REVIEW ARTICLE / PREGLEDNI ČLANAK

ULTRASOUND IN EMERGENCY MEDICINE

ULTRAZVUK U HITNOJ MEDICINI

***Radonić R.[1]**

Abstract

Ultrasound is increasingly becoming an indispensable method and a fundamental tool in emergency medicine as it allows direct visualization of organs and organ systems, providing the attending physician with a better understanding of the patient's pathophysiological processes compared to relying solely on history and physical examination.

Key words: ultrasound, emergency medicine, point-of-care ultrasound (POCUS)

Sažetak

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Ultrazvuk sve više postaje neizostavna metoda i osnovni alat u hitnoj medicini budući da omogućava izravnu vizualizaciju organa i organskih sustava, te liječniku koji zbrinjava hitnog bolesnika omogućava kvalitetniji uvid u patofiziološke procese bolesnika, nego što bi bilo samo na temelju anamneze i fizikalnog pregleda.

Ključne riječi: ultrazvuk, hitna medicina, ultrazvuk uz krevet bolesnika (od engl. point-of-care ultrasound, POCUS)

1 Department for Intensive Care Medicine, Division for Internal Medicine, University Hospital Zagreb, Kišpatićeva 12, 10000 Zagreb, Croatia

* Corresponding author:

Radovan Radonić, MD, PhD
Department for Intensive Care Medicine, Division for Internal Medicine
University Hospital Zagreb, Kišpatićeva 12, 10000 Zagreb, Croatia
e-mail: rradonic@gmail.com

Radovan Radonic
ID: 0000-0002-3147-9160

Introduction

Ultrasound enables visualization of the body's interior, thus providing insight into the morphology and function of internal organs. Unlike radiological methods, it does not involve ionizing radiation, and examinations can be conducted without harmful side effects for either the patient or the examiner. Portable compact devices make it accessible at the examination site, including pre-hospital emergency medicine. In the hands of a trained emergency physician, ultrasound offers immediate and valuable information about the patient, facilitating a quicker and more accurate assessment of their condition, guiding further diagnostics and treatment.

Ultrasound entered emergency medicine through targeted partial training for emergency physicians in ultrasound use, with protocols developed for specific situations. One of the first such protocols is the FAST protocol, designed for trauma patients at risk of internal bleeding, requiring immediate surgical intervention (1-10). Waiting for a specialist qualified in ultrasound examination can delay intervention, jeopardizing the patient's health and life. Free fluid in body cavities lined with serosa accumulates in typical locations and, if present, is easy to identify via ultrasound. Training physicians to perform the FAST protocol accelerates the identification of internal bleeding. Other ultrasound examination protocols, such as RUSH and BLUE, have also been developed for specific emergencies (11,12).

However, we advocate a holistic approach to ultrasound use in emergency medicine, encompassing basic-level whole-body ultrasound tailored to the clinical scenario. This involves using ultrasound to address clinical questions arising during patient management. Such examinations are a logical extension of the clinical evaluation of emergency patients, where the sequence and thoroughness are adapted to the situation and time constraints. Typically, this includes a rapid lung assessment, focused cardiac examination, evaluation of circulatory system volume status by assesment of inferior vena cava diameter, a quick abdominal examination including the abdominal organs, kidneys, abdominal aorta, and other structures. Diagnosing venous thrombosis is also a frequent clinical question in emergency medicine that ultrasound can address. Data obtained are immediately integrated into the clinical reasoning process, and existing patient information can sometimes aid in interpreting ultrasound findings. Ultrasound is also highly useful for performing certain invasive procedures.

> Professional societies support clinician-performed ultrasound by developing guidelines and providing structured education. Ultrasound training is now integrated into medical school curricula and is a mandatory part of specialty training in emergency medicine and other fields.

