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REVIEW

Are lung ultrasound and chest radiograph equally reliable for neonatal imaging? A scoping review

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Abstract
Chest radiograph (CR) has traditionally been the standard in imaging neonatal respiratory diseases. Lung ultrasound (LUS) has recently emerged as a radiation-free alternative. This scoping review compares the reliability of these two techniques for diagnosing respiratory distress syndrome (RDS), evaluating the need of surfactant replacement, and predicting the development of bronchopulmonary dysplasia (BPD). A literature search was conducted in PubMed, Embase, and Cochrane Library for studies published between 1974 and December 2024. The following search terms were used: "neonate," "lung ultrasound," "chest radiography," "reliability," "Respiratory Distress Syndrome," "Bronchopulmonary Dysplasia," and "surfactant administration." The search was limited to full articles. Only studies evaluating the inter- and intra-observer agreement were included. Out of 322 evaluated papers, 14 met the inclusion criteria and were included in this review. LUS had four papers (308 neonates) for RDS diagnosis with Cohen's k or intraclass correlation coefficient (ICC) ≥ 0.9, four studies (480 neonates) for the need of surfactant replacement with Cohen's $k \geq 0.83$, and three papers for BPD prediction (280 infants) showing a Cohen's $k \geq 0.82$. We found no publication on CR reliability for RDS diagnosis, one paper on 56 neonates on its prediction of surfactant need with a Cohen's $k = 0.86$, and two studies (146 neonates) on BPD prediction with Cohen's k ranging from 0.19 to 0.41.
Conclusion: We show that, unlike CR, LUS has good quality evidence in favor of its reliability for both diagnosis and prognosis of significant neonatal respiratory diseases and guiding surfactant delivery.

What is Known:
- *CR has traditionally been the standard imaging method for neonatal respiratory diseases.*
- *LUS has emerged as a radiation-free and highly accurate alternative.*

What is New:
- *This review indicates that LUS offers robust evidence of its high reliability for the diagnosis and prognosis of neonatal respiratory distress syndrome, and for guiding surfactant delivery. In stark contrast, there is a concerning absence of solid evidence regarding CR's reliability for the aforementioned conditions.*

Keywords Lung Ultrasound · Chest radiograph · Neonatal respiratory distress syndrome · Surfactant administration · Bronchopulmonary dysplasia

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Abbreviations

BPD	Bronchopulmonary dysplasia
CR	Chest radiograph
ICC	Intraclass correlation coefficient
LUS	Lung ultrasound
NICU	Neonatal intensive care unit
RDS	Respiratory distress syndrome

Introduction

Neonatal respiratory distress is a leading cause of morbidity and mortality in infants, particularly among preterm births. Accurate and timely assessment of conditions such as respiratory distress syndrome (RDS) and bronchopulmonary dysplasia (BPD) is essential for deploying care strategies that can significantly improve clinical outcomes. Chest imaging plays a crucial role in the diagnostic process of RDS, primarily to exclude other potential causes of neonatal respiratory distress before surfactant administration [1]. Regarding BPD, although imaging is not a conventional diagnostic criterion, the detection of early signs predicting its development can be valuable; this may allow for the early stratification of individual risk shortly after birth, enabling the implementation of preventive and therapeutic strategies [2, 3].

The chest radiograph (CR) has long been the cornerstone of thoracic imaging in the neonatal intensive care unit (NICU) [4]. Although widely available, CR exposes the infant to ionizing radiation, a particular concern in neonates due to their increased sensitivity to radiation-induced damage [5]. Moreover, the interpretation of radiographic images can vary between observers (inter-observer agreement) and within the same observer over time (intra-observer agreement) [6, 7].

Over the past decade, lung ultrasound (LUS) has gained attention as a radiation-free alternative. LUS allows diagnosing pulmonary diseases at the bedside [8], and it shows high accuracy in predicting the need for surfactant administration in preterm infants with RDS and the progression to BPD [9–11].

With the increasing use of LUS in neonatal care, concerns have arisen about the relative reliability of LUS compared to CR in assessing RDS and predicting the need for interventions such as surfactant therapy or the development of BPD.

