea of the newborn more frequently occurs in preterm infants, affecting approximately 10% of those born at 33 to 34 weeks of gestation, whereas it is seen in less than 1% of full-term infants. The diagnosis of TTN relies on clinical signs and chest X-ray (CXR), though CXR findings associated with TTN frequently lack specificity (8).

Copetti R. *et al* conducted a study on lung sonography in 32 newborns with clinical and radiological signs of TTN within the first hour after birth. Their findings were compared to those of 60 healthy infants and those with different conditions such as respiratory distress syndrome, pneumonia, pulmonary hemorrhage and atelectasis. The study identified a unique sonographic pattern, the so-called 'double lung point' in TTN patients, characterized by a difference in echogenicity between the upper and lower lung areas and dense comet-tail artifacts in the lower fields. This pattern was not observed in either healthy infants or those with other respiratory conditions. The 'double lung point' demonstrated 100% sensitivity and specificity for diagnosing TTN. The authors concluded that lung sonography was a highly reliable tool for the early diagnosis of TTN and recommended its use as a first-line imaging technique for neonatal respiratory distress (9).

In a prospective cohort study involving 59 neonates with respiratory distress, LUS demonstrated a sensitivity of 93.3% and a specificity of 96.5% for diagnosing TTN, thus surpassing the sensitivity of 89.4% and specificity of 91.3%

observed with X-ray. The findings indicate that lung ultrasound is an accurate and reliable diagnostic tool for TTN, which is also supported by current evidence (10).

A prospective observational study included 117 newborns diagnosed with MAS and 100 control newborns without lung or heart disease, who were admitted to NICU in Bayi Children's Hospital, Beijing, China, between January 2014 and August 2015. Meconium aspiration syndrome was identified by medical history, clinical symptoms, CXR results, US findings and abnormal blood gas analyses. Chest X-ray included lung overexpansion, widespread coarse and massive bilateral patchy infiltrates, with or without pleural fluid. The study found that all MAS patients had pulmonary consolidation with air bronchograms, pleural line abnormalities with the disappearance of the A-line and alveolar-interstitial syndrome or B-line in non-consolidated areas. Additionally, 16.2% of subjects had atelectasis with visible lung pulse and 13.7% pleural effusion. The data indicate that ultrasonography is a dependable, precise, convenient and non-invasive method for diagnosing MAS (11).

Pneumothorax occurs when air accumulates in the potential space between the parietal and visceral pleurae within the thoracic cavity, causing the pressure inside the lung to exceed the pressure outside the pleura. While PTX is not a disease itself, it can be life-threatening. The incidence of PTX is relatively low in term neonates, around 1%, but it is significantly higher in preterm and very low birth weight (VLBW) infants, ranging from 6% to 10%, likely due to poor lung compliance (12).

In a meta-analysis conducted by Qiang Fei *et al* in 2020, the effectiveness of LUS was compared to CXR for diagnosing neonatal PTX. The analysis included eight studies and found that the combined sensitivity and specificity of LUS for diagnosing PTX were 98% and 99%, respectively, which indicated a high accuracy with a diagnostic odds ratio (DOR) of 920.01 and minimal heterogeneity among studies. In comparison, CXR had lower sensitivity (82%) and specificity (96%), with a DOR of 44.54, showing less accuracy than LUS. Lung ultrasound was also more effective in detecting mild to moderate PTX, especially in premature infants, while CXR was less sensitive and could miss cases depending on the patient's position. Additionally, LUS

showed superior diagnostic performance in the absence of pulmonary consolidation, using indicators like the absence of lung sliding or B-lines and the lung point, which can help determine the severity of PTX. Overall, LUS demonstrated higher sensitivity and specificity compared to CXR in diagnosing neonatal PTX (13).

A study conducted by Jing Liu *et al* between 2013 and 2016 found that LUS was extremely accurate and reliable for diagnosing neonatal pneumothorax. Key ultrasound indicators, such as the absence of lung sliding and B-lines and the presence of the pleural line and A-line, showed 100% sensitivity, specificity, positive predictive value and negative predictive value. The presence of a lung point indicated mild to moderate pneumothorax, while its absence suggested a severe pneumothorax. The above-mentioned study concluded that lung ultrasound was as effective as chest X-ray in diagnosing neonatal pneumothorax (14).

