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Focus ultrasound for cardiology practice. Russian consensus document

This document is a consensus document of Russian Specialists in Heart Failure, Russian Society of Cardiology, Russian Association of Specialists in Ultrasound Diagnostics in Medicine and Russian Society for the Prevention of Noncommunicable Diseases. In the document a definition of focus ultrasound is stated and discussed when it can be used in cardiology practice in Russian Federation.

Keywords Focus echocardiography; focus lung ultrasound; focus ultrasound

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Introduction

The rational use of diagnostic approaches allows timely detection of changes even in the early stages of a pathology. In this connection, ultrasound examinations have long been used in routine clinical practice in all medical specialties, including cardiology. Transthoracic echocardiography, which combines accuracy, safety and reproducibility, can be carried out multiple times without harming the patient. Moreover, it does not rely on ionizing radiation and is well balanced in terms of cost and diagnostic efficacy. By using various echocardiographic modes, it is possible to comprehensively examine heart structure and intracardiac hemodynamics [1]; the standard echocardiographic indicators have been shown to produce high diagnostic and prognostic values [2]. For many decades, echocardiographic equipment was non-mobile, with ultrasound examinations being performed only in specialized departments (laboratories): only ultrasound and func-

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tional test specialists had the necessary expertise to perform such examinations. However, with advancing technology, echocardiographic equipment has been miniaturized, allowing point-of-care ultrasound examination of the heart to be carried out in wider clinical settings, including critical and emergency situations. This provides a background for expanding the professional capabilities of clinical physicians [3]. In 2018, the new professional specialism of «Cardiologist» was approved in the Russian Federation, whose skill set competence includes not only understanding and interpreting echocardiographic data, but also performing transthoracic echocardiography [4]. However, certain contradictions remained following the approval of this professional standard. In particular, many physicians and even trainers of cardiologists continue to lack a full understanding of echocardiography. Moreover, new scientific data suggesting the possibility of carrying out ultrasound examination of the lungs for cardiac patients imply the need for additional professional development. In order to investigate the associated issues, the present consensus paper becomes necessary.

Types of ultrasound systems

Currently available ultrasound equipment offers various parameters, option sets, and diagnostic capabilities. According to GOST R 56331–2014 [5], medical ultrasound diagnostic products (also called hereinafter ultrasound systems, ultrasound devices, ultrasound equipment, ultrasound scanners) can be distinguished into mobile and portable types.

In terms of the quality of generated diagnostic information and functionality, ultrasound systems can also be divided into middle-class, high-class, and expert-class according to GOST R 56331–2014 [5]. High- and expert-class echocardiographic systems can be operated in various modes: two-dimensional (2D; B-mode), one-dimensional (motion, M-mode), Doppler pulse-wave (PW), Doppler continuous-wave (CW), color Doppler imaging (CDI), tissue Doppler imaging (TDI), speckle tracking imaging (STI), vector velocity imaging (VVI), three-dimensional (3D) or four-dimensional (4D), and transesophageal echocardiography stress echocardiography and contrast-enhanced echocardiography. Typically, such ultrasound systems have low mobility and high cost. In Russia, the equipment of this class is mainly used in ultrasound and functional diagnosis departments.

The advantages of portable ultrasound scanners are mainly in terms of their compact size (they are smaller and lighter) and higher mobility (they can be used to perform examination when it is difficult and sometimes impossible to use a permanently installed system, e.g., in operating rooms, wards, and intensive care units, as well as at point of care).

Portable echocardiographic ultrasound systems typically comprise high- or middle-class systems that allow standard transthoracic and transesophageal comprehensive examinations in B-, M-, and Doppler modes (PW Doppler, CW Doppler, CDI, TDI). While they generally lack such options as 3D or 4D echocardiography modes and consequently cannot be used for stress echocardiography or contrast-enhanced echocardiography, these options can be implemented in some portable devices. These devices have the necessary functionality to perform a comprehensive echocardiographic examination [6–8]. Unfortunately, there is currently no generally accepted standardized protocol for transthoracic echocardiography in adults approved by the Ministry of Health Care of the Russian Federation. However, several hospitals use the standardized protocol developed by the European Association of Cardiovascular Imaging (EACVI) in 2017 [7].

Portable devices can also be used for qualitative assessment in differential diagnosis with yes/no answer options in emergency situations. Since portable ultrasound systems are less expensive than their stationary equivalents, they are available to a much wider range of medical experts in routine and emergency settings surgical and mobile teams.

The smallest portable ultrasound systems are handheld devices, comprising a probe that can be connected to a smartphone and/or a tablet with or without dedicated software. Such inexpensive systems that can be conveniently carried in a pocket of a physician's gown or bag and used when needed. Handheld ultrasound systems are very easy to use and usually have only controls to adjust the scanning depth and optimize the image quality. Handheld ultrasound devices are used in brightness (B-mode) and color Doppler imaging (CDI) modes. In some systems, motion mode (M-mode) is possible only when measuring distance and area. Handheld ultrasound systems allow static and dynamic images to be saved in various formats. The acquired data can be exported to a picture archiving and communication system (PACS) or to an external workstation for subsequent archiving and analysis. Despite existing limitations, the real-time scanning and acceptable image quality allows specific clinical questions to be answered in most cases [9–12].

Following specialist training and passing theoretical and practical tests, portable and handheld ultrasound scanners can be applied by physicians of various specialties, including cardiologists. Ultrasound examination can be performed anywhere using handheld systems (e.g., at the point of care).

Services, institutions, and organizational units, in which portable and handheld ultrasound diagnostic systems can potentially be useful in the future (i.e., when more evidence is available, subject to special training and passing the corresponding theoretical and practical tests) include:

- General practice [13];
- Ambulance [14; 15];
- Emergency rooms [16; 17];
- Intensive care units [18];
- First aid posts [19];
- Air ambulance [14; 20];
- Medical aid posts at sports facilities [21];
- Medical schools [22].

It is essential to understand the capabilities, limitations, and availability of ultrasound systems of different classes, as well as the optimal placement locations and categories of employees who may access them subject to special training and passing theoretical and practical tests. It is also essential to clearly understand what types of examination can be performed using this equipment in terms of the aims of such examinations.

