Lung ultrasound for severe acute dyspnea evaluation in critical care patients

Značaj ultrazvuka pluća u proceni etiologije teške akutne dispneje kod bolesnika u jedinicama intenzivne nege

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Introduction

Acute dyspnea is a very common cause of hospitalisation, especially in intensive care units, and it can be precipitated by heart failure, exacerbation of chronic obstructive pulmonary disease, pulmonary embolism, pleural effusions and many other causes. The differentiation of cardiac from non-cardiac causes of dyspnoea poses a huge clinical challenge, since an accurately established diagnosis is the precondition for an adequate therapy, as well as for disease prognosis [1].

Lung ultrasound exam in intensive care unit patients

Chest radiography (RTG) is used as a regular diagnostic procedure for most patients in intensive care units. It involves the use of a portable X-ray device, which produces limited quality images, especially in recumbent patients. Another option for evaluating lung conditions is computed tomography (CT), which entails the transportation of patients, who are often dependent on mechanical ventilation, and their exposure to strong doses of ionising radiation.

Ultrasound diagnostics is commonly employed for intensive care patients, especially echocardiography, abdominal and vascular ultrasound. Air-filled organs, such as the lung, reflect ultrasound waves badly, which has led to lungs being excluded from the ultrasound diagnostics repertoire. The only structure visible in healthy lungs is the pleura, which is visualised as a hyperechoic horizontal line, moving synchronously with the lung during respiration. Conversely to healthy lungs, in pathological conditions such as pneumonia, heart failure, acute respiratory distress syndrome (ARDS), pulmonary fibrosis and others, the volume of air in the lungs decreases, which leads to the appearance of various images (artefacts), based on which the pathological process is diagnosed [2, 3].

Chest ultrasound enables relatively easy and quick detection and diagnosis of various lung abnormalities, more reliably than radiography. Moreover, the examination is inexpensive, infinitely repeatable and it is conducted at the bedside with a portable ultrasound device. As a result, patients are spared from being exposed to ionising radiation, or to contrast dye potentially damaging to the kidneys, from allergies and transportation to remote hospital wards for CT scans. Despite all of these advantages, ultrasound-based diagnostics of lung diseases is still not sufficiently employed in intensive care units, except for detection of pleural effusions. One of the possible reasons for that could be found in the required training of physicians, which takes several months, since the image quality and, consequently, the diagnosis strongly depend on the experience of a person performing the scan [4, 5].

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Lung ultrasound in decompensated heart failure

In patients with heart failure, fluids are typically accumulated in the lungs and the most common sign of this in an ultrasound scan is the appearance of B-lines (Figure 1). They are long, vertical, hyperechoic lines shaped like sun rays or comet tails. They extend from the pleura towards the inside of the lung and they move synchronously with respiration, i.e. with lung sliding. B-lines erase the physiological A-lines – bright echogenic lines, about 2 cm long, which run parallel to the pleura and indicate normal lung structure [6, 7].
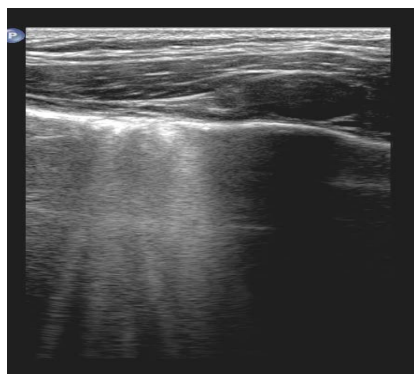

Fig. 1 – Lung ultrasound of a patient with dilated cardiomyopathy and pulmonary oedema. One field of view shows at least 3 B-lines, spreading throughout the lung, while the distance between them is decreased to 3 mm, or they fuse together.