French intensivist Daniel Lichtenstein significantly contributed to this field, conceptualizing principles of "visual medicine" based on ultrasound's role in clinical patient management (13). The development of this field has also been driven by the WINFOCUS organization, which has structured education suitable for emergency ultrasound use and developed a network of training centers offering licensed courses for clinicians worldwide, including in Croatia (14). National and international professional societies recognize the benefits of clinician-performed ultrasound and contribute by proposing guidelines and organizing structured education (15). Ultrasound training for clinicians is increasingly integrated into medical school curricula and has become a mandatory component of specialty training in emergency medicine and other clinical disciplines (16).

Although ultrasound is a relatively simple diagnostic method that clinicians can master, it is essential to distinguish between comprehensive ultrasound examinations by highly trained sonographers under optimal conditions and emergency ultrasound by clinicians with basic short-term training performed under time constraints, suboptimal conditions, based only on visual impressions, without measurements. Awareness of the method's limitations and one's competencies is crucial, using ultrasound as an aid in clinical reasoning in emergency medicine. Ultrasound findings should be verified with consultative examinations or complementary methods when reliability is in question. Initial doubts about one's competence should not hinder the use of ultrasound, even during early learning phases, provided critical judgment is applied in decision-making based on ultrasound findings.

Lung Ultrasound

Daniel Lichtenstein's most significant scientific contribution lies in the development of the concept of lung ultrasound, a groundbreaking advancement that has revolutionised bedside diagnostic approaches and expanded the role of ultrasound in medicine. Beyond classical applications such as diagnosing pleural effusions and lung consolidation, this approach allows the identification of other pathological processes in the lungs (17-20).

Lungs contain air, a medium with acoustic properties vastly different from soft tissues, making it impossible to visualize the structure of lung parenchyma. However, conclusions about pathological processes in the lung parenchyma can be drawn based on artefacts originating from the lung surface. Essentially, two simple questions need to be answered: whether pleural line sliding is observed and whether reverberation artefacts in the form of A-lines or B-lines are present. Based on the combination of findings, the aetiology of acute dyspnoea can be correctly identified in 90% of cases using ultrasound alone (12).

A normal lung finding includes pleural line sliding synchronously with breathing and the presence of A-lines. A-lines are hyperechoic artefacts, parallel to the pleural line, equidistant from it and from each other, corresponding to the thickness of the thoracic wall. They result from multiple reflections of the ultrasound wave between the air-filled lung surface and the ultrasound probe. A shift in the air-to-liquid ratio in the lungs favouring liquid can disrupt the continuity of air on the lung surface. This disruption reduces the surface's "ultrasound mirror" effect, locally preventing reflection and reverberation of ultrasound waves between the lung surface and the probe. Instead, the ultrasound wave penetrates beneath the pleural level into small subpleural areas with water-like acoustic characteristics. Surrounded by air, these areas reflect ultrasound waves internally, creating repeated echoes that generate B-lines on the ultrasound screen (21-24).

Conditions for the formation of B-lines usually first arise in the interlobular septa. As interstitial fluid increases, conditions for small subpleural reverberations expand. B-lines most commonly indicate an excess of extravascular lung water. The appearance of 3–4 B-lines per intercostal space, with the ultrasound probe positioned craniocaudally, suggests oedema of the interlobular septa and interstitial lung oedema, known as the B1 pattern or B1 profile. Five or more B-lines per intercostal space or confluent B-lines indicate a larger amount of interstitial fluid, suggesting partial alveolar filling with fluid. This is referred to as the B2 pattern or B2 profile.

When alveoli are completely filled with fluid, the ultrasound wave can propagate through the lung parenchyma. In cases of lung consolidation (C-pattern or C-profile), the structure of the lung parenchyma becomes visible. In addition to air bronchograms, focal changes otherwise unvisualisable in air-filled lungs, unless they are subpleural, may be visualized with ultrasound. Similar findings occur with air resorption in obstructive atelectasis. In cases of airway obstruction, diaphragmatic effort does not translate into lung expansion, resulting in the absence of pleural line sliding. Minimal pleural line movement synchronous with the pulse may be observed due to heart-induced lung motion (25). The extent of air resorption determines whether an A-pattern or B-pattern is detected with ultrasound, while complete atelectasis appears as lung consolidation. In cases of obstructive atelectasis, a static air bronchogram is observed, in contrast to the dynamic bronchogram found in conditions involving alveolar exudation (26).

