

# Evaluation of the Predictive Value of Lung Ultrasound Scoring Systems in Assessing Bronchopulmonary Dysplasia Severity Among Preterm Infants: Correlation Analysis with Therapeutic Strategies and Clinical Management Protocols

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**Objective:** To evaluate the clinical utility of lung ultrasound (LUS) scoring in assessing the severity of bronchopulmonary dysplasia (BPD) in preterm infants and to explore its correlation with therapeutic strategies.

**Methods:** We conducted a retrospective analysis of clinical data from preterm infants born at our hospital between February 2023 and January 2024. Based on clinical diagnosis, infants were categorized into a BPD group and a non-BPD control group. All infants underwent LUS examinations. We compared LUS scores and clinical characteristics between the two groups and performed correlation analyses to investigate the relationship between LUS findings and subsequent treatment plans.

**Results:** The two groups were comparable in baseline characteristics ( $P > 0.05$ ). The LUS score was significantly higher in the BPD group than in the control group ( $P < 0.05$ ). Univariate regression analysis indicated that lower gestational age, cesarean delivery, lower birth weight, birth asphyxia, invasive ventilation, presence of retinopathy of prematurity (ROP), neonatal respiratory distress syndrome (NRDS), patent ductus arteriosus (PDA), higher fluid intake/output in the first week, and higher LUS scores were all associated with increased BPD risk. Multivariate logistic regression analysis confirmed that lower gestational age and higher LUS scores were independent risk factors for BPD ( $P < 0.05$ ). The area under the curve (AUC) for LUS scoring in diagnosing BPD was 0.928. An optimal LUS score cutoff value of 32 was identified, yielding a sensitivity of 80.11% and a specificity of 85.94%. Spearman correlation analysis revealed a positive correlation between LUS scores and the intensity of the therapeutic interventions employed ( $P < 0.05$ ).

**Conclusion:** A higher LUS score is an independent risk factor for BPD in preterm infants. As a non-invasive, simple, and real-time tool, LUS scoring holds significant clinical value for the early diagnosis of BPD and for guiding the formulation of treatment strategies.

**Keywords:** lung ultrasound scoring, premature infants, bronchopulmonary dysplasia, treatment protocol, clinical value

## Introduction

Bronchopulmonary Dysplasia (BPD) remains the most common chronic lung disease in premature infants, particularly affecting those with extremely low birth weight (ELBW) and extreme prematurity.<sup>1,2</sup> Despite advances in neonatal care



that have improved survival rates, the incidence of BPD continues to rise, with estimates exceeding 60% in ELBW infants.<sup>3-5</sup> As our understanding of the complex and multifactorial pathogenesis of BPD evolves, the focus is increasingly shifting towards early identification, prevention strategies, and personalized management to mitigate long-term pulmonary sequelae.<sup>6</sup>

In this context, the search for effective, accessible, and reliable tools for early risk stratification and diagnosis is paramount. Lung Ultrasound (LUS) has emerged in recent years as a promising, non-invasive, and radiation-free imaging modality for the management of neonatal lung diseases.<sup>7</sup> Its ability to provide real-time visualization of structural lung changes and reflect dynamic functional alterations makes it particularly suitable for the vulnerable preterm population. LUS can assess lung aeration, interstitial thickening, and the presence of pathological findings, offering potential for the identification and severity grading of BPD.<sup>8</sup>

Although LUS shows considerable promise, its application in the context of BPD prediction and management faces significant challenges. A primary limitation is the lack of a standardized, universally accepted scoring system, coupled with the operator-dependency of the technique, which has consequently limited the number of robust clinical studies validating its utility.<sup>9</sup> Furthermore, while previous research has established a general association between LUS findings and BPD diagnosis, there is a critical gap in understanding how quantitative LUS scores correlate with specific clinical management decisions and therapeutic intensification. Recent reviews on BPD prevention underscore the need for better tools to guide targeted interventions.<sup>10</sup>

This study therefore aims not only to validate the predictive value of a specific LUS scoring system for BPD severity but also to extend the current knowledge by performing a detailed correlation analysis between LUS scores and subsequent therapeutic strategies. We hypothesize that a higher LUS score is not merely diagnostic but is actively integrated into clinical reasoning, influencing specific management protocols. By doing so, we seek to provide stronger theoretical support and practical guidance for the use of LUS in the early recognition and individualized treatment of BPD in preterm infants.