B-lines appear as the consequence of accumulated fluid in the interstitial space, i.e. in interlobular septa. The distance between them is about 7 mm, which is the normal distance between interlobular septa. They correspond to Kerley's B-lines visible in the chest X-ray associated to heart failure, i.e. horizontal lines at the lung periphery, which also indicate interlobular septal thickening (Figure 2).
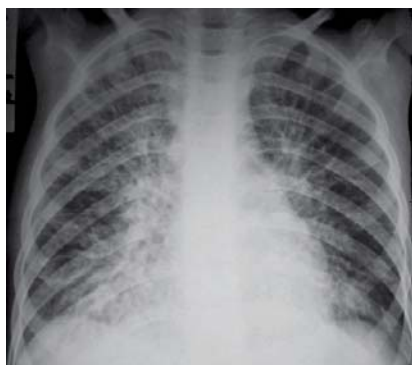

Fig. 2 – Chest radiograph of the same patient, showing Kerley's B-lines – short horizontal lines at the lung periphery, caused by interlobular septal thickening.

The number of B-lines is proportional to the degree of pulmonary congestion. Occasionally, they can also be seen in healthy lungs, two B-lines in one field of view at the most, usually at the bases of the lungs. In pulmonary oedema – the most severe form of heart failure, B-lines are multiple, extending throughout the entire lungs, with the distance between them shrinking from 7 mm to 3 mm, or they fuse

together. B-lines are very reliable in diagnosing pulmonary oedema – equally reliable as the brain natriuretic peptide (BNP). In addition, B-lines are a significant indicator of heart therapy failure, since they disappear very shortly after the use of diuretics or after haemodialysis [8, 9].

For establishing a differential diagnosis of pulmonary oedema from pneumonia or ARDS, in which B-lines also appear, the differentiating indicator is pleural sliding, i.e. the sliding of the parietal and visceral pleural layers against each other during respiration, which is not detected in other diseases. In the conditions of heart failure, there is pleural effusion, usually posterolateral, which cannot be detected by radiography in its early stages, i.e. when its volume is smaller than 100 mL, whereas it is fairly easily identifiable by ultrasound [10].

The appearance of B-lines is very important for a differential diagnosis of dyspnoea, i.e. for distinguishing heart failure from chronic obstructive pulmonary disease (COPD), in which there are no B-lines. These artefacts can also be used for prognosis purposes – stress test called "alveolar-capillary stress echo" refers to monitoring the appearance of B-lines during stress, which effectively assesses the left ventricular systolic function. The appearance of B-lines that were absent before the test indicates a serious disorder of the systolic or diastolic function of the myocardium, as well as very substantial heart valve abnormalities, and calls for immediate intervention [11].

Lung ultrasound in chronic obstructive pulmonary disease (COPD)

The second most common cause of acute dyspnoea in intensive care units is COPD. Lung ultrasonography reveals only A-lines, which are part of a normal ultrasound finding, as well as the usual pleural sliding, with no B-lines or other artefacts [12]. Apparently, ultrasonography of COPD patients produces practically normal findings (Figure 3).

Fig. 3 – Chest ultrasound of a patient with cronic opstructive pulmonary disease (COPD). The scan shows normal A-lines; pleural layers are sliding over each other; there are no B-lines.

Ultrasound evaluation of pneumonia

Ultrasound diagnosing of pneumonia is based on the two types of criteria, parenchymal and pleural.

Parenchymal abnormalities occur due to the inflow of fluid into alveoli as the result of the inflammation process, leading to the decrease of the content of air in them, i.e. to consolidation. As the result, lung tissue resembles the liver and this phenomenon is known as "lung hepatisation" (Figure 4).
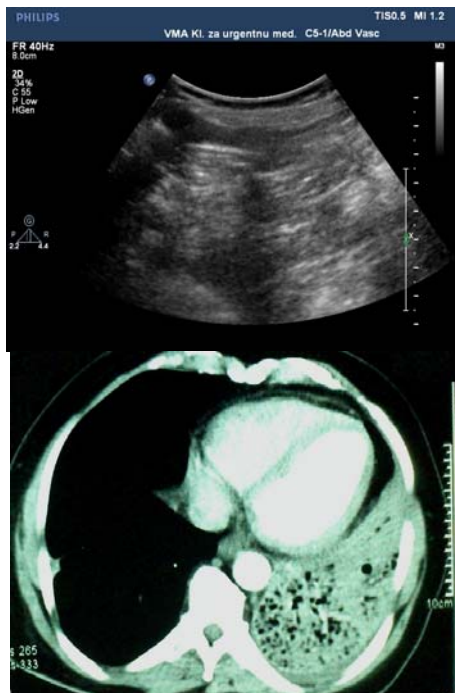

