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REVIEW PAPER

Lung ultrasound in children

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ABSTRACT

Lung ultrasound (LUS) plays an increasingly important role in the diagnosis of chest diseases, and it is often called "the stethoscope of the 21st century". It is a quick, inexpensive, radiation-free tool with a point-of-care option allowing for safe screening and/or follow-up. This paper presents the scanning technique, normal lung image, detectable pathologies, and exemplary applications in different disorders. Although lung ultrasound is of particular importance for the diagnosis of pneumonia in children, it has not been included in official guidelines so far. Advantages of lung ultrasound and advances in medical technology should increase the popularity of this technique as a complement to physical examination.

KEY WORDS:

children, paediatrics, ultrasonography, lung ultrasound.

INTRODUCTION

Until recently, lung ultrasound (LUS) was beyond the scope of interest of clinicians. Due to the presence of air in the lungs, this tool was considered to provide no information on potential thoracic pathological processes. However, the increase in the popularity of ultrasound at the turn of the 20th and 21st centuries allowed for a better understanding of the essence of this diagnostic test, along with its benefits and limitations. It was found to be particularly useful in paediatrics, where the aim is to limit exposure to ionizing radiation to a greater extent than in adults. The child's body contains multiple intensively dividing cells, whose DNA is particularly susceptible to low doses of X-rays, which significantly increases the risk of carcinogenesis, and this effect is inversely proportional to the child's age [1]. The knowledge of possible negative effects of chest radiography (CXR) made it necessary to limit its use and gave an impulse to search for an alternative diagnostic modality, which may turn out to be LUS [2].

LUS was found to be an effective and safe diagnostic method for lung diseases. It has been demonstrated that most clinically significant lesions are located under the pleura, which, using the acoustic window created by the soft tissues in the intercostal spaces, enables their ultrasonographic imaging [3]. LUS has recently been referred to as "the stethoscope of the 21st century" due to its increasing availability, possible point-of-care application, repeatability, as well as relatively easy and quick use, low price, and safety [4, 5]. Lung ultrasound should primarily be a point-of-care procedure performed by a clinician knowledgeable about the child's disease. However, it is important to remember about the limitations of LUS, such as subjectivity and lack of possibility to visualise pathological lesions separated from the chest wall by any amount of air, visualisation is limited to lesions that are in contact with the pulmonary pleura. Bone elements, such as the sternum, ribs, or scapula, also make it impossible to visualise potential lesions located behind them. Despite these limitations, many studies have demonstrated a similar or even greater sensitivity and specificity of LUS to that of chest radiography in the diagnosis of thoracic pathologies [6-14], which should further contribute to its popularity.

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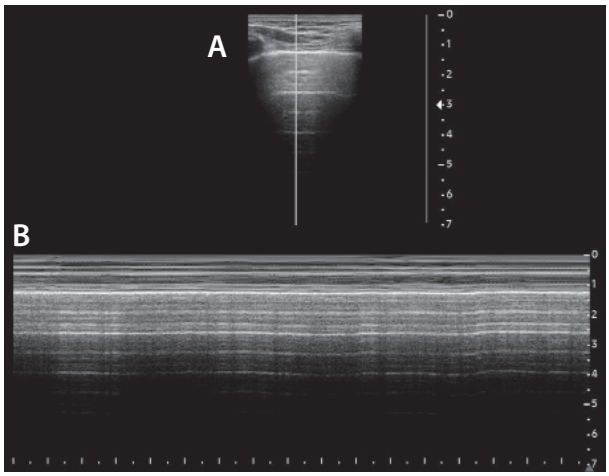

FIGURE 1. A) Normal lung image. **B**) Seashore sign

SCANNING TECHNIQUE

In paediatric LUS, a linear transducer (10 MHz or higher) is mainly used due to better image quality and sufficient penetration depth [3, 15, 16]. A convex or microconvex transducer is used in adolescents and obese children to visualise larger lesions and differentiate B-line artifacts from Z- and I-line artifacts. LUS is performed with the patient placed in a sitting, lying, or reclining position by applying an ultrasound transducer in a transverse and longitudinal orientation in each intercostal space [17]. Additionally, a supraclavicular approach is used to assess lung apices [18]. The patient breathes freely throughout the examination, and if the lesion is suspected to be located behind the rib, he or she is asked to perform forced inspiration and expiration. For accurate description of pathologies each half of thorax is divided in 6 parts: lower and upper for 3 areas: anterior (from parasternal line to anterior axillary line), lateral (from anterior to posterior axillary line), and posterior (from posterior axillary line to paraspinal line).