In this scoping review, we have summarized the available evidence on the reliability of CR and LUS in the aforementioned applications and identified gaps in knowledge that require further investigation.

Materials and methods

Protocol

Our review protocol was drafted using the Preferred Reporting Items for Systematic Review and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines [12].

Eligibility criteria

The search was limited to full articles published in peer-reviewed journals.

Studies were included if they met the following criteria:

1. Focused on neonatal populations.
2. Addressed the diagnosis of neonatal RDS, the prediction of surfactant administration, and the progression to BPD.
3. Assessed the reliability of LUS or CR.
4. Provided quantitative measures of inter-observer or intra-observer agreement, such as Cohen's kappa coefficient or intraclass correlation coefficient (ICC).

Information sources and search strategy

We conducted a search in the PubMed, Embase, and Cochrane Library databases for papers published between 1974 and December 2024.

The following search terms were used: "neonate," "lung ultrasound," "chest radiography," "reliability," "Respiratory Distress Syndrome," "Bronchopulmonary Dysplasia," and "surfactant administration."

The following search string combinations were employed: "neonate AND lung ultrasound AND reliability AND Respiratory Distress Syndrome," "neonate AND lung ultrasound AND reliability AND Bronchopulmonary Dysplasia," "neonate AND lung ultrasound AND reliability AND surfactant administration," "neonate AND chest radiography AND reliability AND Respiratory Distress Syndrome," "neonate AND chest radiography AND reliability AND Bronchopulmonary Dysplasia," "neonate AND chest radiography AND reliability AND surfactant administration".

Selection of sources of evidence

Three independent reviewers (F. G., F. M., F. R.) screened the titles and abstracts of the articles identified through the search. Duplicate publications and multiple reports of the same study were identified and excluded. Full articles of potentially relevant studies were retrieved and examined in detail. Discrepancies among reviewers regarding the inclusion of studies were resolved through discussion and consensus.

Data items and synthesis of results

Data from included studies were independently extracted by two reviewers (F. G., F. R.). Extracted data included study characteristics (author, year), number of neonates examined

