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LUNG ULTRASOUND: CONTEMPORARY POSSIBILITIES - ORIGINAL PAPER

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ABSTRACT

Introduction: For many years, lung ultrasound was considered a controversial, even impossible, technique. Years of research have accumulated compelling evidence for the usefulness of this technique in clinical practice, and its user base has gradually expanded. The greatest boom in this technique occurred with the onset of the COVID-19 pandemic, when it proved extremely effective in monitoring its progression.
Methods: Our personal experience confronted with literature research by Pubmed, Web of Science, Google Schoolar.
Results: The lack of standardized definitions and nomenclature has led to a certain dissonance in publications and controversy, which is evident when reviewing the literature. Other controversial issues include the type of examination equipment used, the measurement of artifacts and the accurate assessment of their sonomorphology, as well as the extension of the examination to include additional elements such as the diaphragm. An issue repeatedly raised in publications is the need to develop a system of training and certification in lung ultrasound skills, which would allow for the standardization of the technique, nomenclature, and diagnostic criteria. Another problem is the lack of inclusion of lung ultrasound in the practice guidelines of various scientific societies in many countries, which is the subject of work by national and international ultrasound associations.
Conclusions: Despite some controversy, lung ultrasound is a valuable tool in everyday clinical practice with great potential for development.

KEYWORDS

Lung Ultrasound, Ultrasonography, Innovative Methods, Artifacts

CITATION

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Introduction.

Ultrasonography is one of the most popular tools in modern medicine, whose effectiveness has been confirmed for decades in countless scientific publications [1]. The technical capabilities of modern ultrasound machines are incredibly high, yet they are constantly being improved by manufacturers to meet all the needs of modern diagnostics [2]. Technological development has also led to the creation of compact ultrasound scanners limited to a mobile transducer paired with a smartphone or tablet device, allowing the physician to access it at any time in the hospital, in an outpatient clinic, even during home visits or emergency medical services [3]. Significant increased access to ultrasound has led to the creation of the so-called Point of Care Ultrasound, or cause-specific ultrasound, should be included in the repertoire of skills of a clinician who, based on a short, cause-specific ultrasound examination, is able to guide further diagnosis or treatment [4]. All of the above-mentioned aspects are part of the concept that ultrasonography is the stethoscope of the 21st century, and its use is not a niche skill bordering on arcane knowledge, but a new global standard [5].

The history of lung ultrasound is very turbulent, as for many years it sparked considerable controversy in the medical community. This was primarily due to the physics of ultrasound in air, according to which it is impossible to image highly aerated structures [6]. It was noted that lung tissue assessment can be performed indirectly, using artifacts, i.e., specific image elements resulting from the processing of reflected waves by the device. Lung assessment using artifacts was considered impossible and incorrect by many, and therefore lung ultrasonography did not gain much popularity for many years [7]. Despite the apparent reluctance of the rest of the medical community, enthusiasts of this method continued to conduct research and gather scientific evidence confirming its usefulness. Year after year, the number of publications on lung ultrasonography systematically increased, and high-quality evidence convinced increasingly larger groups of physicians, fueling further development of this technique [8]. One of the key moments in the development of lung ultrasonography was the publication of a series of scientific papers by Daniel Lichtenstein, who contributed to

the significant popularization of this technique and developed one of the most popular ultrasound protocols in emergency medicine today – the BLUE protocol (Bedside Lung Ultrasound in Emergency) [9]. The greatest boom in this technique and its popularization occurred with the onset of the COVID-19 pandemic, when it proved to be a highly accessible, mobile, and easy-to-use tool for monitoring patients infected with the SARS-CoV2 virus [10]. Currently, lung ultrasound is a recognized diagnostic tool with unwavering popularity, increasingly used in everyday clinical practice [11].

The contribution of Polish physicians to lung ultrasonography is also extremely significant, as already at the turn of the 1960s and 1970s, Professor Janusz Grymiński began pioneering research at the Institute of Tuberculosis and Lung Diseases in Warsaw on the use of ultrasonography in the diagnosis of pleural diseases [12].

The figure who led to the greatest popularization of lung ultrasonography in Poland is undoubtedly Professor Wojciech Kosiak, whose outstanding contributions in this field are recognized not only in Poland but also throughout Europe [13]. The idea of developing this technique by Professor Kosiak was extremely innovative for its time, as it involved intensive training and popularization of ultrasound during his studies, resulting in a current group of outstanding specialists in the field of lung ultrasonography [14]. One of the most important achievements of Polish physicians is the development of international recommendations for the use of lung ultrasonography in internal diseases, which are currently the best-documented work of this type in the world [15].

Methods:

This original work is based on the author's own experience and a critical analysis of the literature available in the medical databases Pubmed, Cochrane, and EmBase. In addition to the analysis of original articles, special attention was paid to expert commentaries, letters to the editor, comparative studies, guidelines, and recommendations. Furthermore, the author's own experience was taken into account in the analysis.