.Daniel Lichtenstein's major scientific contribution is the development of lung ultrasound, which has revolutionized bedside diagnostics. This technique, beyond diagnosing pleural effusions and lung consolidation, enables the identification of various other lung pathologies.

Diffuse bilateral homogeneous B-lines are seen in patients with pulmonary oedema caused by fluid transudation from pulmonary capillaries under increased hydrostatic pressure, typically due to hypervolemia and impaired left ventricular function (23). Another cause of fluid entering the lung interstitium is increased capillary permeability at sites of inflammation. Ultrasound is superior to chest X-rays for pneumonia diagnosis (27-35). Bilateral extensive lung infiltrates are characteristic of patients with ARDS. Morphological differences between ARDS and cardiogenic pulmonary oedema can be summarised as follows: cardiogenic pulmonary oedema typically exhibits homogeneity due to uniform transudation into the lung interstitium, whereas ARDS demonstrates an inhomogeneous distribution of extravascular lung water, with preserved areas and regions of greater fluid accumulation (36). Using ultrasound, the severity of inflammatory pulmonary oedema can be semi-quantitatively assessed, aiding in monitoring ARDS patients. Dividing the lungs into regions and scoring each region based on estimated extravascular lung water allows a cumulative LUS score to evaluate therapeutic efficacy (37).

Absence of pleural line sliding, combined with its lack of movement synchronous with cardiac activity, raises suspicion of pneumothorax. Confirmation of pneumothorax requires identification of its boundary (38). When pleural line sliding is absent in the anterior chest of a supine patient, the probe is moved laterally to locate the lung point, marking the boundary of the pneumothorax. The lung point delineates the area where free air separates the pleura, causing a lack of pleural line sliding, from the zone where the lungs contact the thoracic wall, exhibiting pleural line sliding (39). This point typically shifts during the respiratory cycle as pneumothorax boundaries move with inhalation and exhalation. Its detection is 100% specific for pneumothorax as the cause of absent pleural line sliding, ruling out other conditions like obstructive atelectasis or pleural adhesion due to fibrin or connective tissue. Adding pneumothorax diagnosis to the FAST protocol is referred to as the extended FAST or e-FAST protocol.

Focused Cardiac Ultrasound

Focused cardiac ultrasound (FoCUS) involves imaging the heart in typical planes (subcostal view from the epigastrium, parasternal, and apical views), where systolic function of the left ventricle, signs of right ventricular overload (dilatation of the right ventricle with septal displacement to the left), and the presence of pericardial effusion are assessed without measurements, based on "eyeballing." The significance of a pericardial effusion is evaluated by the patient's clinical condition and by the ultrasound finding of chambers collapse (40).

Assessment of volume status based on the diameter of the inferior vena cava and its changes during the respiratory cycle may be imprecise due to multifactorial influences on its size, including the patient's breathing pattern, right ventricular function, intra-abdominal pressure, measurement errors, and other factors (41-43). Despite these limitations, it provides a better insight than clinical estimation of volume status, and findings inconsistent with clinical expectations can help provide a more comprehensive understanding of the patient and their hemodynamics. Recently, venous congestion assessment has been expanded to include Doppler analysis of flow through the hepatic and portal veins and intrarenal veins via the VExUS protocol (44).

Venous Thromboembolic Disease

Venous thromboembolic disease is a common concern in emergency medicine. Clinical symptoms of deep vein thrombosis are unreliable. Ultrasound is the diagnostic method of choice for venous thrombosis (45-47). Instead of the normal anechoic lumen of the vein, which can be fully compressed by probe pressure, venous thrombosis is identified by hyperechoic content corresponding to the thrombus. Compression testing should be performed cautiously to avoid precipitating thrombus migration, and the absence of compressibility should suffice as evidence. It is most critical to examine the veins of the thigh and popliteal region, as these are the most common sources of pulmonary embolism. The veins of the lower leg, as well as the veins of the arms, neck, and inferior vena cava, are also accessible.