## Subjects and Methods

### Study Design and Subjects

This retrospective study enrolled preterm infants born at our hospital between February 2023 and January 2024. After applying the inclusion and exclusion criteria, a total of 60 infants were included. Based on clinical diagnosis, infants were categorized into a BPD group (n=30) and a non-BPD control group (n=30). General demographic and clinical data were collected for all subjects. The study was approved by the Ethics Committee of Shijiazhuang Fourth Hospital and conducted in accordance with the ethical standards of the Declaration of Helsinki. Given the retrospective nature, the requirement for informed consent was waived by the ethics board. To ensure patient data confidentiality, all data collected for this study will be kept strictly confidential.

### Diagnostic Criteria for BPD and Severity Classification

The diagnosis of BPD was established according to the National Institute of Child Health and Human Development (NICHD) criteria, defined as a persistent oxygen requirement (Fraction of Inspired Oxygen,  $FiO_2 > 0.21$ ) for at least 28 days in preterm infants born at  $< 32$  weeks of gestational age. The severity of BPD was assessed at 36 weeks' postmenstrual age (PMA) based on the level of respiratory support required: Mild BPD: Breathing room air. Moderate BPD: Need for low-flow nasal cannula oxygen ( $< 2$  L/min) or nasal continuous positive airway pressure (nCPAP)  $\leq 5$  cm  $H_2O$ . Severe BPD: Need for positive pressure ventilation (non-invasive or invasive), nCPAP  $> 5$  cm  $H_2O$ , or nasal cannula flow  $\geq 2$  L/min.

### Inclusion and Exclusion Criteria

#### Inclusion Criteria

Preterm infants born in our hospital who met the NICHD diagnostic criteria for BPD and had complete clinical data were eligible for inclusion.

Exclusion Criteria: Infants were excluded if they had any of the following: chromosomal abnormalities, neuromuscular disorders causing chronic oxygen dependency, congenital heart disease (excluding hemodynamically insignificant patent ductus arteriosus, PDA) or congenital lung malformations, severe thoracic or airway deformities, genetic metabolic diseases, immune deficiencies, pneumothorax, pulmonary hemorrhage, severe intraventricular hemorrhage (Grade III or IV according to the Papile classification), or if they were transferred out of the neonatal intensive care unit (NICU) for surgery or other interventions before the assessment was complete.

## Lung Ultrasound Examination and Scoring

Lung ultrasound examinations were performed within 48 hours after birth. All scans were conducted by one of two experienced sonographers who were blinded to the infants' clinical condition and group assignment, using a GE LOGIQ 7 color ultrasound diagnostic system with a 12L linear array probe. The examination followed established guidelines for neonatal lung ultrasound. Each lung was divided into six regions based on anatomical landmarks (the anterior axillary line, posterior axillary line, and the nipple line), resulting in a total of 12 lung regions assessed. The LUS score for each region was determined based on a standardized scoring system, as detailed in Table 1. The final total LUS score was the sum of the scores from all 12 regions, ranging from 0 to 72 points, with a higher score indicating more severe lung pathology.

To ensure scoring consistency and assess inter-rater reliability, a subset of 15 examinations (25%) was independently scored by both sonographers while remaining blinded to each other's assessments and clinical data. The inter-observer agreement for the total LUS score was evaluated using the intraclass correlation coefficient (ICC).

## Treatment Protocols

The primary differences in management pertained to respiratory support. All infants received initial respiratory support as clinically indicated. The modalities were hierarchically categorized from most to least intensive as follows: 1) Invasive mechanical ventilation (endotracheal intubation), 2) Non-invasive positive pressure ventilation (NIPPV), 3) Bilevel positive airway pressure (BiPAP), 4) Continuous positive airway pressure (CPAP), and 5) High-flow nasal cannula oxygen therapy. The specific modality used for each infant was determined by the treating clinical team based on standard unit protocols and the infant's respiratory status.