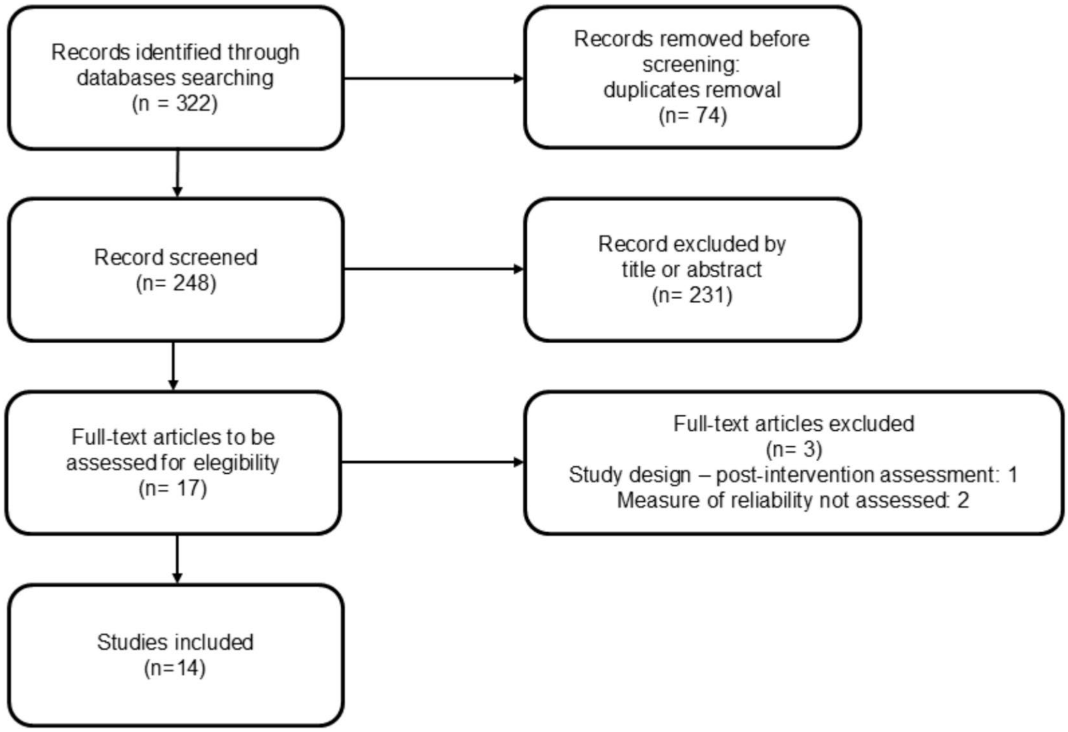

Fig. 1 Flow diagram of search results

and gestational age, imaging modality (LUS or CR), condition (RDS, BPD), number of observers and their level of experience, number and timing of performed scans, and reliability metrics (Cohen's kappa coefficient or ICC). We grouped the studies by imaging modalities (LUS or CR).

Results

The results of the search strategy and study selection process are detailed in Fig. 1. The initial search strategy identified 322 publications. Following deduplication, 74 duplicate records were removed. Subsequently, the remaining 248 records underwent title and abstract screening, resulting in the exclusion of 231 records that did not meet the inclusion criteria. A full-text review of the remaining potentially eligible studies was subsequently performed, leading to the exclusion of an additional three citations. Ultimately, 14 original records were included in this review.

The studies were then grouped into two categories based on the imaging modality used: LUS (Table 1) and CR (Table 2). These tables provide a clear comparison of the reliability metrics reported in the included studies, allowing for direct comparison between LUS and CR. Table 1 in the supplementary material reports the definition of the conditions under review for each of the included studies.

The studies summarized in Table 1 consistently show the high inter- and intra-observer reliability of LUS in the context of neonatal RDS and BPD, as well as in predicting the need for exogenous surfactant administration.

Brusa et al. [13], Corsini et al. [8], Raimondi et al. [14], and Puskarz-Gasowska et al. [15] assessed the inter-rater reliability of LUS applied to the qualitative diagnosis of neonatal RDS in a total of 343 neonates, consistently showing very good agreement, even among novice sonographers.

Further, four studies investigated the reliability of the LUS score in predicting the need for surfactant administration in a total of 480 preterm babies. In addition to demonstrating the high predictive accuracy of the LUS score, the work of Brat et al. [16], Raimondi et al. [10], Perri et al. [17], and Corsini et al. [18] reported very good inter-rater agreement in score assignment, regardless of the specific scoring system applied.

For predicting BPD, we identified three studies encompassing a total of 280 neonates. Alonso-Ojembarrena et al. [19] and Raimondi et al. [11] conducted large multicenter studies, reporting strong inter-observer reliability of LUS. In another study by Alonso-Ojembarrena et al. [20], the intra-observer reliability of LUS in predicting BPD was also high.

Conversely, studies evaluating CR presented less consistent reliability. Many studies did not explicitly assess