Types of transthoracic echocardiographic examinations. Focused ultrasound examination

Echocardiography can be performed in emergency and scheduled care settings [23, 24]. There are many different classifications of echocardiographic examinations in different countries, which depend on their aims and protocols. The following are the basic concepts explained to understand the place of focused ultrasound examination (FoCUS):

1) Standard (comprehensive) echocardiography implies performing a complete protocol [25];
2) Targeted (limited) echocardiography is usually performed shortly after the standard examination to answer a single question (usually it concerns the process evolving). And there is no clinical reason to suspect any changes outside the area of interest [25]. A detailed analysis of this type of echocardiographic examination goes beyond the scope of this paper.
3) Focus echocardiography is a place-of-care ultrasound examination using a limited set of approaches and positions used to detect or exclude a specific disease or condition (e.g., ruling out cardiac tamponade) [25, 26].

It should be noted that both «focus» and «focused» are used in the literature. In the Russian language, the term translated as «focused ultrasound examination of the heart», while the synonymic term «focused echocardiography» is recorded in the Federal Directory of Clinical Diagnostic Examinations (FSIDI) [27] approved by the Ministry of Health Care of the Russian Federation. At the same time, the terms equivalent to «focus ultrasound examination of the heart» or «focus echocardiography» are used in the Russian scientific literature [28–30]. It should also be noted that, as well as the word «focus», which can refer to both echocardiography and ultrasound examinations of other organs, there is an abbreviation FoCUS (focus cardiac ultrasound) in the English-language literature, which is equivalent to the term «focus ultrasound examination of the heart». Therefore, the word «focus» will be used in the present paper.

Standard and targeted echocardiography carried out in emergency and scheduled care settings [23, 24] is usually performed by diagnosticians (specialists in ultrasound and functional diagnosis). Focus echocardiography, which is also carried out in emergency and scheduled care settings, can be performed by a physician of any specialty, whose professional standard skills include ultrasound examination (intensivist, cardiologist, etc.) and who has been trained to perform ultrasound examination and passed the corresponding theoretical and practical tests.

The goal of standard echocardiography is a comprehensive qualitative and quantitative assessment of the structural and functional state of the heart under the complete protocol. The examination is performed following a certain sequence using standard positions of transthoracic echocardiography and a comprehensive assessment of cardiac structure and function. The image is always synchronized with the electrocardiogram (ECG) [7]. Additional approaches, methods, and modes (contrast-enhancement, 3D and 4D modes) can be used during the examination, if necessary. The examination is usually carried out using the devices of high or expert class or, less often, portable devices. The class and type of the ultrasound scanner is also a matter of principle, which is why each echocardiographic protocol requires specifying the ultrasound scanner [23]. Regardless of its urgency (emergency or scheduled

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care), the results of the examination are put in a standard examination report, which includes several quantitative indicators and ends with a conclusion [23, 24].

Focus ultrasound examination of the heart is performed at the point of care (department, emergency room, at home, etc.) following a limited protocol without ECG synchronization, most often using a portable or handheld ultrasound system. The examination is carried out in the B-mode and CDI with a limited, specific number of positions. Typically, a qualitative assessment is performed with yes/no answers [26, 31]. The focus protocol is compact and brief, describing the main pathological changes or their absence to answer a specific question. The main goal of the examination is to identify significant syndromes (e.g., dilatation of the left or right chambers, hypovolemia, pathological blood flow, etc.) or perform differential diagnosis of large groups of diseases or syndromes with yes/no answers. The method can be separately used to perform fast procedures under ultrasound control [32].

Focus echocardiography comprises an examination used to make a decision or an additional examination for physical examination or accompanying a medical procedure [18, 33]. Given the lack of a regulatory framework defining the duration of the training, levels of theoretical knowledge and practical skills, the form of tests, audit, responsibility for errors, and many other important issues, it does not require professional re-training in ultrasound or functional diagnosis

While handheld ultrasound systems can be used for focus echocardiographic examination, these are only designed for focus examinations and never used for the standard ultrasound examination of the heart. The focus protocol can be implemented using other types of ultrasound scanners. The expected benefits and the perspective of using focus examination in routine work are quick diagnosis and treatment modification, contributing to improved quality of care. However, it should be kept in mind that focus ultrasound examination of the heart cannot replace standard echocardiography. A comparative assessment of the standard and focus echocardiographic examinations is provided in Table 1.

General principles of focus echocardiography

Depending on the clinical situation, the same echocardiographic approaches should be used for focus echocardiography as for the standard examination [6, 7]:

- Left ventricular (LV) parasternal long-axis view;
- LV parasternal short-axis view at the heart base level (focus on the aortic valve);
- LV parasternal short-axis view (at the mitral valve level, at the level of the papillary muscles, at the apex level);
- Apical four-chamber view;
- Apical two-chamber view;
- Subcostal inferior vena cava (IVC) long-axis view;
- Subcostal four-chamber view.

The standard views are shown in Figure 1.

LV parasternal long-axis view allows visualizing and evaluating:

- Dimensions of the root and upper tubular segment of the ascending aorta;
- State and motion of the aortic valve leaflets, presence of pathological structures on the leaflets;
- Aortic regurgitation (qualitative assessment), including the presence, severity, and direction of the regurgitation jet;
- State and motion of the mitral valve leaflets, presence of pathological formations on the mitral valve leaflets;
- Mitral regurgitation (qualitative assessment), including the presence, severity, and direction of the regurgitation jets;
- Anteroposterior linear dimension of the left atrium (LA);
- LV end-diastolic and end-systolic linear dimensions;
- Proximal diameter of the right ventricular (RV) outflow tract;
- The thickness of the basal and middle parts of the anterior interventricular septum (IVS), motion of these segments;
- The thickness of the basal and middle parts of the posterior (inferolateral) LV wall, motion of these segments;
- State of the pericardium.

LV parasternal short-axis view at the heart base level (focus on the aortic valve) allows visualizing and assessing:

- State, motion and number of the aortic valve leaflets, presence of pathological structures on the leaflets;
- Proximal and distal dimensions of the RV outflow tract;
- State and diameter of the main pulmonary artery;

Table 1. Comparative assessment of standard and focus echocardiographic examinations

Signs	Focus echocardiography	Standard echocardiography
Where performed	At the point of care, at the patient's bedside	Offices and departments of ultrasound and functional diagnosis, emergency situations – at the point of care, at the patient's bedside
Performed by	Medical specialist (intensivist, cardiologist, etc.) who underwent training and passed theoretical and practical tests	Specialist in ultrasound/ functional diagnosis
Goal/protocol	Limited examination (mainly differential diagnosis of acute conditions)/decision-making protocol	Comprehensive assessment of the structural and functional state of the heart/standard (complete) protocol
Range of tasks	Narrow	Wide
Who makes the clinical decision after the examination?	Physician who performed focus echocardiography	Physician who referred the patient to standard echocardiography
Probes/Modes	Sector ± linear (convex) probes/ modes are determined by the examination protocol	All necessary probes and modes
Measurements	Required scope	Comprehensive
Data storage	If possible	Always
Conclusion	Made by the physician who performed the examination in the inpatient/outpatient medical record, or using a separate special form adopted in a medical facility for focus ultrasound examinations	Specialist in ultrasound/functional diagnosis by making a protocol ending with a conclusion according to the form validated by the regulatory documents of the Ministry of Health Care of the Russian Federation [23, 24]
Mobility of the equipment in use	High	Low

- State and motion of the pulmonary and tricuspid valve leaflets (there is no view showing the entire tricuspid valve), presence of pathological structures on the leaflets;
- Pulmonary and tricuspid regurgitation (qualitative assessment);
- Presence of the pathological communication/blood flow between the aorta and the main pulmonary artery, between the heart chambers.