## Data Analysis

Data were analyzed using SPSS Statistics version 26.0, and graphs were generated with GraphPad Prism 8. Continuous variables are presented as mean  $\pm$  standard deviation (SD) and were compared between groups using the independent samples *t*-test. Categorical data are expressed as counts and percentages [n (%)] and were compared using the Chi-square test or Fisher's exact test, as appropriate. Univariate and multivariate logistic regression analyses were performed to identify factors associated with BPD risk. The inter-rater reliability of the LUS scores was quantified using a two-way random-effects model ICC for absolute agreement, with values  $>0.75$  indicating good reliability. The correlation between

**Table 1** Lung Ultrasound (LUS) Scoring Criteria

Ultrasound Feature	Score 0	Score 1	Score 2
Pleural Line	Normal, sharp, and continuous	Thickened ( $>0.5$ mm) or irregular, with small subpleural consolidations	Not applicable
A-lines / B-lines	A-lines present; $\leq 3$ isolated B-lines	$\geq 3$ B-lines with some fusion; A-lines partially visible	Coalescent B-lines (white lung); A-lines absent
Lung Consolidation	Absent	Small subpleural consolidation or consolidation spanning $\leq 3$ intercostal spaces	Large consolidation involving $>3$ intercostal spaces
Pleural Effusion	Absent	Present	Not applicable

**Table 2** Comparison of General Information Between the Two Groups of Infants

	Presence Group	Control Group	$\chi^2$	P
Number of Cases	30	30	–	–
Male	18	16	0.272	0.602
Female	12	14	–	–
Singleton pregnancy	27	29	0.268	0.605
Multiple pregnancies	3	1	–	–

the total LUS score and the ordinal respiratory support hierarchy was assessed using Spearman's rank correlation coefficient. A two-tailed P-value of  $<0.05$  was considered statistically significant.

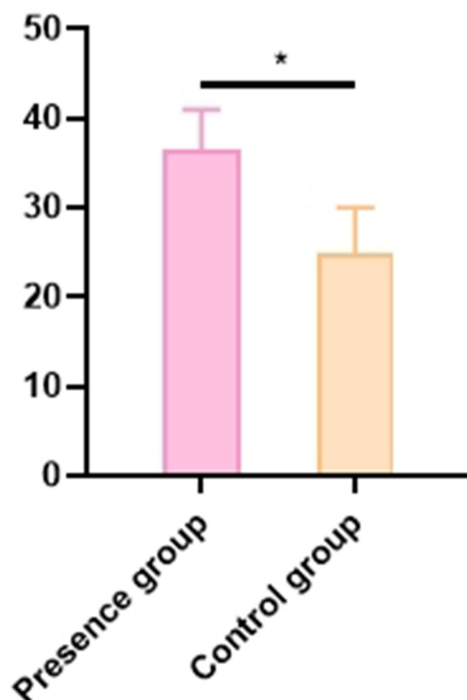
## Results

### General Information

The group with BPD (BPD group) included 30 infants, 18 males and 12 females; 27 singletons and 3 multiples. The control group also included 30 infants, 16 males and 14 females; 29 singletons and 1 multiple. There were no significant differences in the general information between the two groups, and the differences were not statistically significant, indicating that the two groups were comparable ( $P > 0.05$ ). See [Table 2](#).

### Lung Ultrasound Scores

The lung ultrasound scores of the BPD group were significantly higher than those of the control group ( $P < 0.05$ ). See [Figure 1](#).



**Figure 1** Comparison of Lung Ultrasound Scores Between the Two Groups.  
**Note:** \* indicates a significant difference between the two groups,  $P < 0.05$ .

## Univariate Analysis

Univariate analysis showed that factors such as gestational age, mode of delivery, birth weight, asphyxia, invasive ventilation, retinopathy, NRDS, PDA, liquid inflow and outflow in the first week, and lung ultrasound scores all significantly affected the occurrence of BPD ( $P < 0.05$ ). See Table 3.

## Logistic Regression Analysis

Multivariate logistic regression analysis showed that gestational age and lung ultrasound score were independent risk factors for the occurrence of BPD ( $P < 0.05$ ). See Table 4.

## Value Analysis

The area under the curve (AUC) for diagnosing BPD using lung ultrasound scores was 0.928, with an optimal score threshold of 32 points. The sensitivity was 80.11%, and the specificity was 85.94%. See Table 5.