Results:

The literature often states that lung ultrasound should be performed with an older-generation scanner or, in the case of newer ones, with all image-enhancing software disabled. While this is generally true, it should be noted that consolidation is not an artifact but a fragment of the atelectatic lung, and therefore is assessed directly, not indirectly. Therefore, using image-enhancing software for its assessment is highly recommended. Moreover, it will allow for even more detailed evaluation and a more accurate diagnosis. There are a growing number of studies describing consolidation assessment using these programs, but there is still insufficient data to develop specific recommendations in this regard. Without a doubt, the”ultrasound = old-school scanner" doctrine should be replaced by an approach that performs both indirect assessment (enhancing systems disabled) and direct assessment of consolidation (enhancing systems enabled). Thanks to the enrichment of ultrasonography with modern methods, excellent diagnostic and research results are obtained, which constitute a strong premise for the further development of equipment and programs in lung ultrasonography [14-18].

Lung ultrasound is characterized by a dedicated nomenclature not found in other techniques. Basic concepts include: A lines, B lines, C lines, consolidations, I lines, and Z lines. Unfortunately, the lack of standardized definitions has led to some variations in the literature. A lines, which are parallel lines to the pleura and are a reverberation artifact, appear to be defined uniformly in virtually all studies. It should be noted that the first A line lies at the same distance from the pleura as the pleura when the transducer is applied. In some studies, a line located at a shorter distance is classified as A lines, which are actually a mirror image artifact of the tissues above the pleura. This situation should be viewed as a factual error, not a difference in definitions. B, Z, and I lines are vertical artifacts that should be distinguished from each other. The most important of these are B lines, as they are a typical pathological artifact indicating the presence of subpleural fluid, either in the lung interstitium or in the alveoli. Classification of a vertical artifact as B lines requires meeting certain conditions.

Much controversy has arisen among experts regarding the B-line, which requires clarification and commentary. The presence of a B-line in an annulsed pleural motion is problematic, as, on the one hand, it requires differentiation from pneumothorax, and on the other, the presence of a B-line excludes the presence of pneumothorax. Hence, the term”B'-line" (i.e., B-line with annulsed pleural motion) is often used as a guide. This situation requires differentiation from other causes of annulsed pleural motion. Furthermore, it is somewhat ambiguous, but it does not seem to be significant from the perspective of pneumothorax diagnostic criteria (in this case, the presence of an A-line excludes the presence of a B-line). Some experts recommend using the term”comet tail artifact." The hyperechoic nature of a B-line is self-evident, but attempts to expand

the interpretation to include a detailed analysis of its echostructure have led to significant disagreement. First, it should be noted that B lines are a physical phenomenon processed by ultrasound, which has served as an argument for skeptics of their thorough analysis. The appearance of B lines varies subtly in selected disease entities. The best example of this situation is a comparison of the sonomorphology of B lines in cardiogenic pulmonary edema, where they are sharp, thin, with regular septations, strongly resembling a laser beam, while in ARDS (Acute Respiratory Distress Syndrome) they are differentiated, blurred, and less distinct. Such extensive analysis of artifacts is often subject to numerous doubts, but it is difficult to disagree with the data that the aforementioned factual differences are noticeable. While achieving a consensus on this issue is necessary, collecting broader evidence in this area from various centers, using various transducers and ultrasound devices, is paramount.

C-lines are a necessary issue, as they are an artifact not recognized by many experts. According to Polish standards for teaching and performing lung ultrasound, C-lines are a recognized artifact. Unlike B-lines, they do not originate from the pleura, but from consolidation. Studies published by Italian experts, in particular, deny the distinction of such artifacts, stemming from a different doctrine of their perception. C-lines, similarly to B-lines, are associated with the presence of certain amounts of fluid. According to many experts, this differentiation is unnecessary from a physical perspective, and their clinical value is irrelevant for diagnosis. Ultimately, international recommendations have abandoned the distinction of C-lines, but this does not change their continued inclusion in many publications and their de facto controversial status.

Z-lines and I-lines are an important issue to discuss, as they currently have no clinical significance and are therefore often not recognized by some experts. Z lines are vertical artifacts similar to B lines, except that they terminate approximately halfway down the screen, while I lines are no longer than 2 cm. They have been noted to be more common in newborns and young children, but their clinical significance has not yet been observed.