Parasternal LV short-axis view at the mitral valve level allows visualizing and assessing the state and motion of the mitral valve leaflets.

Parasternal LV short-axis view at the papillary muscle level allows assessing the regional motion of the middle part of the LV myocardium.

Parasternal LV short-axis view at the apex level allows assessing the regional motion of the LV apex.

Apical four-chambered view allows the visualization and evaluation of:

- LV/RV dimension ratio;
- State, motion, and opening amplitude of the mitral and tricuspid valve leaflets;
- Mitral and tricuspid regurgitation, including the presence, severity, and direction of the regurgitation jets;
- Inter-chamber septa and pathological flows;
- Transverse and longitudinal LA linear dimensions;
- Movement amplitude of the mitral and tricuspid annuli (mitral annular plane systolic excursion (MAPSE), tricuspid annular plane systolic excursion (TAPSE));
- Regional motion of all parts of posterior IVS, lateral LV wall and RV free wall.

The apical two-chambered view allows the visualization and evaluation of:

- Regional movement of all parts of inferior and anterior LV walls;
- State, motion, and opening amplitude of the mitral valve leaflets;
- Presence of mitral regurgitation and the direction of regurgitation jets.

Subcostal IVC long-axis view allows visualizing and evaluating:

- IVC diameter and collapse during inspiration;

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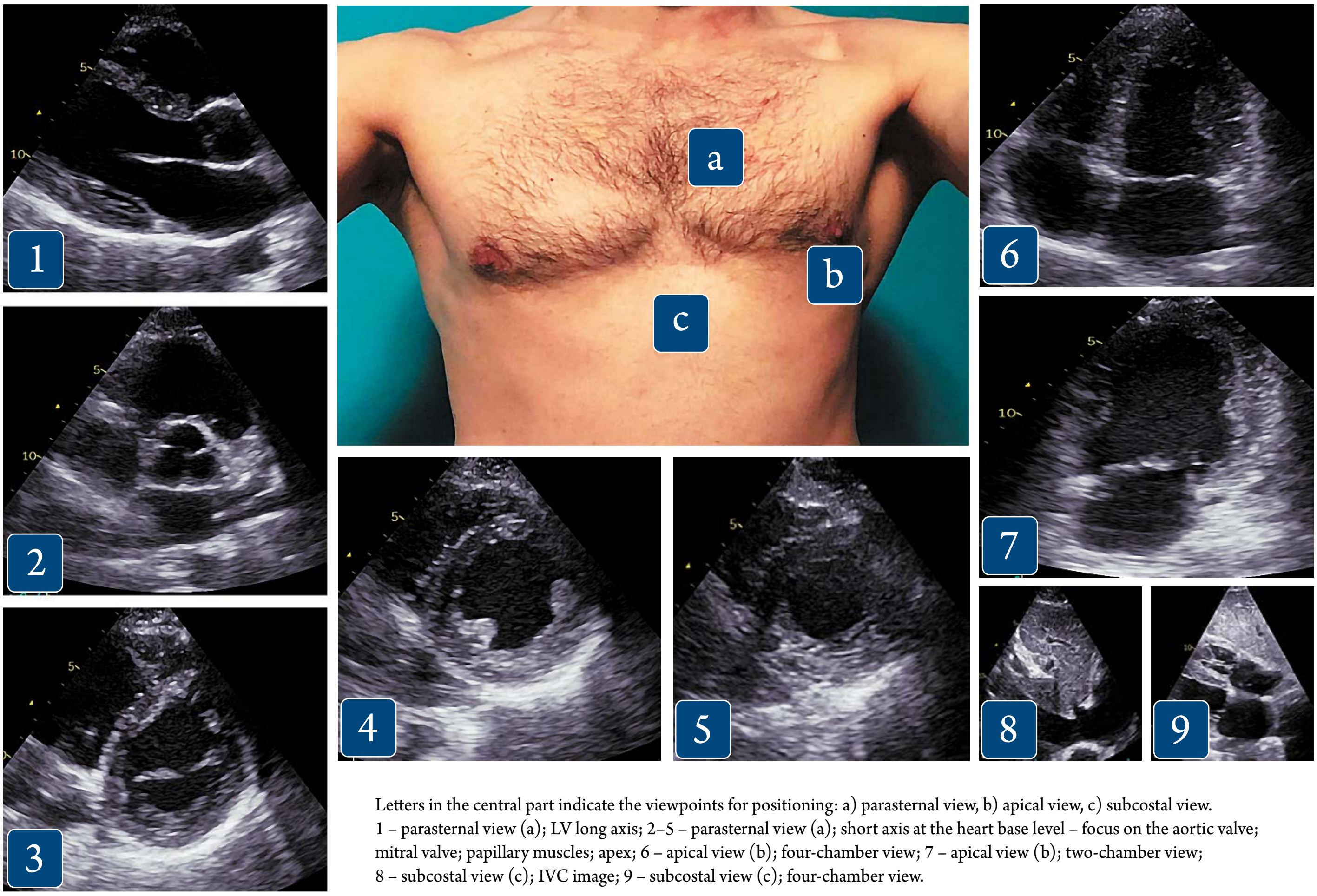
Figure 1. Positions in the focus ultrasound examination of the heart



Letters in the central part indicate the viewpoints for positioning: a) parasternal view, b) apical view, c) subcostal view.
1 – parasternal view (a); LV long axis; 2–5 – parasternal view (a); short axis at the heart base level – focus on the aortic valve; mitral valve; papillary muscles; apex; 6 – apical view (b); four-chamber view; 7 – apical view (b); two-chamber view; 8 – subcostal view (c); IVC image; 9 – subcostal view (c); four-chamber view.

