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# LUNG ULTRASOUND IN PNEUMONIA INCLUDING COVID-19

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**ABSTRACT**

**Introduction:** Lung ultrasound is a non-invasive diagnostic method whose popularity has increased significantly with the onset of the COVID-19 pandemic. Before the pandemic, it was used by a small group of specialists, primarily in intensive care and emergency medicine. Currently, it is an increasingly common tool in many fields of medicine.
**Methods:** The aim of this study was to collect and analyze data on the effectiveness of ultrasound in the diagnosis of infectious pneumonia, comparing it with literature data.
**Results:** The obtained analysis revealed an average sensitivity of ultrasound in the diagnosis of pneumonia of 92% and a specificity of 87%.
**Conclusions:** This high sensitivity allows for extremely effective use of this technique in monitoring both analyzed diseases, and in the case of pneumonia with an etiology other than COVID-19, also for diagnostic purposes. Ultrasonography is a tool with significant clinical and research potential, which could become a fundamental tool in the future for physicians.

**KEYWORDS**

Ultrasound, Lung, Pneumonia, COVID-19

**CITATION**

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## Introduction:

According to the laws of physics, air is a very poor medium for ultrasound propagation, which formed the basis of skeptics' arguments against this examination method. However, various physical phenomena have made it possible to indirectly assess the lungs through artifacts generated by the ultrasound device. In other words, properly aerated lungs will not be visible on ultrasound, and they can only be seen directly in atelectasis (total or partial).

Infectious pneumonias are a common group of infectious diseases in both adult and pediatric populations, with an average incidence of 500-1200/100, 000 (for the adult population). [1]The most common classifications are: hospital-acquired pneumonia (HAP) and community-acquired pneumonia (CAP), as well as classification by etiology. Bacteria are the most common cause of infectious pneumonia in adults, with Streptococcus pneumoniae accounting for approximately 30-42% of CAP cases. In children, the etiological factor is age-dependent, with the exact definitions differing slightly in the literature. Predisposing factors include chronic obstructive pulmonary disease (COPD), smoking, chronic heart failure, older age, immunocompromised immune systems, diabetes, periodontal disease, and many others. Specific risk factors include immune disorders such as primary and acquired immunodeficiency syndromes, including AIDS, use of immunosuppressive drugs, cachexia, and others, which strongly predispose to fungal infections. Classic symptoms of pneumonia, regardless of etiology, include cough, fever accompanied by chills or sweats, tachypnea, and tachycardia, possibly with chest pain. Classic diagnostic methods include a traditional physical examination and ancillary tests such as laboratory and serological blood tests, [2]microbiological cultures, and imaging studies, which typically include chest X-ray and, in doubtful cases, computed tomography. Treatment depends on the etiology, so antibiotics are the most common treatment. In cases of viral infections, symptomatic treatment is primarily used, while fungal infections require the use of antifungal medications. In November 2019, the world faced a new challenge: the SARS-CoV-2 virus, which led to the WHO declaring a pandemic in 2020. The disease caused by this virus was named COVID-19, which could lead to severe pneumonia and acute respiratory failure.[3] Classic symptoms include fever, dry cough, fatigue, sputum production, shortness of breath, musculoskeletal pain, and many others. The gold standard for COVID-19 diagnostics is RT-PCR (reverse transcription polymerase chain reaction), with computed tomography, X-ray, and lung ultrasound being used. Initial treatment consisted of oxygen therapy and symptomatic treatment, but

over time, dedicated drugs against the SARS-CoV-2 virus were developed. A key step in the fight against the COVID-19 pandemic was the development of a vaccine and the introduction of mass immunoprophylaxis. In addition to the severe course of the disease, patients may face numerous post-infectious complications, which are still the subject of numerous studies and observations. [4-10] Another, extremely rare type of pneumonia is immunological pneumonia, a complication of rheumatic diseases or oncological treatment[11-13], which differs in nature from infectious pneumonia[14-17] and requires different management.[18] The use of lung ultrasound in their diagnosis is very sparsely documented, therefore, this group of pneumonias is omitted in this paper.