The final term related to vertical artifacts is”comet tail artifact." This term is highly controversial because it lacks a clearly established definition. Some experts consider the comet tail artifact synonymous with B lines, while others consider it a term encompassing B, C, I, and Z lines. According to the latest definition, a comet tail artifact is considered a vertical artifact that cannot be differentiated into a given”line." Two situations require consideration: the first concerns the examination of newborns and very young children, where only a linear transducer is typically used, with an ultrasound beam penetration of 4-8 cm. This penetration depth prevents differentiation between B lines and Z lines, the definitions of which have been established for the convex transducer. In other words, the B line length should not be less than 10-15 cm. As mentioned, B lines are a pathological artifact, while Z lines have no clinical significance, so clearly differentiating them with a linear transducer would be an error. Hence, the term”comet tail artifact" proves helpful. The second situation is much rarer and occurs when it is impossible to clearly define B from C lines, in which case the term”comet tail artifact" is also found in the literature. However, as previously commented, this type of differentiation is highly dependent on the preferences and definitions used within the team.

Consolidations are another concept that has been practically redefined, as they are no longer perceived as an artifact and are now considered a real image of lung tissue (or other tissue, e.g., cancer) completely or partially devoid of air. This broadened the scope of consolidation analysis, as discussed in Section 4.1. Consideration was also given to limiting the term”consolidation" solely to atelectatic lung lesions, excluding, for example, cancerous lesions or abscesses. Ultimately, it was decided to consider consolidations as any lesions located subpleurally, which can then be further differentiated during further diagnostics [14-15, 18-25].

The pleural line is the junction of the parietal pleura and the pulmonary pleura, which is already considered an artifact. It has been observed that its echostructure changes in various disease states, which further correlates well with the patient's condition and other imaging studies. The most detailed assessment of the pleura occurs in the diagnosis and monitoring of interstitial lung diseases, where numerous pleural anomalies are observed, including localized rupture, retraction, blurring, and thickening. The assessment of pleural thickening, i.e., widths exceeding 2 mm, is controversial. It is worth reconsidering whether such a precise artifact assessment with such subtle measurements is justified and is not highly instrument-dependent. Currently, there is little data in this area, but a significant argument for pleural measurements is the good correlation between ultrasound and high-resolution computed tomography. Therefore, it is difficult to unequivocally assess this practice, but it is undoubtedly worth further investigation [26-29].

Lung ultrasound is widely considered a safe technique, supported by numerous studies. Detailed analyses in animal models have revealed minor damage to capillaries in the lungs following ultrasound exposure, particularly after the use of elastography. Any suspected risk associated with a given procedure should be thoroughly investigated, and further research is warranted in this area. However, estimating such

risk should be approached with caution, due to differences between typical examination procedures and targeted exposure, as well as the differences between human and animal organisms. Lung elastography studies, which are currently undergoing intensive research regarding their usefulness in consolidation studies, should be approached with greater caution [30-34].

The literature contains numerous high-quality studies on lung ultrasound, providing good scientific evidence. However, there is still a lack of carefully designed prospective multicenter studies comparing this technique with other diagnostic methods. Such studies would provide direct and convincing evidence that would allow for the inclusion of lung ultrasound in official guidelines of various scientific societies. It is also worth considering designing studies specifically using lung ultrasound as a screening test for selected diseases [35-40].

Currently, there is no single established technique for performing chest ultrasound examinations, and therefore, the literature contains significant variations depending on the department and the examiner's preferences. International guidelines recommend examining as much of the chest as possible, but the step-by-step procedure is not specified. Physicians who use lung ultrasound primarily in emergency situations prefer a shortened version, such as the BLUE protocol, which involves applying the transducer to several selected points. While the method of performing the examination depends on the clinical situation, it is worth considering a full chest scan to reduce the risk of missing significant pathologies. It is worthwhile to develop a detailed procedure flow chart or at least a standard specifying the structures and scans required for imaging [15, 26, 28, 39-42].

The term”lung ultrasound" is a simplified term, as many experts believe”chest ultrasound" is more accurate. Depending on the examiner's skill level, a basic assessment of the heart, ribs, chest wall, diaphragm, etc. is recommended during a lung examination. The diaphragm is of particular interest, as ultrasound examination of the diaphragm can provide valuable clinical information, especially among patients hospitalized in the intensive care unit. Diaphragmatic pathologies can affect lung imaging, such as diaphragmatic paralysis, which can lead to a false positive diagnosis of pneumothorax. A basic, thorough ultrasound examination of the diaphragm is not necessary, but in doubtful situations, it can prove very valuable. Furthermore, as experience with thoracic ultrasonography increases, it is worth considering expanding the examination to include additional structures, allowing for a full assessment of its contents [15, 30, 44-48].

The significant increase in the popularity of lung ultrasound since the beginning of the COVID-19 pandemic is a very positive phenomenon, as it has led to its widespread use in daily clinical practice. Unfortunately, a large number of false positive diagnoses of various diseases have also been observed, especially by less experienced individuals. This has led to the need to create a method of certifying the ability to perform the examination, which would not only confirm the examiner's skills but also serve as a motivator for further development. Establishing a method of valuable evaluation is a multifactorial process, as it must include clearly defined criteria and requirements, and ultimately, it should be a certificate accepted by individual countries, organizations, societies, etc. Experts agree that the creation of a form of certification is necessary, especially if it would be done in cooperation with recognized international ultrasound societies, such as EFSUMB (European Federation of Societies for Ultrasound in Medicine and Biology) [15, 30, 35, 37, 39, 49-51].