- Presence of retrograde blood flow in the hepatic veins.
- Subcostal four-chamber view allows visualizing and assessing:
- State of the pericardium, the collapse of the right chambers;
- Inter-chamber septa and the pathological flows.

The examinations were mostly performed in the left lateral position, with the left hand under the head, followed by the dorsal position. The points given in Figure 1 are for a better understanding of the positions. Points 1 and 2 correspond to the left lateral position. At point 3, it is more convenient to perform the examination in the dorsal position. In some clinical situations, the patient may be obliged to assume a specific position during echocardiography, e.g., dorsal or half-sitting.

The examination scope will be determined by the clinical situation. If necessary and if a physician has the appropriate qualification, focus ultrasound examination of the lungs can be carried out in addition to focus echocardiography: assessment of B-lines and the severity of hydrothorax [34] (see Focus Ultrasound Examination of the Lungs section). If pleural fluid is detected during the focus examination of the heart, this finding should be mentioned in the conclusion.

Focus echocardiography is most commonly used to [26]:

- Assess the dimensions of the heart chambers (dilatation or decrease in dimensions), wall thickness;
- Assess LV and RV systolic function and regional wall movement;
- Determine the dimensions of the aorta and identify the signs of dissection;
- Measure large vessels (aorta, IVC);
- Detect and assess the severity of valvular regurgitation significant leaflet movement restrictions;
- Assess the presence of pericardial effusion (except for cardiac tamponade);
- Estimate volemic status;
- Identify additional intracardiac and paracardiac formations.

Timely focus ultrasound examination of the heart enables faster decision-making and more accurate diagnosis than standard clinical examination for most cardiovascular diseases; moreover, focus echocardiographic findings are well-correlated with standard echocardiography [35–39]. Nevertheless, it is important to understand that focus and standard echocardiographic examinations have different tasks. Focus examination is an addition to the clinical examination, whose main goal is to identify structural and functional disorders that explain the clinical situation or assess the changes in the previously detected pathologies.

A possible protocol of focus echocardiography is provided given in Appendix 1.

Application of focus ultrasound examinations in cardiology

It is advisable to use focus examinations of the heart and lungs for the screening of cardiac diseases as an additional clinical tool for carrying out early diagnosis and prognosis assessment, as well as helping to select the right patient management strategy. It is essential to understand this approach not only as a screening tool, but also an auxiliary technique in emergency care. Thus, while it provides the necessary information for diagnosis and immediate treatment, it cannot replace the standard echocardiography that should be performed after the focus examination, if necessary [40].

Focus echocardiography carried out in patients with clinical suspicions for congestive heart failure can be a vivid example of a continuation of physical examination for identifying some direct signs of heart disease, which significantly increases the diagnostic value of the classic symptoms and signs of fluid retention in a chronic heart failure (CHF) patient [41–44]. Focus echocardiography helps to detect chamber dilatation, wall thickness, regional movement disorders, global LV motion, reveal mitral, aortic, tricuspid, and pulmonary regurgitation, pulmonary congestion (B-lines in focus ultrasound examination of the lungs), absence of IVC collapse, etc. Razi et al. showed that a physician who had completed a short-term training (20 training examinations) was able to identify patients with reduced LV ejection fraction to allow treatment of heart failure immediately following admission [45].

Much attention has lately been paid to the detection of the so-called B-lines in the ultrasound examination of the lungs. An increased number of B-lines is typical for various interstitial changes in the lungs, including as a manifestation of congestion [40, 46]. A recent meta-analysis has shown [47] that ultrasound examination of the lungs was more sensitive in detecting pulmonary congestion than the chest x-ray. Small randomized clinical trials (LUS-HF, n=123, and CLUSTER-HF, n=126) have shown that managing severe CHF patients after discharge using ultrasound examinations of the lungs can reduce the risk of recurrent decompensated CHF [48, 49].

In atrial fibrillation, focus ultrasound examination of the heart allows determining LA dimensions and LV wall motion, which can be useful in determining patient management strategy.

In unstable patients, focus ultrasound examination of the heart provides valuable information for identifying / ruling out various pathological conditions and assessing clinical status / prognosis [10, 36]. The main task of the examination at the first stage is to perform a differential diagnosis of several conditions characterized by similar clinical symptoms but having a different management strategy (acute coronary syndrome and acute aortic syndrome in acute chest pain, pulmonary embolism, cardiac tamponade, etc.). Many protocols of focus ultrasound examination of the heart have been proposed in the literature to standardize the procedure (Appendix 2). These often include analysis of the heart and other structures.

For example, the RADiUS (Rapid Assessment of Dyspnea with UltraSound) protocol consisting of four main and one additional component can be used for the differential diagnosis of acute dyspnea if it is likely to be of cardiac origin [50]:

- Assessment of the heart (presence of pericardial effusion / tamponade; RV and LV dimensions and wall motion; signs of the right heart load).
- Assessment of IVC (diameter, inspiratory collapse).
- Assessment of the pleural space (the presence of effusion, pneumothorax).
- Assessment of the lungs.
- Exclusion of lower-extremity vein thrombosis, if necessary (additional component).

Focus ultrasound examinations of the heart and lungs should be carried out in patients with acute dyspnea and without clear cardiac history in a different sequence as a differential diagnosis between acute heart and respiratory failure (Figure 2). At the same time, ultrasound examination of the lungs in acute respiratory failure makes it possible to differentiate pneumothorax from pleural effusion [46] (see Focus Ultrasound Examination of the Lungs section).