Ultrasound in Shock or During Cardiopulmonary Resuscitation

In hemodynamically unstable conditions, shock, or cardiac arrest, point-of-care ultrasound can be pivotal in guiding appropriate treatment (48). Various ultrasound protocols adapted for cardiopulmonary resuscitation settings exist, including FEEL, FEER, CAUSE, PEA, and SESAME (49-54). It is crucial to ensure that ultrasound use does not compromise resuscitation procedures, with usage limited to the time designated for pulse checks in resuscitation protocols. Besides providing a more straightforward and reliable assessment of cardiac function than pulse palpation, ultrasound can identify potentially reversible causes of arrest, such as cardiac tamponade, hypovolaemia, pneumothorax, and suspected thromboembolic events.

A fundamental understanding of shock pathophysiology is essential for directing treatment effectively. Ultrasound can identify the components of the circulatory system responsible for shock, informing treatment strategies. For instance, in cardiogenic shock caused by left ventricular systolic dysfunction, fluid resuscitation is not beneficial but harmful, particularly when pulmonary congestion is present (as indicated by diffuse bilateral B-lines). In contrast, fluid resuscitation is a key treatment step in hypovolemic, septic, and some other shock states. A simple and practical ultrasound-based approach for guiding fluid resuscitation is the FALLS protocol, which suggests halting fluid resuscitation at the first appearance of diffuse B-lines in the lungs (55,56). This is especially suitable for patients with left ventricular systolic dysfunction, as fluid resuscitation is stopped upon achieving optimal left ventricular filling pressure, avoiding pulmonary oedema due to congestion. The protocol is not suitable for those with impaired right ventricular function.

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Shock caused by pulmonary embolism is accompanied by signs of acute right ventricular dilatation and an enlarged inferior vena cava. Lung findings typically show an A-line pattern due to reduced pressure in the pulmonary capillaries, resulting from compromised blood flow to the lungs. Other findings suggesting acute cardiac stress include tricuspid regurgitation, McConnell's sign, visualisation of thrombi in the right heart, early systolic notching in the right ventricular outflow tract, and more (57,58).

The finding of an abdominal aortic aneurysm in the emergency department in a patient with abdominal pain and hypovolemic shock primarily suggests a potential rupture. While the resulting retroperitoneal haematoma may or may not be clearly visible on ultrasound, directing the patient to urgent MSCT aortography will provide all necessary answers before likely urgent intervention.

Ultrasound in shock and cardiopulmonary resuscitation can also assist significantly with airway establishment, vascular access, and management of conditions such as cardiac tamponade, pneumothorax drainage, and more.

Abdominal Ultrasound

Examination of abdominal organs can be useful in the emergency department, especially in patients presenting with abdominal pain (59,60). It allows for easier and more precise assessment of liver and spleen size compared to physical examination, providing valuable information about parenchymal structure and the presence of any focal lesions. Ultrasound is the primary method for diagnosing cholelithiasis and acute cholecystitis (61-63). It can also indicate dilation of the extrahepatic and intrahepatic bile ducts. Although it is not the first-choice method for examining the gastrointestinal tract, ultrasound findings can be striking in cases of severe bowel inflammation with wall thickening and increased fluid content or in cases of ileus. Ultrasound can easily detect free abdominal fluid, which should be interpreted in the context of clinical presentation, and, if necessary, samples can be taken for analysis, facilitated by ultrasound guidance. In addition to free abdominal fluid, free air can also be identified, which may suggest gastrointestinal perforation. The use of ultrasound in diagnosing acute appendicitis requires specific expertise and is not part of the basic ultrasound examination that supplements physical examination (64).