**Methods:**

This work is a review and was created through the development and critical analysis of scientific publications (original articles, reviews, meta-analyses) covering lung ultrasound and its use in the diagnosis and monitoring of infectious inflammatory lung diseases and COVID-19, which was subjected to a separate analysis. The research material was collected using the PubMed medical database and included only English-language papers published after 2000. Furthermore, only papers involving a study group of adults with a study sample of at least 100 patients were analyzed. Papers that incorrectly differentiated artifacts specific to lung ultrasound were also excluded from the analysis.

**Results:**

Based on the adopted exclusion criteria, 10 original studies were selected and analyzed. They covered the period 2004-1015, of which 3 were from France, 3 from Italy, 2 from China, and 1 each from Germany and Egypt. The studies included patients admitted to the Emergency Department (ED) or hospitalized in the Intensive Care Unit (ICU). In all studies, the initial examination for the diagnosis of pneumonia was computed tomography (CT). In 5 studies, an additional chest X-ray (X-ray) was performed, supplemented by computed tomography. In the study by Cortellaro et al. [20], a CT scan was ordered when work conditions permitted, whereas in the study by Reissig et al. [21] CT scan was the definitive examination when there was a discrepancy between the results of X-ray and lung ultrasound. Data on the study group size, gender distribution, mean age, and follow-up examinations and hospitalizations are summarized in Table 1

**Table 1.**

| Publ. | Year | Country | Mean age | M/F | No | Control examination | Unit |
|---|---|---|---|---|---|---|---|
| Liechtenstein 18] | 2004 | France | 53 | 37/23 | 117 | CT | ICU |
| Liechtenstein [19] | 2008 | France | 68 | 140/120 | 260 | CT; X-ray | ICU |
| Cortellaro [20] | 2010 | Italy | 69 | 77/43 | 120 | Ct; X-ray | Emergency Dept. |
| Reissig [21] | 2012 | Germany | 64 | 228/134 | 356 | X-ray; CT | ICU |
| Nafae [22] | 2013 | Egypt | N | 56/44 | 100 | X-ray CT | ICU |
| Bourcier [23] | 2014 | France | 77,5 | 72/72 | 144 | CT | Emergency Dept. |
| Xiao-lei[24] | 2014 | China | 72 | N | 179 | X-ray, CT | Emergency Dept. |
| Liu . [25 | 2015 | China | 71,5 | N | 179 | CT | Emergency Dept. |
| Pagano 26] | 2015 | Italy | 59 | 59/46 | 105 | CT | Emergency Dept. |
| Nazerian 27] | 2015 | Italy | 71 | 133/152 | 285 | CT | Emergency Dept. |

The results from the studies included in each publication are summarized in Table 4, where they are categorized into positive, false positive, false negative, and negative results. Sensitivity was calculated by dividing the positive result by the sum of the positive and false negative results. Specificity was calculated by dividing the negative result by the sum of the negative and false positive results. 95% CIs were provided for the selected studies and are also included in Table 2

**Table 2.**

| Publ. | Year | No | TP | FP | FN | TN | Sen | 95% CI | Spe | 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|
| Liechtenstein [18] | 2004 | 117 | 59 | 1 | 6 | 51 | 91% | 81-97% | 98% | 90-100% |
| Liechtenstein[19] | 2008 | 260 | 74 | 10 | 9 | 167 | 89% | 80-95% | 94% | 90-97% |
| Cortellaro 20] | 2010 | 120 | 80 | 2 | 1 | 37 | 99% | 93-100% | 95% | 83-99% |
| Reissig [21] | 2012 | 356 | 211 | 3 | 15 | 127 | 93% | 89-96% | 98% | 93-100% |
| Nafae 22] | 2013 | 100 | 78 | 5 | 2 | 15 | 98% | 91-100% | 75% | 51-91% |
| Bourcier.[23] | 2014 | 144 | 116 | 9 | 7 | 12 | 94% | 89-98% | 57% | 34-78% |
| Xiao-lei 24] | 2014 | 179 | 80 | 0 | 32 | 57 | 71% | 62-80% | 100% | 95-100% |
| Liu 25] | 2015 | 179 | 106 | 1 | 6 | 66 | 95% | 89-98% | 99% | 92-100% |
| Pagano[26 | 2015 | 105 | 67 | 13 | 1 | 24 | 99% | 92-100% | 65% | 47-80% |
| Nazerian 27] | 2015 | 285 | 72 | 15 | 9 | 189 | 89% | 80-95% | 93% | 88-96% |

The total number of patients examined in the 10 selected studies was 1845, of which the average sensitivity and specificity, were 92% and 87%, respectively.