Table 1 Summary of extracted data from studies on LUS included in this review

Study	Type	Patients (n)	GA	Observers	Scans	Coefficient of agreement
Respiratory distress syndrome						
Brusa et al. J Ultrasound Med 2015 [13]	Retrospective	114	34 (25–41) w ((median (range))	Agreement between the main interpreter (emergency medicine physician) and 1 expert, 1 intermediate and 1 beginner control interpreters (neonatologists)	1 exam within 24 h of life (85%)	κ1 (95% CI) = 0.94 (0.87–1.00), expert † κ2 (95% CI) = 0.90 (0.81–0.99), intermediate † κ3 (95% CI) = 0.87 (0.78–0.97), beginners †
Corsini et al. Neonatology 2019 [8]	Prospective	25	33 ± 5 w (mean ± SD)	7 novice and 1 experienced sonographers (neonatologists)	1 exam at 4 h of life	$\kappa = 1.00$ †
Raimondi et al. Pediatrics 2014 [14]	Prospective	54	GA < 29 w $n = 10$ GA > 29 w $n = 44$	1 neonatologist and 1 pediatric radiologist	1 exam at 2 h of life	$\kappa = 1.00$ †
Puskarz-Gasowska et al. Healthcare 2024 [15]	Prospective multicenter	155	32 (30–33) w ((median (IQR))	Agreement between an expert's evaluation (highly qualified sonographer and neonatal intensivist) and ratings of point-of-care sonographers, stratified into experienced and inexperienced evaluators (neonatology consultants and residents)	4 exams (0–6 h, 2 days, 3 days, 7 days of life)	ICC (95% CI) experienced = 0.92 (0.90–0.94) Szymanski's score † ICC (95% CI) inexperienced = 0.93 (0.92–0.94) Szymanski's score †
Surfactant administration						
Brat et al. JAMA Pediatr 2015 [16]	Prospective	130	33 ± 3 w (mean ± SD)	4 neonatologists (a couple of beginners and a couple of expert in LUS)	1 exam in the first hours of life	$\kappa = 0.89$ Brat's score †
Raimondi et al. Chest 2021 [10]	Prospective multicenter	240	between 25^0 and 33^6 w	Neonatologists of the individual NICU and one of two investigators located in the reference center (neonatologists)	1 exam within 2 h from birth	$\kappa = 0.91$ Raimondi's score †
Perri A et al. Pediatr Pulmonol. 2018 [17]	Prospective	56	31 ± 3 w (mean ± SD)	2 neonatologists performing LUS and 1 radiologist who scored both echograms and radiograms	1 exam within 2 h from nasalCPAP positioning (dyspnoeic newborns within 2 h of life and treated with nCPAP were eligible)	$\kappa = 0.85$ Brat's score †

Table 1 (continued)

Study	Type	Patients (n)	GA	Observers	Scans	Coefficient of agreement
Corsini I et al. Eur J Pediatr 2023 [18]	Retrospective multicenter	54	30^{+2} [$29^{+1}-31^{+4}$] w ((median (IQR))	Neonatologists expert in LUS calculation	1 exam between 1 and 3 h of life	κ (95% CI) = 0.896 (0.698–1.000) Brat's score * κ = 1.000 Raimondi's score * κ (95% CI) = 0.922 (0.767–1.000) Rodriguez-Fanjul's score * κ (95% CI) = 0.896 (0.698–1.000) Brat's score † κ (95% CI) = 0.911 (0.741–1.000) Raimondi's score † κ (95% CI) = 0.833 (0.612–1.000) Rodriguez Fanjul's score †
Bronchopulmonary dysplasia						
Alonso-Ojembarrena et al. Chest 2021 [19]	Prospective multicenter	20	29 (26–30) w ((median (IQR))	Each center calculated their patient's LUS scores independently, and interobserver agreement was calculated using 20 anonymous LUS images	Exam on the first and third DOLs, then weekly until 28 DOL, and later in patients who were still on respiratory support. After 28 DOL, if the patient was not on respiratory support, exam every 2 weeks	κ (95% CI) = 0.82 (0.74–0.87) Brat's score † ICC (95% CI) = 0.98 (0.96–0.99) Brat's score †
Alonso-Ojembarrena et al. Pediatr Pulmonol 2019 [20]	Prospective	20	29.5 (27-32) w in Non-BPD patients (n = 38) 27.4 (23-31) w in BPD patients (n = 21) ((mean (95%CI))	A neonatologist with LUS experience, blinded to the status of the patients	Exam on the first and third DOLs, then weekly until 28 DOL, and later in patients who were still on respiratory support. After 28 DOL, if the patient was not on respiratory support, exam every 2 weeks	κ (95% CI) = 0.87 (0.63–1.00) Brat's score *
Raimondi et al. Pediatrics 2021 [11]	Prospective multicenter	240	3 GA cohorts: 65 infants in the 25 to 27 w' group, 76 in the 28 to 30 w' group, and 99 in the 31 to 33 w' group	2 experts in neonatal lung ultrasound (neonatologists)	First exam at 24 h of life and a weekly scan afterward	κ = 0.91 Raimondi's score †

n number, *GA* gestational age, *w* weeks, κ Cohen's kappa coefficient, *ICC* intraclass correlation coefficient, *CI* confidence interval, *SD* standard deviation, *IQR* interquartile range, *DOL* day of life

