ZALEWA, Karolina, OLSZAK, Joanna, KAPŁAN, Wojciech, ORŁOWSKA, Dominika, BARTOSZEK, Lidia, POLESZCZUK, Mikołaj, POLESZCZUK, Karol, CZUBA, Anna and MILEWSKA, Alicja. Ultrasonography in the Diagnosis of Bronchiolitis: Evaluation of Effectiveness and Application in Clinical Practice. Journal of Education, Health and Sport. 2024;75:55983. eISSN 2391-8306.
https://dx.doi.org/10.12775/JEHS.2024.75.55983
https://apcz.umk.pl/JEHS/article/view/55983

The journal has had 40 points in Minister of Science and Higher Education of Poland parametric evaluation. Annex to the announcement of the Minister of Education and Science of 05.01.2024 No. 32318. Has a Journal's Unique Identifier: 201159. Scientific disciplines assigned: Physical culture sciences (Field of medical and health sciences); Health Sciences (Field of medical and health sciences).
Punkty Ministerialne 40 punktów. Załącznik do komunikatu Ministra Nauki i Szkolnictwa Wyższego z dnia 05.01.2024 Lp. 32318. Posiada Unikatowy Identyfikator Czasopisma: 201159. Przypisane dyscypliny naukowe: Nauki o kulturze fizycznej (Dziedzina nauk medycznych i nauk o zdrowiu); Nauki o zdrowiu (Dziedzina nauk medycznych i nauk o zdrowiu).
The authors declare that there is no conflict of interests regarding the publication of this paper.
Received: 04.11.2024. Revised: 20.11.2024. Accepted: 04.12.2024. Published: 04.12.2024.

Ultrasonography in the Diagnosis of Bronchiolitis: Evaluation of Effectiveness and Application in Clinical Practice

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ABSTRACT

Introduction and Purpose

This study investigates the effectiveness and clinical applicability of lung ultrasound (LUS) in diagnosing acute bronchiolitis in young children, a respiratory condition predominantly caused by the respiratory syncytial virus (RSV). Bronchiolitis is challenging to diagnose due to symptom overlap with other respiratory infections and varying clinical presentations. While conventional diagnosis relies on patient history and physical examination, LUS has emerged as a promising, non-invasive tool that may improve diagnostic accuracy and provide valuable insights into disease severity without the radiation risks associated with X-rays.

Material and Methods

This review is based on articles from the PubMed database, covering the years 2012-2024, using keywords: bronchiolitis, LUS, lung ultrasound, LUS in bronchiolitis.

Results

The study found that LUS demonstrated a high sensitivity and specificity for identifying bronchiolitis-related lung abnormalities, including areas of consolidation and interstitial involvement. A strong association was observed between ultrasound scores and clinical severity, with elevated scores correlating with increased need for respiratory support. LUS was more effective than conventional chest X-rays for detecting consolidations over 1 cm and predicting oxygenation issues in critically ill patients.

Conclusions

LUS proves to be a valuable diagnostic tool for bronchiolitis, providing a safe, radiation- free alternative to traditional imaging and yielding reliable information on disease severity. Its ease of use, combined with its predictive value in identifying children at risk for respiratory complications, highlights LUS as a practical method for bedside assessment. Moreover, advancements in AI-supported LUS analysis hold potential for reducing operator dependency, enhancing diagnostic consistency, and improving workflow efficiency in emergency settings. Integrating LUS into routine practice could thus enhance care for pediatric bronchiolitis patients, supporting more accurate, timely diagnoses and targeted treatment interventions.