**Discussion:**

It's difficult to imagine modern medicine without ultrasound, as it is widely used in virtually every medical specialty. Decades of research and observations have unquestionably proven its effectiveness in diagnostics, monitoring, and performing invasive procedures such as central venous catheters. [3,6,8,9]For years, lung ultrasound has been a proverbial "bone of contention." It has been met with strong resistance and skepticism among physicians and scientists, primarily due to difficulties in visualizing lung tissue in a normally aerated lung, and basing diagnostics on artifact analysis was unacceptable to many. The popularity of this technique can be divided into two periods: before and after the COVID-19 pandemic.[16] Before the pandemic, lung ultrasound was practiced mainly by a relatively small group of physicians who systematically and methodically conducted research on its use and gradually increased the number of scientific reports. Furthermore, it was used in intensive care units and hospital emergency departments, gaining particular recognition among physicians specializing in emergency and critical care medicine. [5-10]A significant breakthrough occurred in 2008, when French intensivist Daniel Liechtenstein developed his own diagnostic protocol, which he called the "BLUE protocol" (Bedside Lung Ultrasound in Emergency). In his protocol, Liechtenstein developed a rapid diagnostic path enabling the diagnosis of the most common causes of acute respiratory failure in a life-threatening patient, based on the simple identification of basic artifacts with just 4-6 applications of the transducer to the patient's chest. [2,5,7,10] This protocol enabled the rapid diagnosis of: pneumonia, tension pneumothorax, pulmonary edema, and exacerbation of asthma or chronic obstructive pulmonary disease. It was also possible to diagnose pulmonary embolism, which required an additional test of the deep veins of the lower limbs at three points: the division of the common femoral vein into the superficial femoral vein and the deep femoral vein; the so-called The V-point, i.e., imaging the superficial femoral vein above the knee, and the last of the applications, performed on the lateral aspect of the lower leg below the knee, to visualize the deep veins of the tibial region. The presence of embolic material at any of these points was a very strong indication of pulmonary embolism. [7,9] The particular advantages of the BLUE-protocol were its high efficacy, reaching 90.5%, with examination times of up to 1 minute, or up to 3 minutes when examination of the deep veins of the lower limbs was necessary. Furthermore, lung ultrasound was an additional tool in monitoring acute respiratory distress syndrome (ARDS) in critically ill patients. [20-21]

The COVID-19 pandemic has led to a period of rapid growth in popularity for chest ultrasound, as evidenced by a significant increase in scientific reports using this technique in many fields of medicine, an increase in the number of articles using this topic on medical websites, and a significant increase in the number of commercial training courses available. This significant increase in popularity is due to the confluence of several medical and logistical factors. The high infectiousness of the SARS-CoV-2 virus has caused a serious imbalance in the number of critically ill patients and the available medical personnel. Consequently, additional diagnostic methods were sought, primarily including X-ray, computed tomography, and ultrasonography.[16-17] Unquestionably, computed tomography is the most sensitive of these examinations, but it is associated

with serious limitations, such as the difficulty of transporting the patient to the CT scanner, which requires the involvement of more personnel the more severe the patient's condition. Moreover, the patient was exposed to very high doses of radiation, which further contraindicated frequent monitoring using this method. X-ray examinations could be performed at the patient's bedside using a mobile X-ray unit. Unfortunately, this also led to irradiation of the patient, therefore the frequency of these examinations had to be limited. Ultrasonography was not only a diagnostic aid, but also the best tool for monitoring the course of the disease, which was related to the possibility of performing the examination at the bedside and the lack of harmful biological effects on the patient.[15]

The possibilities of using lung ultrasound are extremely broad, as they include the ability to diagnose many diseases, such as: pneumonia, lung abscess, pleural empyema, pneumothorax, pleural effusion, primary and metastatic lung and pleural tumors, pulmonary embolism, sarcoid lesions, fibrotic and emphysematous lesions. Moreover, it is a valuable tool for monitoring the above-mentioned diseases, as well as for monitoring lung aeration in the course of ARDS or monitoring fluid management. The use of ultrasound during pleural puncture to drain fluid allows for a much safer procedure, and in the case of intubation of a patient without the possibility of auscultation of the chest, it serves to detect the presence of pleural slippage. Such numerous applications make it possible to use this technique in many different hospital departments (intensive care and emergency, conservative, surgical), and even in family physician offices.