Fig. 4 – Pneumonia – parenchymal abnormalities in chest ultrasound and computed tomography (CT) scan: images reveal consolidation (alveoli are filled with fluid), as well as hepatisation – the lungs look like the liver; B-lines are visible in the inflammation area.

B-lines can be seen in the inflammation area, localised in one part of the lung, as opposed to pulmonary oedema, where B-lines are diffused. Sometimes it is possible to detect the "lung pulse", i.e. the transfer of heart contractions on the lungs due to lung parenchyma consolidation [13, 14]. The scan may also show the "air bronchogram", i.e. the bronchial walls have thick end, so the bronchi are visualised as branching white lines in the longitudinal section, or as lentil-sized hyperechoic circles of few millimetres in diameter in the transverse section (Figure 5).

Fig. 5 – "Air bronchogram" – thickened bronchial walls in longitudinal and transverse sections (hyperechoic circles and lines).

Pleural abnormalities include the occurrence of pleural effusions. Sometimes the amount of fluid in the pleural space is so large that one gets the impression that lung tissue is swimming in the effusion. The pleura is inflamed, thickened and missing one of the key features of healthy lungs – the sliding of the parietal over the visceral pleura during respiration [15].

Ultrasound in diagnosing pneumothorax

In intensive care units, pneumothorax is most commonly detected among patients with lung injury or as the complication of subclavian vein puncture for administration of parenteral therapy (Figure 6). Thoracic ultrasound has the same sensitivity as CT in diagnosing pneumothorax (95%), while RTG sensitivity is much smaller (75%). Examination is conducted with a high-frequency linear transducer, positioned in the third or fourth intercostal space bilaterally, along the midclavicular line, since pleural air collects in the nondependent zones of the lung. Scanning is continued laterally along the anterior or midaxillary lines because of the possibility of partial pneumothorax [16].
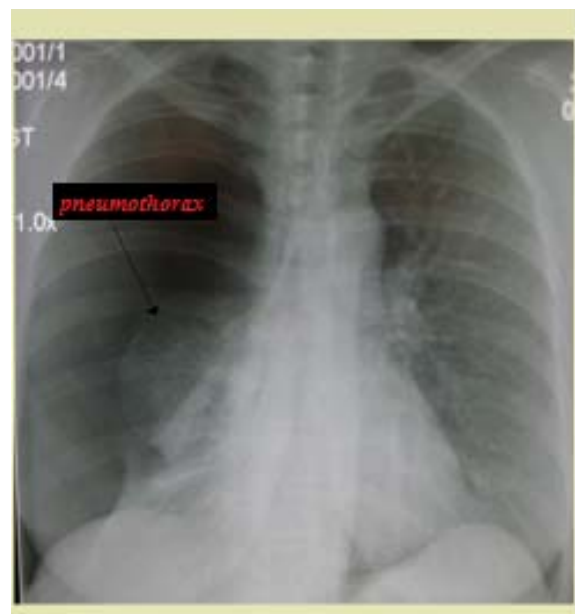

Fig. 6 – Chest and heart RTG – pneumothorax. The right lung has collapsed as a result of pleural air.