B-mode and M-mode are used for lung imaging. B-mode is used to evaluate a 2-dimensional image in real time, while M-mode is used to assess the mobility of the chest organs or diaphragm and to detect ultrasonographic symptoms of pneumothorax. Color Doppler can also be used to assess the vascularisation of detected lesions or to differentiate fluid spaces and vessels.

NORMAL ULTRASONOGRAPHIC IMAGE OF THE LUNGS

After applying the transducer to the chest wall, an image in a longitudinal projection is obtained, which shows the following thoracic elements: skin, subcutaneous tissue, muscles, ribs, and the pleural line. The basic image that should be obtained is the "bat sign", i.e. 2 neighbouring ribs and a hyperechoic continuous pleural line between them (Figure 1A). The sign of lung sliding, which is an imitation of the movement of the visceral pleura in relation to the parietal pleura, is the second important normal sign. In the M-mode (Figure 1B) the "seashore sign" additionally confirms normal lung image, where the pleural line and the chest wall imitate waves, while the "sand" is produced by aerated lungs.

The key artifacts are as follows:

- A-lines – horizontal, hyperechoic lines, repeatable at a distance equal to the distance from the transducer to the pleural line. These artifacts result from reverberation, i.e. multiple reflections of ultrasound waves in an aerated lung.
- Comet-tail artifacts, among others:
  - B-lines – one of the comet-tail artifacts that are created in reverberation mechanisms. These are vertical, hyperechoic lines arising from the pleural line and reaching the bottom of the screen, erasing the A lines and moving with respiration. Their presence is due to an increased water-to-air ratio in the lung parenchyma. They may physiologically occur in the basal parts of the lungs.
  - Z-lines – these do not originate from pleural line and do not move with lung sliding, fade with increasing depth, they have no clinical significance so far.
  - I-lines (lung comets) – these appear similar to B-line artifacts, but they disappear at most at half of an ultrasound screen height (2-3 cm depth) and do not erase A-lines. They are found in about 80% of normal lung images and have no clinical significance so far [19].

ELEMENTS OF AN ABNORMAL LUNG IMAGE

The presence of at least 3 B-lines in the same intercostal space is referred to as interstitial syndrome. When the distance between these lines is less than 3 mm, alveolar-interstitial syndrome is diagnosed [20]. When B-lines merge with each other without normal spaces between them, the term "white lung" is used. One of the most common pathologies is consolidation. It is a subpleural, liver-like, hypoechogenic area with an uneven outline. There are usually also some additional features, like absence of A-lines and pleural line in the area of consolidation, some B-lines around it, comet-tail artifacts arising from the deep end of consolidation, or air bronchogram (hyperechoic tree-like brunching structures) inside consolidation.

THE USEFULNESS OF LUS IN SELECTED RESPIRATORY CONDITIONS IN CHILDREN

PNEUMONIA

Community-acquired pneumonia (CAP) is one of the most common causes of hospitalisation among children. The diagnosis of CAP is usually based on clinical symptoms, with imaging diagnosis recommended only in the case of doubt or suspected complications. LUS seems to be a better diagnostic imaging method than chest radiography due to the aforementioned advantages and higher sensitivity and specificity [15, 21-25], which,

however, is still not reflected in international guidelines. The ultrasound image correlates with the radiological and anatomical classification of pneumonia. In lobar or segmental pneumonia, large (> 1 cm) consolidations are detectable, with visible air (Figure 2) and/or fluid bronchograms. Peribronchial lesions usually appear as several small (< 1 cm) consolidations surrounded by an interstitial or alveolar-interstitial syndrome [18]. In contrast, no consolidations, but only interstitial or alveolar-interstitial syndromes (Figure 3), usually in one location, are found in interstitial pneumonia.