Key words: bronchiolitis, lus, lung ultrasound

Introduction

Acute bronchiolitis is a viral infectious disease of the lower respiratory tract, primarily caused by the respiratory syncytial virus (RSV). It commonly affects children under two years old due to their immature immune systems and narrow airways. The disease involves acute inflammation, edema, necrosis, and shedding of the epithelial lining in the lower airways, along with increased mucus production. Initial symptoms often resemble a mild nasal infection or follow exposure to an infected individual. Diagnosis relies on patient history and clinical presentation, as the symptoms can mimic pneumonia and bronchitis. [1,2]

Bronchiolitis follows a seasonal pattern, beginning around late October in the northern hemisphere, peaking in winter months, and tapering off by April. Worldwide, respiratory syncytial virus (RSV) tends to surge in predictable annual or biannual waves, although exact timing varies by location. According to estimates from the World Health Organization, respiratory syncytial virus (RSV) is responsible for more than 60% of acute respiratory infections in children worldwide and over 80% in infants under the age of one during peak viral season. As a result, RSV is the primary culprit behind pediatric cases of bronchiolitis and pneumonia. [3] Climate factors seem to play a role: RSV cases often rise during wet months in rainy regions and cooler months in warmer climates. Crowded indoor settings, common in colder or rainy seasons, may further promote virus spread. Cold, dry air can also contribute to infection severity by impairing ciliary function and weakening airway defenses. [2]

Despite the existence of various clinical practice recommendations, there is significant variability in the methods used for diagnosing, monitoring, and treating viral bronchiolitis. Consequently, it is crucial to standardize the diagnostic and treatment criteria. Worldwide, the diagnosis of bronchiolitis relies on the patient's clinical history and physical assessment. [4]

Pathophysiology of Bronchiolitis

The most common pathogen causing bronchiolitis is respiratory syncytial virus. However, there are more viruses causing this disease, e.g. human rhinovirus, coronavirus, human metapneumovirus, adenowirus, parainfluenza virus, human bocavirus. RSV is the primary cause of most cases, but approximately 30% of infants can have concurrent infections with two different viruses. [5]

Although respiratory syncytial virus (RSV) and rhinoviruses (RV), like other respiratory pathogens, spread through direct contact and aerosolized droplets while replicating in the airway epithelial cells, their infections involve both common and distinct pathogenic pathways. Typically, after a respiratory viral infection occurs, there is a rapid increase in type I and III interferons as a result of innate immune system activation. This initial response is followed by the release of various cytokines, including alarmins, chemokines, and growth factors, which activate and attract innate lymphoid cells, granulocytes, dendritic cells, and monocytes to the site of infection. The interplay between the virus and the ensuing inflammatory response leads to the apoptosis, necrosis, and shedding of epithelial cells, along with heightened mucus production. [6] The epithelial layer is usually safeguarded by a mucus barrier that acts as a protective shield. Viral infections can disrupt host epithelial cells, rendering mammalian cells more prone to bacterial adherence. Moreover, these viruses can compromise the mucociliary clearance system, resulting in heightened bacterial attachment to mucins and subsequent colonization. Infectious agents like influenza and RSV can harm ciliated cells, causing ciliostasis and thereby worsening the efficiency of mucociliary clearance. [7] The initial response of the mucosa to RSV infection is a strong induction of antiviral type I and type III interferons and interferon-induced genes. As RSV has developed potent mechanisms to evade this innate interferon response, the virus is able to infect most infants through RSV-NS1/2 proteins inhibiting IRF-3 and STAT-2 reducing both IFN-I and INF-III responses and RSVF protein suppressing IRF-1 through EGRF activation. [6]

It is generally accepted that severe bronchiolitis arises from an overactive inflammatory response and the resulting immunopathological effects rather than from cytological alterations triggered by the virus. In children with RSV-induced bronchiolitis, neutrophils serve as the primary inflammatory cells, accounting for as much as 80% of the cellular infiltration during the peak of symptoms. However, the specific role of neutrophils in antiviral immunity is still poorly defined. [8]

Notably, while RSV is primarily responsible for causing severe lower respiratory tract disease in infants, RV is more commonly linked to significant wheezing in slightly older children, especially those with atopic tendencies. To appreciate these differences, it is crucial to deepen our understanding of the immunological mechanisms at play in the lungs following these early respiratory infections. The initial response of the mucosa to RSV infection is a strong induction of antiviral type I and type III interferons and interferon- induced genes. As RSV has developed potent mechanisms to evade this innate interferon response, the virus is able to infect most infants through RSV-NS1/2 proteins inhibiting