In a multicenter study conducted in 2022 on 135 newborns with neonatal pneumonia and 50 healthy newborns as a control group, the use of LUS was evaluated for diagnosing and differentiating the severity of pneumonia. All patients with pneumonia exhibited abnormal pleural lines and pulmonary consolidations, with the majority also showing signs of pulmonary edema, and some presenting with air bronchograms and pleural effusion. In the control group, no significant abnormalities were observed, except for a few isolated cases of pulmonary edema. The study results showed that LUS could effectively distinguish between severe and mild forms of pneumonia, highlighting its utility as an important diagnostic tool for newborns (15).

In a study on the value of lung ultrasound in neonatal pneumonia, Jing Liu *et al* showed that LUS had 100% sensitivity and specificity for detecting large regions of lung consolidation with irregular borders, making it a dependable diagnostic technique for newborn pneumonia. According to Liu's study, lung ultrasonography might be used in the NICU to diagnose pneumonia instead of chest radiography (16).

Based on the appearance of large consolidated regions with irregular boundaries and air bronchograms, a 2013 study showed that LUS was very successful in detecting newborn pneumonia, with stated sensitivity and specificity both at 100% accuracy. These findings highlighted

LUS as a reliable diagnostic tool, particularly in NICUs, where it has been used to assess ultrasonographic changes before and after treatment. In addition to diagnosing neonatal pneumonia, LUS has been proven effective for monitoring disease progression, evaluating severity through LUS scores (which are inversely related to disease severity) and serving as an alternative to CXR for diagnosing ventilator-associated pneumonia (17).

In 2020, a literature review assessed the global practices regarding radiation exposure in neonatal intensive care units (NICU) due to the risks associated with X-ray radiation in premature infants. Twenty-five empirical studies published after 2000 were analyzed, comparing radiation doses, number of X-rays per NICU stay and recommendations. The number of X-rays ranged from 0 to 159 *per patient*, with younger and lower birth weight infants receiving more. Recommendations varied, reflecting inconsistent interpretations of the ALARA principle. The review highlights the need for standardized imaging protocols and dose monitoring in NICUs to reduce the public health risk associated with radiation exposure (18).

In a retrospective study conducted in China, the feasibility of using LUS instead of CXR to diagnose neonatal lung diseases (NLDs) was assessed. Data from 1,381 newborns with respiratory distress admitted to NICU between 2017 and 2020 were analyzed. Lung ultrasound demonstrated higher diagnostic accuracy compared to CXR, which had a misdiagnosis rate of 20.7% and a missed diagnosis rate of 5.5%. The findings suggest that LUS can fully replace CXR for diagnosing NLDs in the NICU setting, offering improved reliability and accuracy (19). ■

CONCLUSIONS

The present study emphasizes the need for individualized neonatal management based on prematurity and respiratory risk. Lung ultrasound is becoming increasingly preferred due to its multiple benefits, while X-ray is used more selectively.

The findings demonstrate a higher frequency of ultrasound use in preterm infants compared to term infants, reflecting a significant need for non-invasive, real-time imaging in managing their increased respiratory risks. Conversely,

X-ray use was less frequent in both groups, with preterm infants undergoing more X-rays than term infants, likely due to their clinical instability and higher incidence of respiratory complications. The significant inter-group differences in

both imaging modalities underscore the tailored approach needed in neonatal care. 

Conflicts of interest: none declared.

Financial support: none declared.