## Correlation

Spearman correlation analysis showed that there was a significant positive correlation between lung ultrasound scores and the treatment regimen, specifically the type of respiratory support required ( $P < 0.05$ ). That is, the higher the lung ultrasound score, the higher the level of treatment support needed by the infant. See Table 6.

**Table 3** Univariate Analysis of Factors Affecting the Occurrence of BPD

	Presence Group	CONTROL GROUP	$t/\chi^2$	P
Number of Cases	30	30	–	–
Gestational age (w)	30.02±1.25	34.25±1.36	12.543	<0.001
Caesarean birth	7	16	5.711	0.017
Birth weight (g)	1349.11±252.22	2035.25±355.14	8.628	<0.001
Asphyxia	15	6	5.934	0.015
Invasive ventilation	14	3	9.932	0.002
Retinopathy	8	1	4.706	0.030
NRDS	24	11	11.589	0.001
PDA	18	9	5.455	0.020
Difference in liquid inflow and outflow in the first week (mL/kg d)	28.14±3.85	37.56±4.88	8.301	<0.001

**Abbreviations:** PDA, Patent Ductus Arteriosus; NRDS, Neonatal Respiratory Distress Syndrome.

**Table 4** Logistic Regression Analysis of Risk Factors for BPD

	$\beta$	SE	Wald $\chi^2$	P	OR	95% CI
Gestational age	−0.841	0.250	5.256	0.018	0.678	0.125–0.997
LUS score	0.355	0.091	13.215	<0.001	1.351	1.025–1.874

**Table 5** Value Analysis of Lung Ultrasound Scores in Diagnosing BPD

	AUC	Best Rating Threshold	Sensitivity	Specificity
Number of Cases	0.928	32	80.11%	85.94%

**Table 6** Correlation Between Lung Ultrasound Scores and Treatment Regimen

	r	P
VFA	0.325	<0.001

## Discussion

Bronchopulmonary Dysplasia (BPD) is the most common chronic lung disease in premature infants, with a complex pathogenesis and profound long-term health impacts on affected infants. Early identification and timely treatment of BPD are crucial for improving the prognosis of premature infants.<sup>11,12</sup> Traditional diagnostic methods for BPD primarily rely on the observation of clinical symptoms and imaging studies, but these methods often have certain limitations. In recent years, lung ultrasound (LUS), as a non-invasive, radiation-free, and real-time diagnostic tool, has shown great potential in the early diagnosis of BPD and in the adjustment of treatment strategies.<sup>13,14</sup> This study, through a retrospective analysis, explores the clinical value of lung ultrasound scoring in assessing the severity of BPD in preterm infants and examines its relationship with treatment options.

The regression analysis in this study indicates that gestational age and lung ultrasound scores are independent risk factors for the occurrence of BPD. Preterm infants with lower gestational ages are more prone to developing BPD, which is closely related to incomplete lung development and prolonged oxygen therapy and mechanical ventilation support. Lung ultrasound scoring effectively reflects the structural and functional abnormalities in the lungs of preterm infants, helping to assess the severity of BPD. Therefore, the relationship between lung ultrasound scores and gestational age suggests that in preterm infants, lung ultrasound can be an important tool for determining BPD risk, especially for extremely low birth weight (ELBW) and very low birth weight (VLBW) infants, where the clinical application of lung ultrasound scoring is particularly important.

Additionally, this study found that lung ultrasound scoring effectively reflects the pathological changes in the lungs of preterm infants and is highly correlated with the clinical diagnosis of BPD. By scoring different lung regions, it can accurately assess characteristics such as bubble development, lung interstitial thickening, and pulmonary vascular changes, thereby reflecting the severity of BPD.<sup>15–17</sup> Our results show that the lung ultrasound scores in the BPD group were significantly higher than those in the control group, suggesting that lung ultrasound scoring can serve as a reliable tool for evaluating the occurrence and progression of BPD. This finding is consistent with previous studies and supports the clinical value of lung ultrasound scoring in the diagnosis of BPD in preterm infants.