†Inter-observer agreement

*Intra-observer agreement

Table 2 Summary of extracted data from studies on CR included in this review

Study	Type	Patients (*n*)	GA	Observers	Scans	Coefficient of agreement
Respiratory distress syndrome						
None						
Surfactant administration						
Perri A et al. Pediatr Pulmonol. 2018 [17]	Prospective	56	31 ± 3 w (mean ± SD)	Data not provided	The timing of CR was decided by physicians following standard protocols of our unit, in any case before surfactant administration	κ = 0.86†
Bronchopulmonary dysplasia						
Fitzgerald J et al. Peadiatr Child Health 1996 [21]	Retrospective	46	27 ± 2.4 w (mean ± SD)	2 pediatric radiologists	1 exam at 28 DOL	κ = 0.063†
Moya M P et al. Pediatr Radiol 2001 [22]	Retrospective	100	BPD group: 26.6 ± 0.5 w No BPD group: 29.8 ± 0.5 w (mean ± SD)	3 pediatric radiologists and 1 neonatologist	1 exam at 36 corrected weeks of life	κ = 0.19–0.41†

n number, *GE* gestational age, *w* weeks, κ Cohen's kappa coefficient

†Inter-observer agreement

inter-rater or intra-rater reliability, and those that did often reported lower coefficients of agreement. Table 2 summarizes the studies included in the review regarding CR.

Our search strategy identified no publication on CR reliability for RDS diagnosis.

In the context of predicting the need for surfactant administration, Perri et al. [17] reported good inter-rater reliability for the radiographic score, although the methodology did not specify the observers involved in the agreement analysis. Importantly, their work demonstrated the superior accuracy of the LUS score compared to the radiographic score for this purpose.

Additionally, for predicting BPD, two studies have evaluated the reliability of the examined radiographic scores. The work of Fitzgerald et al. [21] highlighted a poor agreement between two radiologists who examined radiographs of 46 oxygen-dependent neonates at around 28 days of life. In the study by Moya et al. [22], inter-rater agreement was evaluated among four blinded observers (three pediatric radiologists and one neonatologist) interpreting radiographs of 100 neonates at 36 corrected weeks of life; the calculated Cohen's kappa coefficients ranged from 0.19 to 0.41, indicating poor agreement.

Discussion

Thoracic imaging modalities play a crucial role in the management of major neonatal lung diseases. RDS is the most frequent cause of respiratory distress in extremely preterm neonates; however, as gestational age increases, the relative incidence of RDS declines, making the differential diagnosis of other causes of neonatal respiratory distress (e.g., transient tachypnea of the newborn (TTN), persistent pulmonary hypertension of the newborn (PPHN), and congenital pneumonia) imperative. Historically, imaging has played a significant role in this process. [1] While bronchopulmonary dysplasia (BPD) diagnosis is not based on chest imaging, the identification of early imaging signs predictive of BPD development can be valuable for stratifying individual risk soon after birth and implementing preventive and therapeutic strategies [2, 3].

The results of this scoping review indicate that LUS consistently demonstrated high inter-observer and intra-observer reliability across numerous studies. The strong agreement observed among different observers, regardless of their experience level, suggests that LUS provides consistent and reliable diagnostic information for neonatal respiratory conditions. The evidence supporting the reliability of LUS is robust, with several studies reporting very good agreement among observers. This consistency across studies and clinical scenarios suggests that LUS may be a more reliable and safer tool for assessing neonatal respiratory pathologies, such as RDS and BPD, as well as for predicting the need for surfactant administration.

Some studies have also documented that only a small number of LUS exams are needed for operators to become reliable in performing the examination: the work of Corsini et al. [8] reports a need for 31 ultrasound examinations (25 supervised LUS during the training period and six independent LUS) to achieve complete agreement with CR in diagnosing a wide range of neonatal lung diseases. This finding could promote the widespread adoption of this technique in NICUs. A recent study further supports this, demonstrating very good inter-rater agreement and reliability for LUS interpretation in neonates across different probes and operator experience levels, confirming that overall reliability remains high irrespective of the probe used—with the sole exception of a slight reduction in agreement among less experienced operators using non-linear probes [23].