REFERENCES

1. **Pramanik AK, Rangaswamy N, Gates T.** Neonatal respiratory distress: a practical approach to its diagnosis and management. *Pediatr Clin North Am* 2015;62:453-469. doi: 10.1016/j.pcl.2014.11.008
2. **Gallacher DJ, Hart K, Kotecha S.** Common respiratory conditions of the newborn. *Breathe (Sheff)* 2016;12:30-42. doi: 10.1183/20734735.000716.
3. **Kotecha SJ, Gallacher DJ, Kotecha S, et al.** The respiratory consequences of early-term birth and delivery by caesarean sections. *Paediatr Respir Rev* 2016;19:49-55. doi: 10.1016/j.prrv.2015.12.002
4. **Ma HR, Liu J, Yan WK.** Diagnostic value of lung ultrasound for neonatal respiratory distress syndrome: A meta-analysis and systematic review. *Med Ultrason* 2020;22:325-333. doi: 10.11152/mu-2485.
5. **Liu J.** Ultrasound diagnosis and grading criteria of neonatal respiratory distress syndrome. *The Journal of Maternal-Fetal & Neonatal Medicine* 2023;36:2206943. doi: 10.1080/14767058.2023.2206943.
6. **Neves SG, Reis ZSN, de Castro Romanelli RM, et al.** The role of chest X-ray in the diagnosis of neonatal respiratory distress syndrome: a systematic review concerning low-resource birth scenarios. *Glob Health Action* 2024;17:2338633. doi: 10.1080/16549716.2024.2338633.
7. **Brusa G, Savoia M, Vergine M, et al.** Neonatal lung sonography: interobserver agreement between physician interpreters with varying levels of experience. *J Ultrasound Med* 2015;34:1549-1554. doi: 10.7863/ultra.15.14.08016.
8. **Nobile S, Sette L, Esposito C, et al.** Diagnostic accuracy of lung ultrasound in neonatal diseases: A systematized review. *J Clin Med* 2024;13:3107. doi: 10.3390/jcm13113107.
9. **Copetti R, Cattarossi L.** The 'double lung point': An ultrasound sign diagnostic of transient tachypnea of the newborn. *Neonatology* 2007;91:203-209. doi: 10.1159/000097454.
10. **Liang HY, Liang XW, Chen ZY, et al.** Ultrasound in neonatal lung disease. *Quant Imaging Med Surg* 2018;8:535-546. doi: 10.21037/qims.2018.06.01.
11. **Liu J, Cao HY, Fu W, et al.** Lung ultrasonography to diagnose meconium aspiration syndrome of the newborn. *J Int Med Res* 2016;44:1534-1542. doi: 10.1177/0300060516663954.
12. **Adekoya AO, Amosu LO.** Primary spontaneous pneumothorax in a term neonate. *Afr Health Sci* 2022;22:178-181. doi: 10.4314/ahs.v22i4.21.
13. **Fei Q, Lin Y, Yuan TM et al.** Lung Ultrasound, a Better Choice for Neonatal Pneumothorax: A Systematic Review and Meta-analysis. *Ultrasound Med Biol* 2021;47:359-369. doi: 10.1016/j.ultrasmedbio.2020.11.011.
14. **Liu J, Chi J-H, Ren X-L, et al.** Lung ultrasonography to diagnose pneumothorax of the newborn. *Am J Emerg Med* 2017;35:1298-1302. doi: 10.1016/j.ajem.2017.04.001.
15. **Ma H-R, Deng B-Y, Liu J, et al.** Lung Ultrasound to Diagnose Infectious Pneumonia of the Newborns: A Prospective Multicenter Study. *Pediatric Pulmonology* 2022;58:122-129. <https://doi.org/10.1002/ppul.26168>.
16. **Liu J, Liu F, Liu Y.** Lung ultrasonography for the diagnosis of severe neonatal pneumonia. *Chest* 2014;146:383-388. doi: 10.1378/chest.13-2852.
17. **Wang J, Wei H, Chen H, et al.** Application of ultrasonography in neonatal lung disease: An updated review. *Front Pediatr* 2022;10:1020437. doi: 10.3389/fped.2022.1020437.
18. **Gislason-Lee AJ.** Patient X-ray exposure and ALARA in the neonatal intensive care unit: Global patterns. *Pediatr Neonatol* 2021;62:3-10. doi: 10.1016/j.pedneo.2020.10.009.
19. **Gao YQ, Qiu RX, Liu J, et al.** Lung ultrasound completely replaced chest X-ray for diagnosing neonatal lung diseases: a 3-year clinical practice report from a neonatal intensive care unit in China. *J Matern Fetal Neonatal Med* 2022;35:3565-3572. doi: 10.1080/14767058.2020.1830369.