Focus ultrasound examination can be useful in shocked patients for the diagnosis, management and monitoring of treatment efficacy. If cardiogenic

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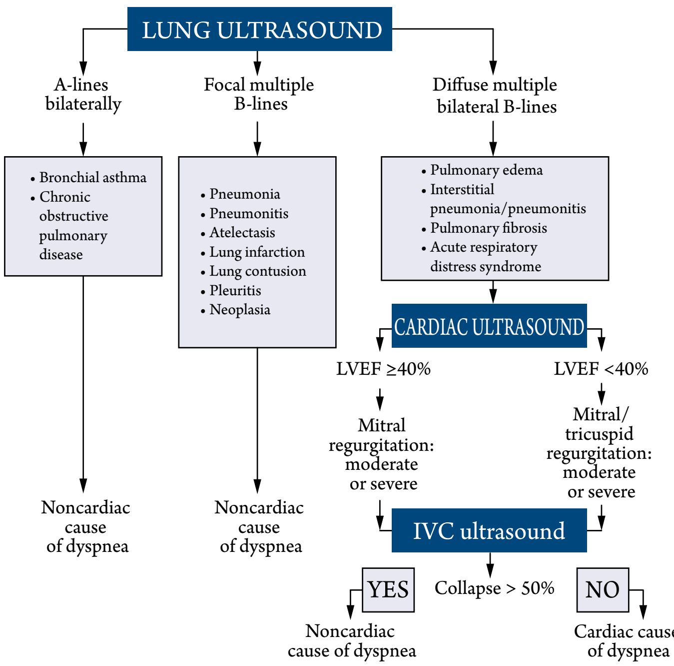
shock is suspected, the dimensions of heart chambers, LV systolic function, IVC diameter and collapse, pericardial layer separation, and pulmonary congestion (B-lines) can be assessed [52].

Focus ultrasound examination can be useful in cardiac tamponade to detect fluid between the pericardial layers and signs of cardiac compression; this helps to select the best approach for pericardiocentesis or pericardial fenestration [53].

Some literature sources correlate the results of focus ultrasound examination of IVC with central venous pressure [54]; in some situations, IVC examination can be used to assess volemic status. Volemic status is estimated by changes in the IVC diameter according to the respiratory phases (ΔIVC) [55]. For this purpose, various indices have been developed: IVC collapsibility index for patients with spontaneous breathing [56]; IVC strain index in patients with artificial ventilation using the formula by Barbier et al. [57] or Feissel et al. [58].

In focus ultrasound examination of IVC, three main states can be distinguished at the initial stage: normal, «flat» and plethoric IVC. Normal IVC (euvolemia): diameter – 1.2–2.1 cm [7, 59]; inspirational collapse <50% of the initial diameter. «Flat» IVC (hypovolemia): anteroposterior IVC dimension <1.2 cm; inspirational collapse>50% of the initial diameter. In addition to absolute hypovolemia, «flat» IVC is visualized in redistribution shocks and increased intra-abdominal pressure. Plethoric IVC: diameter>2.1 cm [59, 60]; inspirational collapse <50% of the initial diameter, characteristic of increased pressure in the right heart and volume overload, as well as obstructive and cardiogenic shocks. At the same time, assessment of volemic status based on focus examination of IVC has the same limitations as measurement of central venous pressure, especially in patients with elevated pressure in the right heart. Therefore, the assessment of volemic status should be ideally supplemented by a focus ultrasound examination of the lungs to clarify the infusion therapy strategy [61]. Focus ultrasound examination of IVC cannot replace the invasive study of central hemodynamics [62, 63].

Figure 2. Diagnostic algorithm for the causes of acute dyspnea based on the analysis of ultrasound examination of the lungs, heart, and IVC. Adapted from Kajimoto et al. [51]



Focus ultrasound examination helps differentiate chest pain syndrome at all stages of medical care. Focus echocardiography can be used to visualize wall motion anomalies and study LV function, as well as to detect dilated RV with free wall hypokinesia, estimate dimensions and morphology of ascending aorta and diagnose aortic regurgitation or pericardial effusion. Thus, this can be one of the first necessary steps toward the differential diagnosis of acute coronary syndrome, acute aortic syndrome, pulmonary thromboembolism and pericarditis. Some clinical conditions and corresponding parameters that can be determined using focus ultrasound examination are listed in Table 2.

Focus ultrasound examination of the lungs

Focus ultrasound examination of the lungs is a relatively new diagnostic tool that can reveal some pathologies accompanied by abnormal changes in the lung parenchyma and pleural cavities. Ultrasound examination of the lungs was initially positioned as an optimized method for express diagnosis of the causes of sudden dyspnea [64–66]. The literature describes the method as being highly sensitive and specific in detecting pulmonary edema, pneumothorax, hydrothorax [40, 67–69]. Lung ultrasound is included in the algorithms that complement the examination of the heart to determine the causes of acute respiratory failure.

As well as its high diagnostic value, the strengths of ultrasound examination of the lungs include ease-of-use and reproducibility of the method. Focus ultrasound examination of the lungs does not require long-term training for cardiologists having basic echocardiography skills to detect interstitial syndrome, pneumothorax, and hydrothorax [4, 70, 71]. However, it should be mentioned that mastering

Table 2. Parameters of Emergency Focus Ultrasound Examination

Conditions	Parameters estimated	Protocol*
Acute heart failure	• Sizes of the heart chambers • Ventricular wall motion • IVC • Lung ultrasound profile	RUSH RUSH-HIMAP
Shock	• Dimensions of the heart chambers • Ventricular wall motion • IVC • Pericardial layer separation • Collapse of the heart chambers	BLEEP EGLS FATE RUSH RUSH-HIMAP
After cardiac arrest	• Dimensions of the heart chambers • Ventricular wall motion • Separation of pericardial layers • Presence and severity of pathological transvalvular flows • Presence of blood clots in the heart cavities	CAUSE FEEL FEER
Chest trauma	• Ventricular wall motion • Presence of fluid between the pericardial layers and in the pleural cavities, signs of cardiac tamponade • Signs of valvular dysfunction • Signs of trans-septal rupture	BEAT FAST FATE
Chest pain	• Dimensions of the heart chambers • Ventricular wall motion • Dimensions of the aorta, signs of aortic dissection • Signs of valvular dysfunction • Presence of fluid between the pericardial layers and in the pleural cavities	RUSH-HIMAP

* Full names of the protocols with overviews and links are provided in Appendix 2.

ultrasound examination of the lungs requires a multi-stage training program lasting for a number of hours [72–74].

The present paper does not cover lung ultrasound in COVID 19, which can be found in recent guidance papers focusing on this issue [75, 76].

General principles of ultrasound examination of the lungs

Ultrasound device

For lung ultrasound, the same equipment can be used as for echocardiography as described in the Types of Ultrasound Systems subsection.

If an ultrasound device has no pre-installed lung examination mode, some authors recommend disabling smoothing and artifact suppression (multi-beam scanning and harmonic imaging) and reducing the dynamic range [77, 78]. While ultrasound examination of the lungs can be performed using various types of probes, it is generally preferred to use a convex probe in the standard abdominal program without significant image post-processing or a linear probe in the superficial organ scanning mode. Phased array sector probe tends to be less informative due to the narrow imaging zone at the lung surface level, which does not allow a sufficient area to be examined in a single image; nevertheless, it can be used if there are no other probes.