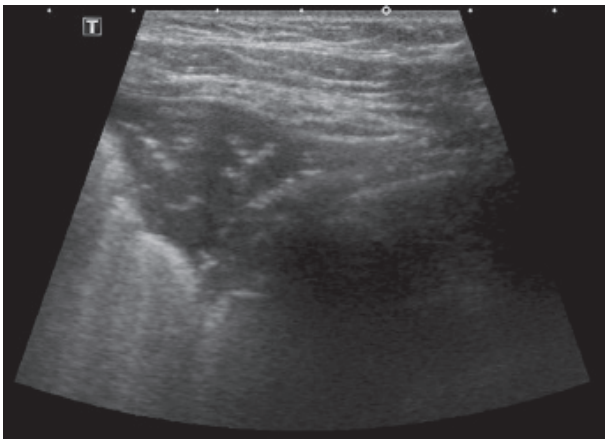

FIGURE 2. Pneumonia. Consolidation with air bronchogram

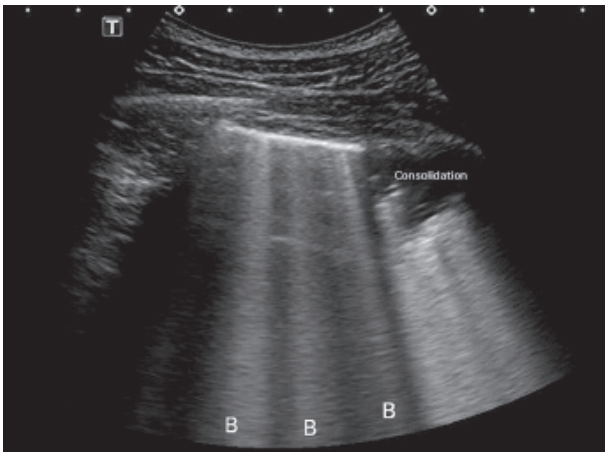

FIGURE 3. Interstitial syndrome

BRONCHIOLITIS

Imaging methods are not needed for the diagnosis of bronchiolitis. However, in the case of diagnostic doubts, LUS can be performed to assess the prognosis and monitor the course of treatment [21, 26]. The presence of bilateral lesions, such as small consolidations, multiple B-lines, changes in the pleural line, or a small amount of pleural fluid in LUS correlates with the clinical picture [27, 28]. As with pneumonia, LUS is safer than chest radiography and provides the clinician with more information about the course of the disease; also, the number of ultrasound lesions correlates with the severity of the disease [29-32]. A normal ultrasound image can be obtained in the case of mild bronchiolitis.

PNEUMOTHORAX

Despite the apparent ultrasonographic similarity of a normal lung and pneumothorax (which is due to the presence of air), this diagnosis can be made with 100% specificity if typical findings are detected [33]. When pneumothorax is present, there is an area of the anterior chest wall with no sliding sign or B-lines, and there can be seen a transition point between normal lung surface and pneumothorax, known as the lung point, with the patient in a supine position. Barcode pattern is present in M-mode instead of seashore sign [34].

PLEURAL FLUID

Ultrasound imaging of the pleural fluid was used much earlier than scientists and practitioners began to be interested in the LUS assessment of other chest structures [35]. In the case of uncomplicated parapneumonic pleural effusions (or uninfected effusion of different aetiology), an anechoic or hypoechoic space is visible between the pleural line and the chest wall or diaphragm above the liver or spleen [36, 37]. The fluid moves with different phases of breathing. Complicated parapneumonic effusion and empyema are seen as a space with higher echogenicity, without color Doppler vascularisation (which distinguishes it from consolidation), and with visible single strands of fibrin or septa forming chambers (Figure 4). Ultrasonography is an important tool for finding the optimal puncture site (which is safe when there is 10 mm or more fluid separation) and/or in qualifying for surgical treatment [38].