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Common clinical manifestations

Key symptoms include rhinitis, coughing, wheezing, use of accessory respiratory muscles, tachypnea, and abnormal lung sounds upon auscultation, such as crackles and wheezing. A key feature of bronchiolitis is the rapid fluctuations in clinical signs, as mucus and debris are removed from the airways through coughing or as the child shifts from sleep to wakefulness. [1,2] Younger children may also exhibit symptoms such as fever, difficulty feeding, and increased irritability. [9] This variability can complicate the assessment process and often requires multiple evaluations over a period of observation. Additionally, nasal congestion can interfere with the clinical assessment. [1,2]

Risk Factors and Severity Indicators

Risk factors for developing bronchiolitis can begin as early as the perinatal period, as studies have shown that delivery via cesarean section increases the likelihood of illness. Additionally, prematurity and the use of antibiotics during the neonatal and infant stages further elevate the risk of developing bronchiolitis. These factors are associated with disruptions in the microbial flora, which can contribute to the onset of the condition. [10] Furthermore, research has shown that children born in the spring and summer months have a higher risk of hospitalization due to bronchiolitis. [11] Additionally, higher rates of illness are observed in male children. Other studies indicate that maternal asthma is also a risk factor for the development of bronchiolitis in children. [12] Other risk factors cited in the literature include age below 3 months, overcrowded living conditions, congenital immunodeficiency disorders, airway abnormalities, parental tobacco use, chronic lung conditions, low-income population. [5]

Bronchiolitis is one of the more common respiratory diseases in the infant population, significantly burdening healthcare systems worldwide. Research and clinical experience indicate that in most cases, the condition is self-limiting and can be managed on an outpatient basis. Studies show that only 1-3% of cases require hospitalization. To ensure proper patient selection, a standardized scale is necessary for accurately assessing the health status of patients and guiding decisions regarding potential admission to the hospital and further treatment. Unfortunately, there is no single approved and recommended scale for assessing the severity of a patient with bronchiolitis. Currently, physicians utilize several different scales, including the Tal Score, Modified Tal Score (MTS), Respiratory Distress Assessment Instrument (RDAI), Wang Respiratory Score (WRS), and Kristjansson Respiratory Score (KRS). Currently, the most commonly used scale is the Respiratory Distress Assessment Instrument (RDAI). [13] This scale takes into account factors such as the presence of wheezing during inhalation and exhalation, their location during auscultation, as well as the use of accessory respiratory muscles and the severity of this use. [14]

Traditional Diagnostic Methods

Bronchiolitis is diagnosed through clinical assessment. Blood tests and imaging are required solely to eliminate other potential causes. Performing serological and additional laboratory tests to detect the virus is primarily for research purposes. Laboratory evaluations for bronchiolitis are beneficial for epidemiological research but offer minimal practical relevance. The detection of the virus in the bloodstream does not correspond with the symptoms or progression of the illness. A chest X-ray should be performed only if there is a clinical indication of a complication, such as pneumothorax or bacterial pneumonia. [5]

Role of Ultrasonography in Bronchiolitis

Ultrasound is the safest imaging method available. It does not expose patients to X-ray radiation and is relatively inexpensive, quick, and widely accessible. USG can assist in both the diagnosis of bronchiolitis and the assessment of its severity and prognosis, especially when correlating findings with laboratory results and clinical evaluations. [15]