Technique

The probe is held perpendicular or parallel to the ribs so that the ultrasound window provides intercostal access to the lung. Holding the probe perpendicular allows faster operation, but the ultrasound window is limited. If abnormal artifacts are detected, the probe is placed parallel to the ribs for a more detailed examination of the area of interest. Imaging limitations may occur in obese patients [79].

The technique and scope of the examination depend on the pathology being detected (Table 3).

The semiotics of lung ultrasound are based on the analysis of ultrasound images of real anatomical parts (soft tissue, ribs, pleural cavity) and various ultrasound artifacts (A-lines, B-lines) caused by the interaction of ultrasound and air (Table 4) [65].

Ultrasound signs, artifacts, and their combinations form ultrasound profiles corresponding to a particular condition (Appendix 3).

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Ultrasound pattern of the normal lung (A-profile)

Ultrasound pattern of normal lung corresponds to the A-profile in two-dimensional mode and is presented in Figure 3. The anatomical landmark is the transverse rib sections producing acoustic shadows. However, the shadow is vague behind the cartilaginous part of the ribs. The pleural line with the glide sign and multiple horizontal A-lines are seen behind the intercostal soft tissues.

A-lines, which represent re-echos or reverberations, appear due to the repeated reflections of ultrasound waves between the probe aperture and the surface of the inflated lung. They are a sign of the normal state of subpleural lung regions and visceral pleura [83].

Normally, single B-lines (less than three per intercostal space) can be detected. They are comet-tail artifacts [83].

The physical nature and pathomorphological basis of this artifact are not clear. However, several authors suggest that B-lines result from multiple reverberations between interlobular septa [83].

In one-dimensional (M-mode), linear, relatively stationary signals are recorded in the immediate field above the pleural line that comes from the chest soft tissues. Signals resembling a sandy shore are recorded in the far field. They correspond to the lung sliding, which is the so-called seashore sign (Figure 4). This ultrasound pattern indicates a normal lung sliding and allows excluding pneumothorax.

Ultrasound pattern of the interstitial syndrome (B-profile)

The interstitial syndrome is characterized by the registration of multiple B-lines (three or more per intercostal space) [84–86] (Figure 5).

The appearance of multiple B-lines is typical of several conditions (Table 5) [67, 87]:

- Pulmonary edema, including cardiogenic;
- Decompensated chronic heart failure;
- Interstitial lung diseases;
- Pneumonia / pneumonitis;
- Respiratory distress syndrome and others.

The ultrasound pattern of the cardiogenic interstitial syndrome is typically characterized by multiple symmetrical bilateral B-lines (B-profile) without abnormal changes of the pleural line. Interstitial syndrome of presumable cardiogenic origin may be caused by decreased pumping function and valvular pathologies detected by echocardiography [88, 89].

To identify cardiogenic fluid congestion in the lungs, the anterior and lateral chest is scanned in the supine position using an 8- or 4-zone technique (Figure 6) [80, 90, 91]. Examinations should be repeated performed in the same position since the number of B-lines detected depends on the patient's position (a supine position allows the maximum number to be detected) [92].

The presence of pulmonary congestion can be assessed using a quantitative and scoring method (Table 6). The first (quantitative) assumes the summation of the number of B-lines in all zones. When using the scoring method, the number of positive zones with three or more B-lines is summed up [84].

Ultrasound pattern of pneumothorax

If the pneumothorax is suspected, a sequential examination of intercostal spaces is performed from the anterior to lateral chest on the pneumothorax side [81, 93]. Although the area corresponding to pneumothorax has neither signs of lung sliding nor B-lines, there are multiple A-lines. The so-called lung point is the most specific ultrasound sign of pneumothorax. The lung point corresponds to the pneumothorax margin, where signs of pneumothorax presence and absence alternate due to breathing with a probe fixed at the scanning point [81, 94].

However, it should be kept in mind that the lung point can also be recorded in patients with pulmonary bullae or pleural thickening and adhesion [95]. Unlike the seashore sign under normal conditions, linear stationary signals are recorded in the M-mode throughout the entire field of examination, resulting in the so-called barcode sign (Figure 7).

Ultrasound pattern of pleural effusion

Ultrasound examination of the lungs can quickly and accurately detect the presence of pleural fluid [40]. An echo-negative space between the visceral and parietal pleura is a sign of the presence of pleural fluid (Figure 8) [67]. If the volume is sufficient, it is possible to assess the echogenicity of the effusion in terms of the presence of inclusions, adhesions, commissures, fibrin deposition, which allows the nature of a pathology to be indirectly ascertained (transudate, exudate, empyema, hemothorax).

Effusion can be evaluated using several formulas that allow quite accurately calculating the volume of pleural fluid using simple measurements. The probe

Table 3. Patient position and area of examination depending on the pathology

Pathology	Patient position	Area of examination	Examination technique*
Cardiogenic interstitial syndrome [80]	Supine	Anterior and lateral chest	Scanning of 4 or 8 zones
Pneumothorax [67, 81]	Supine	Anterior and lateral chest	Examination of intercostal spaces is performed from the anterior to the lateral chest on the pneumothorax side.
Hydrothorax [82]	Seated**	Lateral and posterior chest	Examination of the lower intercostal spaces
	Supine***	Lateral chest	The examination is carried out from the most dorsal regions.

* The technique is described in the corresponding section; ** Preferable and most informative;
*** Used when it is impossible to carry out the examination in the seated or lateral decubitus position.

Figure 3. Planar ultrasound pattern of normal lung (A-profile) Arrows show A-lines