In contrast to the findings for LUS, our review highlighted a concerning lack of solid evidence for reliability in the interpretation of CR for neonatal chest imaging.

Indeed, it emerged that there are no studies reporting inter-rater or intra-rater agreement in the radiographic evaluation of neonatal RDS. Regarding the use of CR to predict the need for surfactant, we found only one paper reporting inter-rater agreement in this area [17]; however, this study did not describe in the methodology which observers were involved in calculating the degree of agreement while reporting a statistically significant difference in correlation between LUS and CR with the SpO_2/FiO_2 ratio (Spearman's coefficients were, respectively, 0.48 and 0.29, with $P<0.001$).

The available literature evaluating the reliability of CR used to predict progression to BPD shows a poor degree of inter-rater agreement.

The scarcity of published data and the variability of interobserver agreement reported in the few available studies highlight a significant gap in the literature and underscore the need for further research to clarify the reliability of CR in this context.

Since reliability is a key factor in determining the utility of an imaging technique, the absence of data on the reliability of CR suggests that its continued use in neonatal chest imaging should be reevaluated.

The results of this review have important implications for clinical practice in neonatology. The high reliability of LUS and its functional applications suggest that it may be a superior imaging modality for diagnosing neonatal respiratory pathologies and guiding therapeutic decisions, such as the administration of exogenous surfactant. Furthermore, it has been shown that the LUS score may describe oxygenation independent of the type of respiratory condition or gestational age [10, 16]; this quality further validates its usefulness in neonatal settings.

Given the limited availability of evidence regarding the reliability of CR, adopting LUS as the preferred imaging modality in neonatology could lead to more accurate and consistent diagnoses, reducing the risk of diagnostic errors and improving patient outcomes. Moreover, the safety advantages of LUS, particularly the absence of ionizing radiation, make it a more suitable option for repeated assessments in neonates.

A recent study reported findings from a NICU in China where lung LUS completely replaced CR as the primary imaging modality for a 3-year period. Compared with CR, LUS exhibited superior accuracy and reliability in diagnosing NLDs [24].

Despite its advantages, LUS cannot yet fully substitute for CR in the NICU setting. The visualization of small lesions away from the pleura and/or under the bony structures (less common in the neonate compared to later ages in life) may be hampered or impossible by ultrasound. Therefore, if clinical symptoms persist or are inconsistent with LUS findings, further radiological interventions are essential [25].

In conclusion, this review highlights that, unlike CR, LUS has good quality evidence in favor of its reliability for both diagnosis and prognosis of significant neonatal respiratory diseases and guiding surfactant delivery. The absence of data on the reliability of CR calls for further research to ensure that neonatal care is based on the most reliable imaging modalities available. The findings support the growing adoption of LUS in neonatal care and suggest that it may offer a more reliable alternative to CR for neonatal respiratory conditions.

The implementation and widespread adoption of LUS in neonatology require the creation of standardized training programs and easy access to ultrasound devices. Additional challenges may come from the need for integration with existing clinical protocols and resistance to introduce a significant change in clinical routine.

As neonatal imaging practices continue to evolve, it is imperative that future research addresses the gaps identified in this review to optimize care provided to this vulnerable population.

Our results call for further analysis of inter/intra observer reliability including a greater number of observers with varying degrees of experience as is the practical nature of neonatal care and the provision of LUS in the clinical setting.

This scoping review acknowledges certain limitations. First, this review included only full-text papers reporting reliability metrics published within the last 50 years, potentially excluding studies relevant to the review's topic that did not meet the search criteria, data from conference abstracts, case reports, or other publication formats. Furthermore, the review focused on selected (albeit very common) neonatal respiratory diseases, RDS and BPD, potentially missing relevant studies on other neonatal conditions. Finally, the conclusions of this review are based on a small body of available evidence reporting on inter/intra-observer reliability, particularly regarding CR.

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Authors' Contributions All authors contributed to the study conception and design. F G, F M e F R performed literature search. F G and F R performed material preparation and data extraction. The first draft of the manuscript was written by F G and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests F G, F M, C V, S S, I C, C D,F R and L C have none to report. D D L serves as an Editor in the European Journal of Pediatrics.

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