It is indicative that there is no lung sliding, i.e. the movement of the visceral and parietal pleura. A-lines are visible just as in the scan of healthy lung tissue. There are no B-lines whatsoever, since the parietal and visceral pleural layers are divided by air, while the presence of a single B-line, as well as of lung sliding, rules out the possibility of pneumothorax.

The M-mode scan produces the "stratosphere sign", i.e. horizontal lines appear both above and below the pleura, resulting from ultrasound reverberation due to the presence of pleural air. Another specific sign of pneumothorax is the "lung point", which refers to the transition point between the normal lung pattern and pneumothorax [17]. At this point, in a two-dimensional image, lung sliding alternates with the absence of lung sliding (Figure 7).
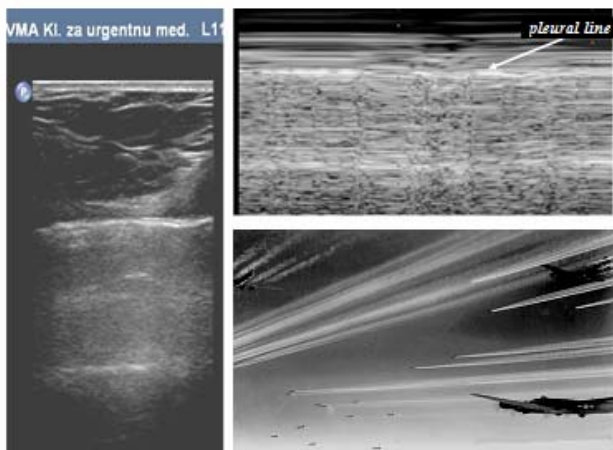
Fig. 7 – Pneumothorax diagnosed by ultrasound the two-dimensional image on the left shows A-lines, with no lung sliding or B-lines. On the right, the M-mode shows the "stratosphere sign" or the "barcode sign" – horizontal lines under the pleura, as a result of the presence of air in the pleural space.

Ultrasound in diagnosing acute respiratory distress syndrome

Acute respiratory distress syndrome is a severe inflammatory lung condition that leads to diffuse damages to alveolar epithelium and vascular endothelium, increasing their permeability, as well as to pulmonary oedema and acute hypoxia. This condition is diagnosed by lung ultrasound with 98% sensitivity and 88% specificity, almost the same as in CT and much higher than in radiography.

Examination findings are quite diverse: zones dominated by B-lines alternate with areas of lung consolidation due to inflammation and atelectasis, and with zones of normal lung parenchyma (Figure 8). B-lines are diffusely distributed in the lung and are typically visible in the posterior chest, influenced by the gravity. They are caused by the interstitial oedema resulting from increased alveolar-capillary membrane permeability [18].

The pleura has thickened to more than 2 mm, it is irregular, and there are zones of subpleural lung consolidation. The occurrence of pleural effusions is very frequent. Lung sliding is missing, as is the lung pulse, which is a very indicative sign.

It is very important to differentiate ARDS from cardiogenic pulmonary oedema. Diffuse B-lines are visible in both of these conditions; in ARDS, however, B-lines alternate with zones of lung consolidation and zones of normal lung tissue. In addition, the pleura in ARDS thickens and the sliding of its layers cannot be perceived, whereas these signs are absent in heart failure. Moreover, in left ventricular insufficiency, effusions are more frequent and usually larger [19].

Lung ultrasound in diagnosing pleural effusions and in guiding thoracentesis

A typical indication for thoracic ultrasonography is pleural effusion. Under the influence of gravity, fluid collects in lower and posterior regions of the lung, so these zones should certainly be scanned during an examination. When a patient is in supine position, a low-frequency (cardiac or abdominal) transducer is placed on the posterior axillary line, above the diaphragm, with the orientation marker pointed cephalad. The scan usually starts from the diaphragm upwards.