Infectious lung diseases are among the best-documented diseases for which lung ultrasound is used. In 2018, the first Polish guidelines for the use of this technique in internal medicine were developed by a team of experts and updated in 2020. According to these guidelines, pneumonia can be diagnosed based on specific criteria without the need for X-ray confirmation. Furthermore, they state that ultrasound has higher sensitivity and specificity than X-ray, with values comparable to CT. The guidelines estimate its sensitivity at 87-95% and specificity at 80-96%. Experts believe it is particularly useful in the geriatric population, in patients as a bedside examination, and in patients with chest deformities.

The guidelines rightly emphasize its particular usefulness in the geriatric population, as further demonstrated by the work of Ticinesi et al. [29]which compared ultrasound with conventional X-ray. For the 74-91 year old study group, the sensitivity and specificity of ultrasound were 92% (95%CI 86-97%) and 94% (95%CI 89-99%), respectively, while for X-ray it was 47% (95%CI 37-57%) and 93% (95%CI 87-99%).

Furthermore, it was noted that with increasing Roockwood Frailty Index, there was only a slight decrease in the sensitivity of ultrasound, while the decrease in X-ray sensitivity was significant.

The results obtained during the literature analysis allowed us to calculate the average specificity and average sensitivity for lung ultrasound at 92% and 87%, which is consistent with the results presented in the guidelines by Buda et al.

The international guidelines developed by expert consensus emphasize the same diagnostic criteria as the Polish guidelines. The experts additionally emphasize the possibility of using contrast (contrast-enhanced ultrasound), which allows for a more detailed sonomorphological assessment of subpleural consolidations, and strongly recommend the use of this technique whenever possible. However, they do not provide information on its sensitivity and specificity in the diagnosis of pneumonia, nor do they compare its effectiveness with other imaging techniques.

The use of lung ultrasound in the diagnosis of COVID-19 required the development of guidelines or at least consensus on the procedure among experts. Initial studies were often inconsistent and incorrectly assumed high specificity in the diagnosis of COVID-19.

One of the first meta-analyses, conducted and published in April 2020, was an analysis of seven selected original papers, based on which the frequency of artifacts and their correlation with the patient's clinical condition were examined.

In total, the researchers assessed: the presence and number of B lines, changes in the course of the pleural line, including its thinning, and the presence of subpleural consolidations.

Based on the presented data, lung ultrasound cannot be unequivocally considered a highly reliable method for diagnosing COVID-19. However, its high sensitivity in detecting changes makes it an excellent tool for monitoring disease progression or regression. The non-invasive nature of the test, the wide availability of ultrasound scanners, especially in dedicated "COVID" hospitals, and the virtually zero cost of the test are very strong arguments for the widespread use of this method. The literature also describes cases of using portable ultrasound transducers for initial diagnosis among patients undergoing home isolation, which, with frequent or urgent visits, significantly facilitated the decision-making process regarding hospitalization or home treatment.

**Conclusions:**

Chest ultrasound is a branch of ultrasonography characterized by its own nomenclature and distinctive interpretation method. The COVID-19 pandemic has led to a significant increase in its popularity and a much wider implementation not only in emergency departments and intensive care units, but also in internal medicine and surgical departments, and in family physicians' offices. Based on the conducted research and the analysis of the collected literature, lung ultrasound is an extremely effective tool in the diagnosis and monitoring of infectious pneumonia, as evidenced by its high sensitivity and specificity. Furthermore, thanks to its non-invasive nature, low cost, and the possibility of bedside examination, it is arguably becoming the most accessible imaging examination. The specificity of COVID-19 diagnostics is not high enough to make a definitive diagnosis, but its very high sensitivity in detecting pathological changes makes it an extremely precise tool for monitoring the course of the disease. The use of portable probes and POCUS examinations allows for rapid diagnosis and the establishment of a probable preliminary diagnosis, making it possible to implement targeted, detailed diagnostics and initial treatment very quickly.

**Disclosure**

**Author's contribution:**
Conceptualisation: Rafał Rajski
Methodology: Jarosław Jarosławski, Wiktor Warda
Software: Dominik Tenczyński, Michał Kostro
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