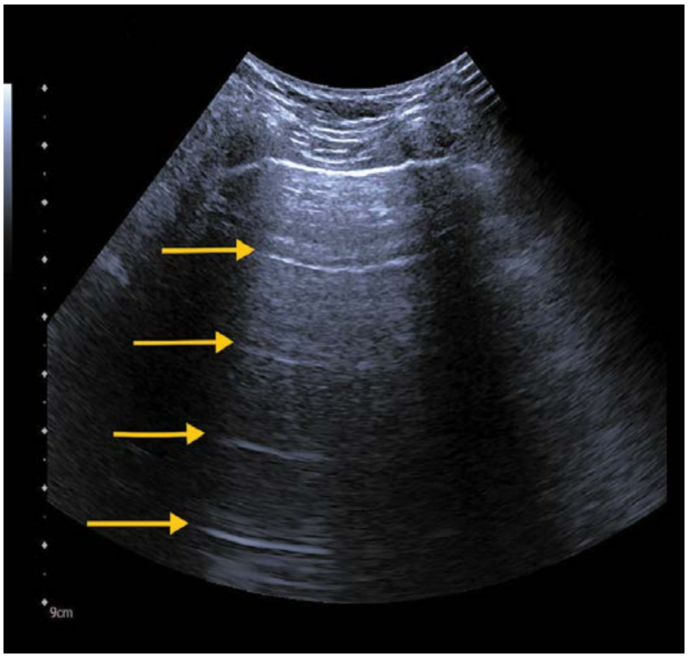

Figure 4. Ultrasound pattern of normal lung. Seashore sign in M-mode

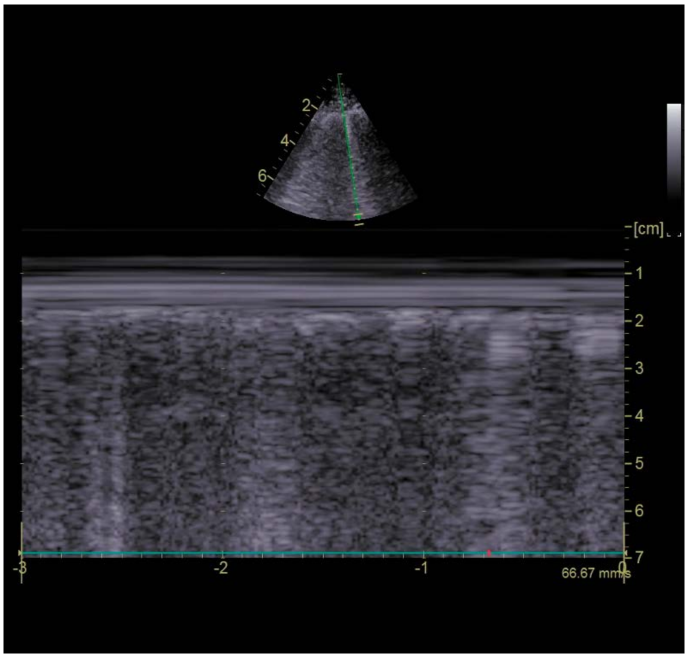

Table 4. Signs and artifacts detected by ultrasound examination of the lungs [79]

Ultrasound signs/artifacts	Description
Pleural line	Bright hyperechoic line seen behind the intercostal soft tissues between the acoustic shadows of the ribs
Lung sliding	The planar movement of the pleural line is coordinated with the act of breathing (lung sliding).
A-lines	Horizontal acoustic artifacts consisting of hyperechoic lines parallel to the pleural line and repeating at equal distances
B-lines (comet-tail artifacts)	Vertical linear artifacts from the pleural line to the end of the ultrasound scanning sector visualized without attenuation, moving synchronously with lung sliding
Lung point	Area corresponding to the pneumothorax margin where the signs of pneumothorax presence and absence alternate due to breathing with a probe fixed at the scanning point

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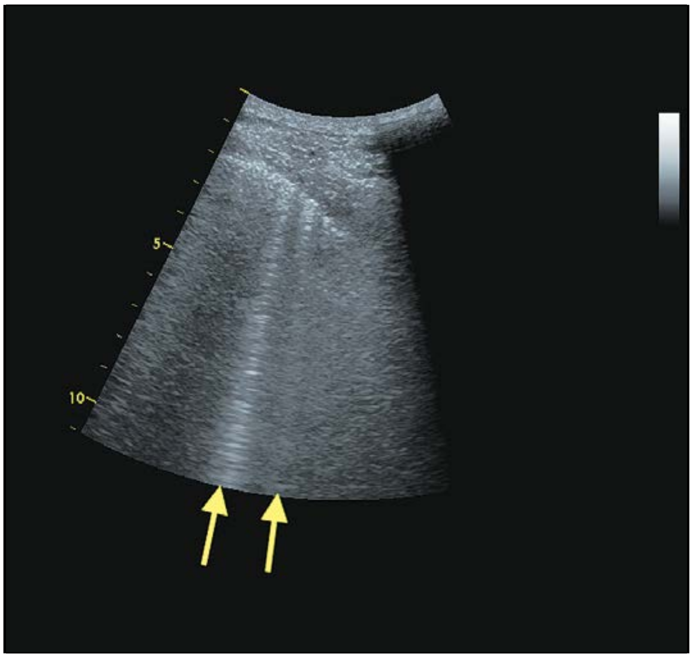
Table 5. Differential diagnosis of the interstitial syndrome [87]

Sign	Cardiogenic pulmonary edema	Acute respiratory distress syndrome	Interstitial pneumonia
Clinical course	Acute heart failure or decompensation of chronic heart failure	Acute	Acute, subacute, or chronic
B-lines	Multiple bilateral diffuse B-lines, mainly in the anterior chest	Multiple, scattered bilateral diffuse B-lines. B-lines are absent over noninvolved lung areas	More often localized in the basal parts
Pleural surface morphology	Normal, smooth	Abnormal	Abnormal
Subpleural consolidation	No	Yes	No/yes
Pleural effusion	Normally, yes, bilateral	Yes/no	Normally, no
Echocardiography	Abnormal changes	Normal at the beginning	Long-term course may include the signs of RV dysfunction or pulmonary hypertension

Table 6. Assessment of congestion severity using pulmonary ultrasound examination

Number of zones of interest	Method of assessment	Result
4	Score [85, 86]	0 – <3 B-lines per zone 1 – ≥ 3 B-lines per zone Result: score
8	Quantitative [86]	Sum of B-lines per zone
	Score [84]	0 – <3 B-lines per zone 1 – ≥ 3 B-lines per zone Result: score

Figure 5. Ultrasound pattern of the lung with B-lines (shown by arrows)



must be positioned during measurements strictly perpendicular to the body axis. The examination is performed along the posterior axillary line using a convex or sector phased probe.

The B-mode image should be obtained at the end of expiration and include pleural effusion, collapsed lung, and diaphragm for subsequent measurements (Figure 8). The distance from the lung base to the top of the diaphragm is measured (A; Figure 8). The height of the pleural effusion is measured between the highest point of the pleural effusion and the diaphragmatic sinus, which are detected when the probe is moved to the higher and lower intercostal spaces (B; Figure 8).

The following formulas have been composed for the images obtained using a convex probe.

$$\text{Effusion volume (mL)} = (A\ (cm) + B\ (cm)) \times 70\ [96, 97].$$

The formula includes two variables. When compared to the actual aspirated amount of effusion, the calculated volume shows a high correlation [intraclass correlation coefficient (ICC) 0,835 (95% confidence interval (CI): 0.687–0.913) [96].