Ultrasound allows us to distinguish effusions from elevated diaphragm, tumour, atelectasis or consolidated lung parenchyma, which is sometimes unfeasible through chest X-ray or auscultation. This examination has multiple benefits: pleural effusion diagnosis; effusion volume assessment; provisional identification of the content of effusion; ultrasound can be used as guidance in pleural puncture [20].

Pleural effusion is visualised as a hypoechoic or anechoic space between the two pleural layers, often with a zone of lung consolidation visible underneath it – atelectasis, resulting from compressive effect of effusion and disappearing if effusion is evacuated. If effusion is small, it is the consequence of the pathological process in the lungs (inflammation, tumour) and the

Fig. 8 – Acute respiratory distress syndrome (ARDS) – chest radiograph on the left and ultrasound on the right: consolidation zones alternating with zones of normal lung parenchyma and zones with fluid in the interstitial tissue.

consolidation zone also remains after the pleural puncture. If the pleura and the effusion are scanned in M-mode, the resulting image shows the "sinusoid sign", i.e. the undulating movement of the visceral pleura and the lung during respiration (Figure 9).
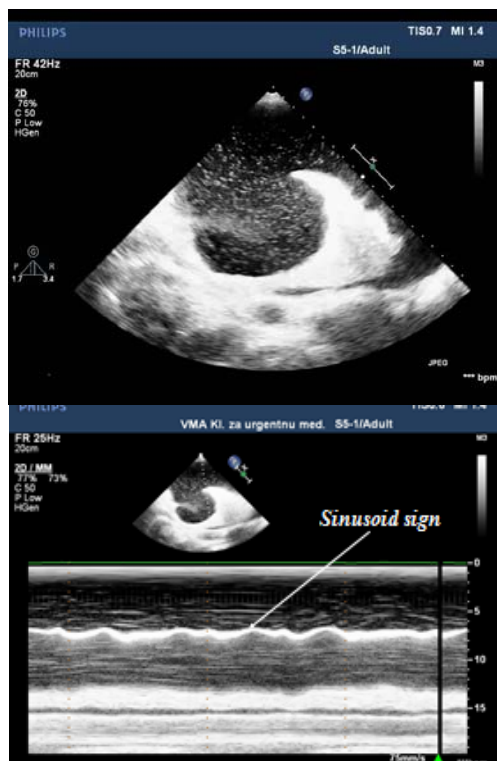

Fig. 9 – Pleural effusion: above is a twodimensional image showing compressive atelectasis of the lung; bellow is an M-mode image showing the "sinusoid sign", i.e. the undulating movement of the lung and visceral pleura.

Ultrasonography enables differentiation between different types of effusions: transudate is visualised as an anechoic, dark, homogeneous space; exudate generates a stronger reflection, it is heterogeneous, fibrinous, often with visible pleural septa creating pockets; hemothorax has a strong reflection, it is heterogeneous and often contains small pieces of tissue, although it may also be anechoic if it is of recent onset.

Ultrasound can be used as a guide in thoracentesis, especially in cases where puncture was previously unsuccessful. It is convenient because it prevents injury of the liver on the right side, or the spleen and kidneys on the left side, while the patient is sitting or in semi-recumbent position. The thickness of the effusion needs to be at least 1 cm for a pleural puncture, and it is made at the point where the effusion is thickets [21,22].

Conclusion

Lung ultrasound is a new domain of ultrasound-based diagnostics, which has gained popularity in the past 15 years. The key aspect in the development of this technique is the detection of abnormalities in lung parenchyma, in addition to its traditional use for diagnosing and evacuating pleural effusions. It is exceptionally useful in intensive care units for differentiating cardiogenic pulmonary oedema from acute lung conditions such as acute repiratory distress syndrome, pneumonia, chronic obstructive pulmonary disease, pneumothorax and pulmonary embolism. Examination is done at the bedside, using a minimum of equipment; it is simple, harmless and inexpensive. In the future, thoracic ultrasonography may also find application in other areas including cardiology, pulmonology, dialysis, or as part of the out-of-hospital emergency medical service.

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