Currently, we have high-quality international recommendations for lung ultrasound diagnostics, supported by credible scientific evidence. A significant problem is the lack of inclusion of lung ultrasound in official guidelines issued by various scientific societies, not only in Poland but also worldwide. This is problematic from the perspective of practical medicine, because despite scientific evidence confirming the effectiveness of this technique, there is a risk of physicians being called to provide explanations for non-compliance with guidelines or even being accused of medical malpractice. This is a complex situation, straddling the boundaries of medicine and law, but it undoubtedly effectively discourages clinicians from its widespread use. Therefore, a dialogue is necessary to recognize lung ultrasound as a valuable method in light of national guidelines [15, 30, 35, 52-54].

Discussion:

Years of research have demonstrated that lung ultrasound is an important tool in modern medicine [6-7]. Among other ultrasound techniques, it is characterized by, among other things, dedicated nomenclature, indirect assessment, and the need to manipulate various transducers and software (especially at the advanced level) [15]. With further development, controversy and problems stemming from the lack of standardized definitions and criteria have begun to arise [35]. This paper presents the most popular and important issues from the perspective of everyday use, requiring reconsideration and discussion. The author believes that a dialogue among experts is necessary to clearly establish standardized definitions and criteria for individual

artifacts. This will allow for better understanding between various research centers in the future and reconcile differences in research. The most important issue concerns the B line, which is a pathological artifact and extremely important from a clinical perspective. It has also been assumed that the number of B lines ≤ 3 in a single transverse scan (perpendicular to the intercostal space) is a pathological phenomenon, but this number was assumed arbitrarily and is the subject of dispute among experts [15, 19-20, 25]. Most scientific studies adopt this assumption, resulting in a good correlation between the ultrasound image and the clinical image. However, it is worthwhile to undertake appropriate clinical studies to determine the threshold number of B lines indicative of pathology, which would allow for the establishment of a reliable and confirmed criterion for the diagnosis of an abnormal image [24-25]. It is also important to examine the correlation between the sonomorphology of artifacts on various ultrasound devices and the patient's clinical condition and other imaging studies. It cannot be ruled out that a thorough analysis of artifacts will further expand the interpretation of lung ultrasound images; therefore, this issue is worth investigating in detail [12-14]. Ultrasonography has been recognized as a safe technique based on numerous studies, but further investigation of the safety profile is necessary, particularly in lung ultrasound. Although the potential risk of complications appears to be marginal, empirical confirmation of the safety profile is necessary. Studies involving lung elastography, in particular, should be conducted with great caution [30-34].

The development of the recommendations was a milestone in unifying diagnostic criteria, not only facilitating daily clinical work but also enabling the design of high-quality scientific studies [30, 49-51]. Accumulating evidence confirmed by high-quality studies constitutes a strong argument in the discussion regarding the inclusion of lung ultrasonography in the guidelines of scientific societies [30]. A major challenge for national and international ultrasound organizations is the preparation of a project enabling the unification of training and certification of skills, which will not only contribute to the further development of this technique but also reduce the number of false positive diagnoses [52-54]. The training process is an extremely important issue that affects not only physicians but also students, therefore, introducing the basic theoretical and practical scope of lung ultrasonography already during medical studies would be an extremely beneficial step [15, 30]. The widespread use of ultrasound has led to it being dubbed the”stethoscope of the 21st century." Therefore, it is essential to properly prepare future physicians to use it, not only to meet global standards but, above all, to better provide patient care [4].

As presented in this article, there are still areas of lung ultrasound that require standardization and discussion. However, aside from highly specialized diagnostic considerations, it can undoubtedly be admitted that this technique is extremely helpful in everyday clinical work. Therefore, the author encourages everyone to expand their diagnostic skills with this technique, which has repeatedly proven its usefulness and has great potential for development.

Conclusions:

Based on this study, the following conclusions can be drawn:

- Controversial issues exist in lung ultrasound that require additional research and discussion.
- Unified definitions of vertical artifacts and a clear definition of the term”comet tail artifact" are necessary.
- High-end ultrasound equipment allows for obtaining more extensive information about consolidations than low-end equipment.
- High-quality prospective studies based on unified diagnostic criteria providing the highest quality scientific evidence are necessary.
- The safety profile of lung ultrasound, particularly with regard to elastographic techniques, must be confirmed.
- Discussion should be held regarding the inclusion of lung ultrasound in the guidelines of scientific societies.

Disclosure

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