Gori L. and co-authors proved that lung ultrasound (LUS) protocols were standardized regarding examination methods and timing to ensure consistent results. A specific linear probe was utilized by experienced physicians to capture images at various intervals following the initial clinical assessment. The protocol involved examining eight lung fields using both longitudinal and transverse scans to assess the presence of ultrasound signs associated with bronchiolitis. Various findings were classified according to their significance, with certain patterns indicating more severe disease. The study developed four analysis models, including qualitative and quantitative measures, to evaluate ultrasound findings related to bronchiolitis severity. The ultrasound score for each patient was derived from individual scores across affected lung areas, reflecting the severity of lung involvement. Findings indicated a clear association between LUS results and the severity of bronchiolitis, with higher scores correlating to more extensive lung involvement. Children with moderate to severe bronchiolitis were more likely to show positive LUS results and greater lung area involvement. The study demonstrated that specific ultrasound patterns could serve as reliable indicators of disease severity. This research represents a significant contribution to understanding the role of LUS in managing bronchiolitis, as it is the largest prospective multicenter study to date utilizing a standardized protocol. This investigation employs a holistic method to evaluate the severity of lung conditions in children diagnosed with bronchiolitis, which corresponds with the underlying pathophysiology of the illness. Bronchiolitis results in structural alterations in the lungs due to inflammation, leading to issues such as air trapping and atelectasis. Utilizing ultrasound facilitates an efficient bedside assessment of lung density, indicating that a combination of clinical evaluations and ultrasound results may enhance patient care. The findings of this study validate that the presence of B-lines in ultrasound images reflects particular focal areas associated with changes in lung density. A structured follow-up timeline was established, demonstrating gradual enhancements in ultrasound results over time, which underscores the generally mild nature of bronchiolitis. Furthermore, the research introduces a quantitative scoring method for short vertical artifacts, taking into account their reversible characteristics and minimal influence on the overall evaluation of lung ventilation. [16]

Another study by Hernández-Villarroel AC and co-authors shows that lung ultrasound is becoming an increasingly utilized non-invasive method for evaluating pediatric patients with acute respiratory illnesses. This observational study aimed to determine the effectiveness of a clinical ultrasound scoring system for infants diagnosed with acute bronchiolitis in emergency departments and its capability to accurately identify those at higher risk for clinical deterioration. The research involved infants younger than six months displaying symptoms consistent with acute bronchiolitis, who underwent both clinical and ultrasound evaluations. The study included a total of 50 participants, with a median age of 2.2 months. Results indicated that infants requiring either invasive or non- invasive respiratory support had significantly elevated ultrasound scores. The data demonstrated a strong association between ultrasound scores and the necessity for respiratory intervention, with a significant predictive value for scores below a defined threshold. Furthermore, infants with higher scores were more likely to need respiratory assistance within the following 24 hours. Overall, these findings suggest that integrating lung ultrasound findings into clinical evaluations could significantly improve prognostic accuracy for infants with acute bronchiolitis. [17]

The benefits of ultrasound outweighing conventional X-ray imaging

A key advantage of ultrasound is that it does not expose patients to ionizing radiation. Instead of using X-rays, ultrasound machines produce sound waves, and the returning echoes can be utilized for both screening and diagnostic evaluations. Moreover, the portability of ultrasound allows for its easy application at the patient's bedside. [18]

Diagnosis of bronchiolitis primarily relies on clinical symptoms, yet it can be difficult to differentiate between uncomplicated cases and those complicated by bacterial infections. Chest X-rays typically provide limited assistance, as they cannot accurately determine the underlying causes of observed radiopacities. A study conducted in Italy in 2018 found that lung ultrasound (LUS) was more sensitive and specific than chest X-rays for identifying pneumonia signs in hospitalized children with bronchiolitis, particularly for consolidations greater than one centimeter. Additionally, research by Ingelse and colleagues demonstrated that LUS scoring is associated with oxygenation issues on the first day of mechanical ventilation in critically ill pediatric patients and can effectively predict the need for oxygen therapy and the method of delivery. [19]

Limitations and Challenges of Ultrasonography

Ultrasonography, although beneficial, is not an ideal diagnostic tool by itself. A primary limitation is its capability to scan only one anatomical slice at a time, which complicates comprehensive imaging of the entire affected area in clinical practice. Furthermore, lung ultrasound (LUS) is confined to the surface of the lung, meaning that any deeper lesions that do not reach the pleura are likely to be missed. Additionally, bony structures such as ribs and scapulae can obstruct ultrasound waves, concealing potential issues beneath them. However, the thoracic cages of children, especially neonates, are less calcified, facilitating more effective LUS evaluations in this population.