The occurrence of bronchopulmonary dysplasia (BPD) is closely related to factors such as prematurity, oxygen therapy, and mechanical ventilation. Its pathological mechanisms involve multiple factors, including incomplete alveolar development, pulmonary interstitial hyperplasia, and abnormal pulmonary vascular structures. These pathological changes lead to severe lung function impairment, manifested by respiratory distress and hypoxemia, and even in the later stages of prematurity, affected infants may still rely on oxygen therapy or mechanical ventilation. BPD not only impacts the quality of life of premature infants but also has profound long-term effects on their health. Therefore, the early diagnosis and treatment of BPD have become major issues that need to be addressed by neonatologists and pediatricians.<sup>18,19</sup> Traditional diagnostic methods for BPD rely on the observation of clinical symptoms and imaging examinations such as X-ray chest films or CT scans. Although these methods have some value in diagnosing BPD, they also have significant limitations. For example, X-rays and CT scans require radiation, which can pose potential risks to premature infants. Furthermore, these imaging techniques often fail to reflect the dynamic changes of BPD in a timely manner, which can lead to delayed or incorrect diagnoses. Additionally, there is considerable individual variation in the clinical presentation of BPD, and some early cases may not exhibit obvious symptoms, further complicating early recognition.<sup>20–22</sup>

In contrast, lung ultrasound scoring (LUS), as a standardized lung ultrasound evaluation tool, plays an important role in the early diagnosis and clinical management of BPD. In this study, the lung ultrasound scoring criteria included the pleural line, A-lines and B-lines, lung consolidation, and pleural effusion. A normal pleural line appears as a hyperechoic horizontal line located on the outermost layer of the lung. There is ongoing debate regarding whether the pleural line seen on ultrasound represents the anatomical visceral pleura.<sup>23,24</sup> Some studies suggest that the pleural line seen on ultrasound is actually an echo line formed by superficial lung tissue. A-lines are multiple parallel hyperechoic lines to the pleural line and are usually considered an ultrasound sign of normal lung. B-lines, which originate from the pleural line and are perpendicular to it, are hyperechoic lines. The number of B-lines is positively correlated with the amount of fluid in the lung. The length of A-lines and B-lines can reflect the extent and severity of pulmonary lesions. Lung consolidation is an

ultrasound manifestation of atelectasis, and larger areas of atelectasis can be observed on both X-ray chest films and lung ultrasound images. However, if atelectasis is limited to one or two intercostal spaces, X-ray chest films may not detect it, which is referred to as occult atelectasis. The extent of lung consolidation in neonates correlates with the severity of the lesions. Pleural effusion is a non-specific manifestation of pulmonary disease and may occur in various neonatal lung conditions, including BPD. In summary, by scoring the images of different lung regions and combining clinical symptoms and other examination results, LUS can accurately assess the severity of BPD.<sup>25–27</sup> In the early stages of BPD, lung ultrasound scoring not only allows for timely and effective assessment of lung conditions but also helps physicians develop individualized treatment plans and perform dynamic monitoring during the treatment process. Particularly for premature infants, lung ultrasound scoring can reflect changes in the condition in real time, providing critical support for treatment decisions.

Moreover, lung ultrasound scoring (LUS) offers advantages such as non-invasiveness, real-time monitoring, and ease of operation, making it particularly suitable for neonates and preterm infants. Compared to traditional X-ray chest films or CT scans, lung ultrasound not only avoids the risks associated with radiation but also allows for repeated examinations, which is beneficial for dynamic monitoring of the condition. For preterm infants, whose lung lesions can progress rapidly, lung ultrasound can promptly reflect the progression of pulmonary changes, helping clinicians make quick decisions during treatment.<sup>28–30</sup> Therefore, lung ultrasound scoring plays an irreplaceable role in the early diagnosis and management of BPD.

This study found a significant positive correlation between lung ultrasound scores and respiratory therapy methods ( $P < 0.05$ ). This result indicates that lung ultrasound scoring not only effectively reflects the severity of BPD but also provides important guidance for selecting respiratory treatments. Based on the lung ultrasound assessment, doctors can adjust oxygen therapy and mechanical ventilation methods according to the severity of pulmonary lesions. For infants with higher lung ultrasound scores, more aggressive respiratory support treatments, such as endotracheal intubation and non-invasive positive pressure ventilation (NIPPV), may be required to improve lung function. On the other hand, for infants with lower lung ultrasound scores, less intensive treatments, such as high-flow oxygen therapy or continuous positive airway pressure (NCPAP), may be chosen. This finding further underscores the importance of lung ultrasound scoring in the management of BPD.