Ultrasound enables visualisation of kidney morphology. It can reliably answer whether there is dilation of the renal collecting system. Assessment of kidney size, parenchymal thickness, and echogenicity can help determine whether the condition is acute or chronic kidney disease. The incidental discovery of a kidney tumour can be highly significant for the patient. Pelvic organ ultrasound in emergency medicine most often focuses on determining bladder fullness and the presence of free fluid in the pelvis. However, it can also aid in diagnosing pregnancy, ectopic pregnancy, determining the cause of bleeding during pregnancy, suspecting ovarian torsion, identifying pyosalpinx, detecting tumours, and more (65).

Ultrasound in Sepsis

Identifying the source of sepsis is crucial for selecting empirical antimicrobial therapy. Ultrasound can strongly suggest sinusitis, pneumonia, endocarditis, pleural empyema, suppurative pericarditis, peritonitis, cholecystitis, cholangitis, pyelonephritis, pyonephrosis, abscesses in various locations, and more (66). Targeted sampling for microbiological analysis under ultrasound guidance is beneficial. Drainage of purulent collections is essential in managing patients with sepsis and septic shock. Percutaneous aspiration and drainage of empyema and abscesses are minimally invasive and often definitive treatment methods. Even when not definitive, they can contribute to stabilising patients who require surgical intervention.

Interventional Ultrasound

The use of ultrasound to assist in various invasive procedures such as vascular access (central or peripheral), pleural puncture or drainage for effusion or pneumothorax, pericardiocentesis, or drainage of purulent collections in any part of the body is well established (67-70),(68). Ultrasound-guided methods can be categorised as in-plane and out-of-plane. The in-plane technique ensures the needle remains continuously within the ultrasound beam plane during its path to the target lesion.

There is a wide range of additional potential applications of ultrasound in emergency medicine, including musculoskeletal ultrasound for diagnosing fractures, ligament injuries, and muscle injuries, as well as ocular ultrasound, neurological ultrasound, and more.

From our experience, it is better to perform pleural punctures using plastic intravenous cannulas rather than needles prepared for this purpose in puncture kits (71). Usually, it is sufficient to use ultrasound to locate and mark the optimal puncture site, with the procedure carried out without direct ultrasound control. Puncture with a green intravenous cannula does not require local anaesthesia, whereas placing a small drain warrants the use of local anaesthetic. For mechanically ventilated patients who cannot sit upright, a thin drain is preferred, inserted from the side in a semi-recumbent position with the head of the bed elevated. Pericardial puncture is traditionally performed from the epigastrium, which is not straightforward under direct ultrasound guidance. After prior orientation, the puncture is typically performed blindly. When feasible, the preferred approach is pericardiocentesis via the intercostal route, commonly using a high-frequency probe with in-plane technique. This involves placing the probe along the intercostal space to visualise only the thoracic wall and the pericardial fluid layer (72). Ultrasound-guided regional anaesthesia nerve blocks may also be suitable in emergency care (73).

Other Applications

There is a wide range of additional potential applications of ultrasound in emergency medicine, including musculoskeletal ultrasound for diagnosing fractures, ligament injuries, and muscle injuries, as well as ocular ultrasound, neurological ultrasound, and more (74-77). The use of ultrasound in diagnosing and managing paediatric intussusception is one example of replacing conventional radiological and surgical methods with less invasive procedures that avoid ionising radiation, which should be minimised, particularly in children (78). Numerous other examples demonstrate how the use of ultrasound by emergency physicians can be enhanced beyond the basic level. The scope of effective implementation will depend on individual enthusiasm, local conditions, and needs.

Conclusion

Ultrasound is a tool that facilitates and enhances diagnostics in emergency medicine and is increasingly becoming a standard extension of clinical examination. Training in basic ultrasound applications is not demanding. Mastery of one application simplifies the use of ultrasound in others, ultimately leading to proficiency in full-body ultrasound examination. When using ultrasound, it is important to critically assess the reliability of findings and incorporate them into the logic of clinical reasoning. Complementary investigations and specialist consultations enable further verification of findings and improve the acquisition of experience in ultrasound interpretation wherever possible and appropriate.

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