Another significant limitation of LUS is its reliance on the operator's expertise. Studies have shown that the reliability of lung point-of-care ultrasound varies among different practitioners, with moderate agreement noted among various operators treating pediatric patients with respiratory issues. While some research has demonstrated high consistency even among less experienced operators, there remains a critical need for standardized training programs to improve diagnostic accuracy across all users. [19]

Table 1.

Advantages of Lung Ultrasound	Disadvantages of Lung Ultrasound
• Cheap • No radiation • Portable • Fast – suitable for emergency situations • Easy to use • Increased sensitivity and specificity when linked to the clinical presentation	• Bone structures obstruct ultrasound waves • Targeted anatomical imaging • Reduced resolution in individuals with obesity • Cannot identify lesions that are not in contact with the pleura • Dependent on the skill of the operator

Future Perspectives in Bronchiolitis Imaging The COVID-19 pandemic has profoundly impacted the landscape of medical diagnostics, particularly in the realm of lung ultrasound. In emergency settings, ultrasound has become an essential tool for evaluating patients suspected of having respiratory illnesses, especially when quick results from diagnostic tests are not accessible. This imaging technique can assist in the detection of interstitial lung diseases, informing clinicians in their treatment decisions and overall patient care. Although lung ultrasound has demonstrated its value in assessing respiratory issues, its specificity alone does not suffice to definitively confirm a lung disease diagnosis, indicating the necessity for additional diagnostic approaches. Additionally, lung ultrasound has limitations in identifying deeper lesions within the lungs, which may require supplementary imaging modalities when necessary. As new management protocols develop for patients with lung conditions, lung ultrasound is anticipated to be crucial in tracking disease progression and assessing recovery, ultimately supporting public health initiatives aimed at controlling infection transmission. [20]

Dack E and co-authors discuss the integration of artificial intelligence (AI) in lung ultrasound diagnostics, highlighting its potential to enhance the accuracy and efficiency of evaluations. AI algorithms can assist in detecting abnormalities in lung images, improving the differentiation between various lung diseases, such as pneumonia and interstitial lung disease. By analyzing ultrasound data, these technologies can potentially reduce operator dependency and variability in interpretation, leading to more consistent diagnostic outcomes. The use of AI in lung ultrasound may streamline workflows, allowing for faster decision-making in clinical settings, particularly in emergency departments. Additionally, machine learning models trained on extensive datasets can continuously improve diagnostic precision as they process more cases. Overall,AI has the potential to transform lung ultrasound diagnostics by enhancing accuracy, reducing interpretation errors, and supporting clinicians in providing timely care for patients with respiratory conditions. [21]

Conclusion

The study concludes that acute bronchiolitis, primarily caused by the RSV virus, presents a significant healthcare challenge, especially for infants. Clinical evaluation and patient history remain central to diagnosis; however, lung ultrasound (LUS) has proven more effective than traditional X-rays in detecting signs of pneumonia, particularly in children needing respiratory support. Research shows that ultrasound can more accurately reflect lung inflammation, aiding clinicians in assessing disease severity. Additionally, LUS can minimize radiation exposure and is suitable for use in settings like emergency departments. Despite its advantages, LUS has limitations, including its inability to detect deeper lung lesions and its reliance on operator skill. Advances in artificial intelligence (AI) could address some of these challenges by standardizing image interpretation, reducing subjective errors, and improving diagnostic accuracy. Utilizing machine learning algorithms could speed up emergency care and enhance disease monitoring and prognosis. In the future, integrating AI into LUS could significantly improve care for patients with respiratory illnesses.

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All authors have read and agreed with the published version of the manuscript. Founding Statement: The study did not receive funding.

Institutional Review Board Statement: Notapplicable.

Informed Consent Statement: Notapplicable. Data Availability Statement: Notapplicable.

Conflict of Interest Statement: The authors declare no conflicts of interest. Acknowledgments: Notapplicable.

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