Through real-time lung ultrasound assessments, clinicians can promptly adjust treatment plans, thereby improving treatment outcomes and reducing complications. In clinical practice, the choice of ventilator treatment mode is often closely related to the severity of BPD. Infants with more severe conditions typically require higher levels of oxygen supply, which also reflects the higher intensity of the ventilator treatment mode. Therefore, by combining lung ultrasound scores with ventilator treatment monitoring, doctors can more scientifically assess the infant's condition and formulate appropriate respiratory therapy plans to promote the infant's rapid recovery.

Moreover, combining previous relevant literature from both domestic and international sources, it can be observed that lung ultrasound scoring (LUS) plays an important role not only in the diagnosis of bronchopulmonary dysplasia (BPD) but also in evaluating treatment efficacy. In neonatal intensive care, as a real-time and continuous assessment tool, lung ultrasound scoring can reflect the therapeutic effects on lung improvement, thus providing a basis for adjusting clinical treatment plans. By regularly assessing the progress of lung recovery, doctors can more scientifically adjust treatments such as oxygen therapy, ventilation methods, and nutritional support, thereby reducing the incidence of complications and improving treatment outcomes for preterm infants. However, the repeatability and consistency of lung ultrasound scoring still face challenges, particularly across different hospitals, equipment, and operators. Therefore, optimizing the operational procedures of lung ultrasound scoring and improving its clinical accessibility and reliability remain key research focuses.

In conclusion, while lung ultrasound scoring has shown high diagnostic value in this study, it still has some limitations. First, lung ultrasound scoring requires a high level of technical skill from the operator, and the quality of ultrasound images is closely related to equipment performance. Therefore, lung ultrasound examination should be performed by experienced sonographers and conducted under standardized procedures. Additionally, although lung ultrasound scoring can effectively reflect structural and functional changes in the lungs, its ability to assess micro-pathological changes is limited, and it may not fully replace other diagnostic methods such as CT scans or gas exchange

analysis. Future research could explore the combined use of lung ultrasound with other imaging techniques (such as CT) to further improve the diagnostic accuracy of BPD.

## Future Prospects

Building on our findings, several promising directions for future research emerge. First, there is a critical need for multi-center studies to further standardize the LUS scoring system and rigorously evaluate its inter-observer reliability and reproducibility across different institutions and ultrasound platforms. This will enhance its generalizability in clinical practice.

Second, the integration of artificial intelligence (AI) and machine learning represents a transformative frontier. Deep learning algorithms, particularly convolutional neural networks (CNNs), can be trained on large datasets of LUS images to automate the scoring process. Such AI-driven pattern recognition could objectively identify and quantify key features like B-lines, consolidation areas, and pleural line abnormalities, thereby reducing operator dependency and improving scoring consistency. Beyond automation, machine learning models could be developed to integrate LUS data with other clinical parameters (eg, gestational age, ventilatory settings, and oxygenation indices) to generate predictive algorithms for BPD risk and disease progression, potentially enabling pre-symptomatic intervention.

Finally, the application of LUS should be prospectively evaluated within early intervention paradigms for BPD. By serially tracking LUS scores alongside physiological parameters, it could evolve into a multi-dimensional tool for guiding targeted therapies, such as the timing of corticosteroid administration or diuretic use, and for personalizing weaning protocols from respiratory support.

## Conclusion

Lung ultrasound (LUS) scoring serves as a non-invasive, straightforward tool that permits real-time assessment of pulmonary status in preterm infants. This study confirms that higher LUS scores are independently associated with the development and severity of bronchopulmonary dysplasia (BPD) and demonstrate a significant positive correlation with the intensity of required respiratory support. As an objective and reproducible method, LUS scoring provides critical information for the early diagnosis of BPD and facilitates the formulation of individualized treatment strategies. By enabling a structured evaluation of lung pathology, it assists clinicians in making informed therapeutic decisions.

Despite existing challenges related to operator dependence and the need for standardized protocols, LUS scoring holds substantial promise for routine clinical integration. With ongoing technological refinement and procedural standardization, it is poised to become an indispensable component in the management of BPD, ultimately contributing to improved patient outcomes.

## Disclosure

The authors report no conflicts of interest in this work.

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