COVID-19

SARS-CoV-2 virus infections have become a serious public health problem and a major health threat globally since 2019. Children, who usually develop mild symptoms, have been affected by this disease to a lesser extent. LUS turned out to be a good alternative to other imaging tools in children requiring hospitalisation due to COVID-19, not only because of the advantages mentioned above, but also due to the point-of-care option. Bedside ultrasonography reduces the risk of contamination of the radiology suites, the need for their disinfection, and the risk of infection for medical personnel. The ultrasound image is similar to those in other types of viral pneumonia – pleural irregularities, B-lines, and subpleural consolidations can be observed [39-41].

OTHER

An ultrasound transducer can also visualise such pathologies as neoplastic lesions, pulmonary embolism, pul-

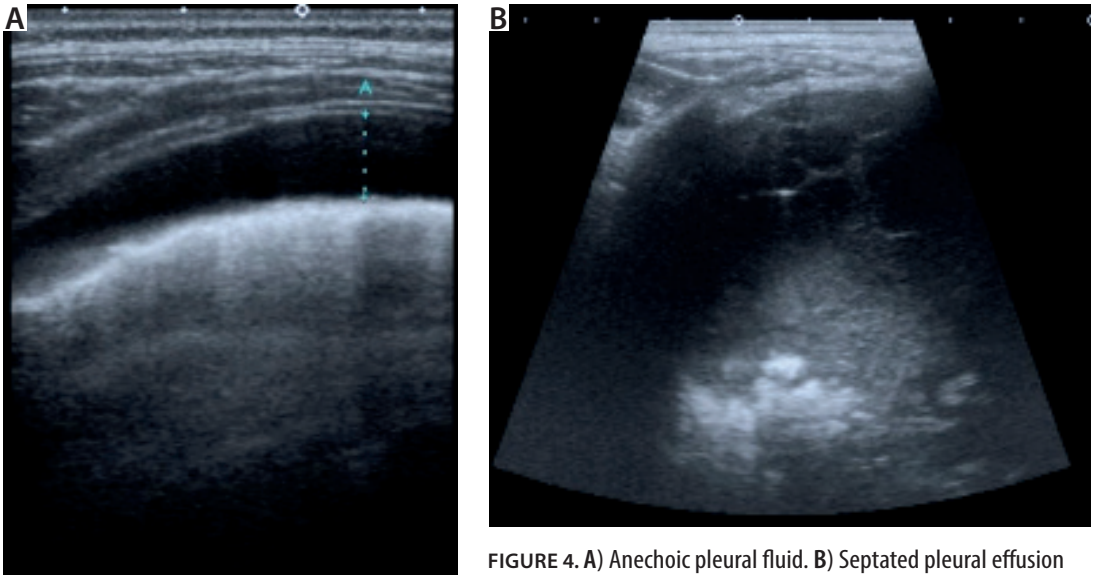

FIGURE 4. **A**) Anechoic pleural fluid. **B**) Septated pleural effusion

monary oedema, necrosis, lung abscess, some respiratory congenital abnormalities, and impaired diaphragm mobility. Although there are only sparse studies on the diagnostic imaging of these lesions in the paediatric population due to their rarity, they should be considered in the differential diagnosis after obtaining an abnormal lung ultrasound image.

FUTURE

LUS is relatively repeatable and easy to perform and interpret; therefore, attempts are being made to develop mechanisms that will allow for automatic interpretation of images. A combination of algorithms detecting specific image patterns (e.g. consolidations, interstitial syndromes) and neural networks may provide support for the operator performing the scan in the future [42, 43].

CONCLUSIONS

Currently, LUS is increasingly used as a diagnostic method in the paediatric population. There is a growing amount of evidence supporting its role in diagnosing chest diseases. It should be expected that soon it will become the primary tool in the diagnosis and follow-up of treatment outcomes in children with lower respiratory tract diseases. However, there is still need of further LUS paediatric research.

DISCLOSURE

The authors declare no conflict of interest.

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