A modified simplified version of this equation has been also proposed:

$$\text{Effusion volume (mL)} = 100 \times B\ (cm)\ [96]$$

This formula requires only one measurement to calculate the volume, which is simple and timesaving, yet relatively accurate [xICC – 0.798 (95% CI:0.651–0.888)] [96].

Conclusion

Focus echocardiography produces basic information about the morphology and function of the heart, allowing an assessment of changes to some important indicators. In complementing focus echocardiography, focus ultrasound examination of the lungs can be used to collect real-time information about the lungs and pleural cavities to become a valuable diagnostic tool as part of routine cardiological practice.

These techniques extend physical examination with an ultrasound focus protocol aimed at providing fast diagnosis, early treatment, and basic monitoring of cardiovascular diseases. This comprises a limited but rapid, reproducible, and easy-to-use approach. The training of doctors of various specialties can be short but informative. While the focus protocol should not be taken as a substitute for a comprehensive echocardiographic examination, as a basic clinical tool like a stethoscope, it can be used for early diagnosis (at bedside) to assess the origin, pathophysiology, and prognosis of an event. By implementing this protocol, the physician is empowered to make quick decisions on patient management.

Figure 6. Lung areas scanned using 8- and 4-zone techniques to detect interstitial syndrome of cardiogenic origin

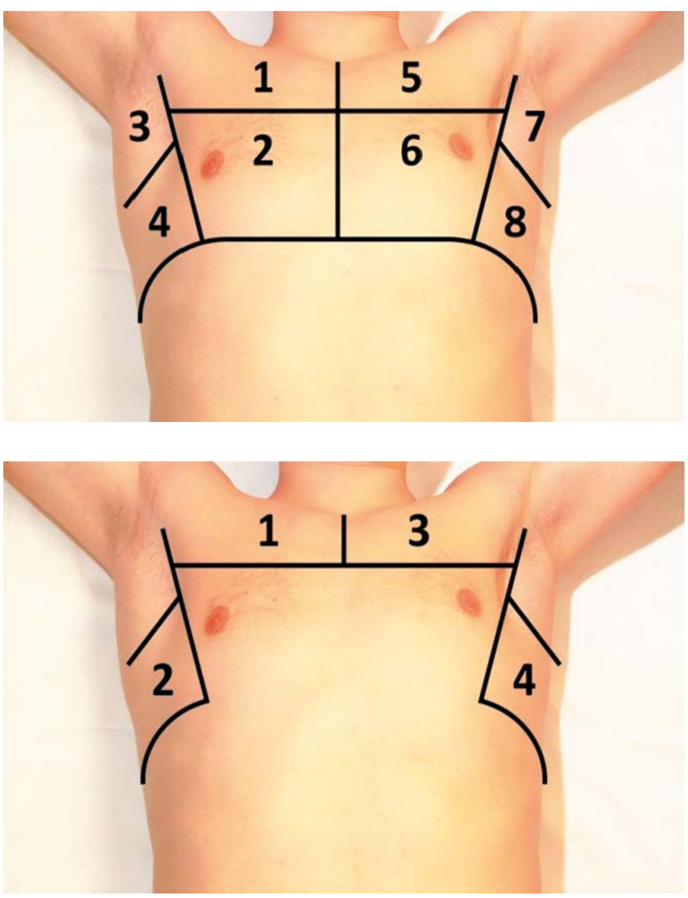
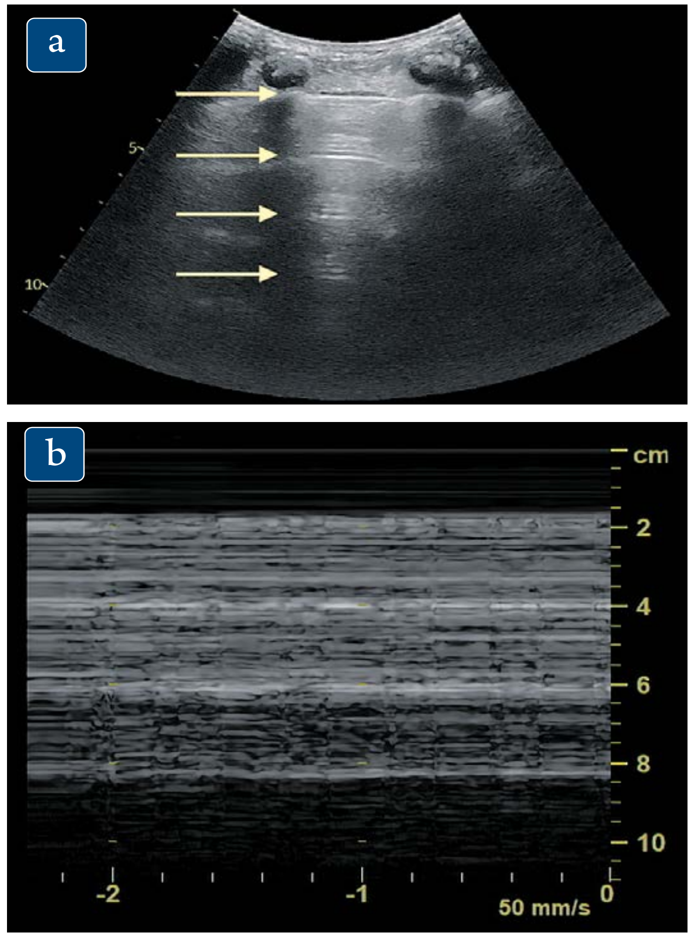


Figure 7. Ultrasound pattern of pneumothorax.
a – B-mode. A-lines are shown by arrows.
b – M-mode. Linear stationary signals throughout the field of interest – barcode sign



List of abbreviations

BLUE – Bedside Lung Ultrasound in Emergency
CW – Continuous Wave (Doppler)
MAPSE – Mitral Annular Plane Systolic Excursion
PACS – picture archiving and communication system
PLAX – Parasternal Long AXis
PSAX – Parasternal Short AXis
PW – Pulsed Wave (Doppler)
RADiUS – Rapid Assessment of Dyspnea with UltraSound
TAPSE – Tricuspid Annular Plane Systolic Excursion
TDI – Tissue Doppler Imaging
LV – left ventricle
LA – left atrium
IVS – interventricular septum
IVC – inferior vena cava
RV – right ventricle
CHF – chronic heart failure
ECG – electrocardiography

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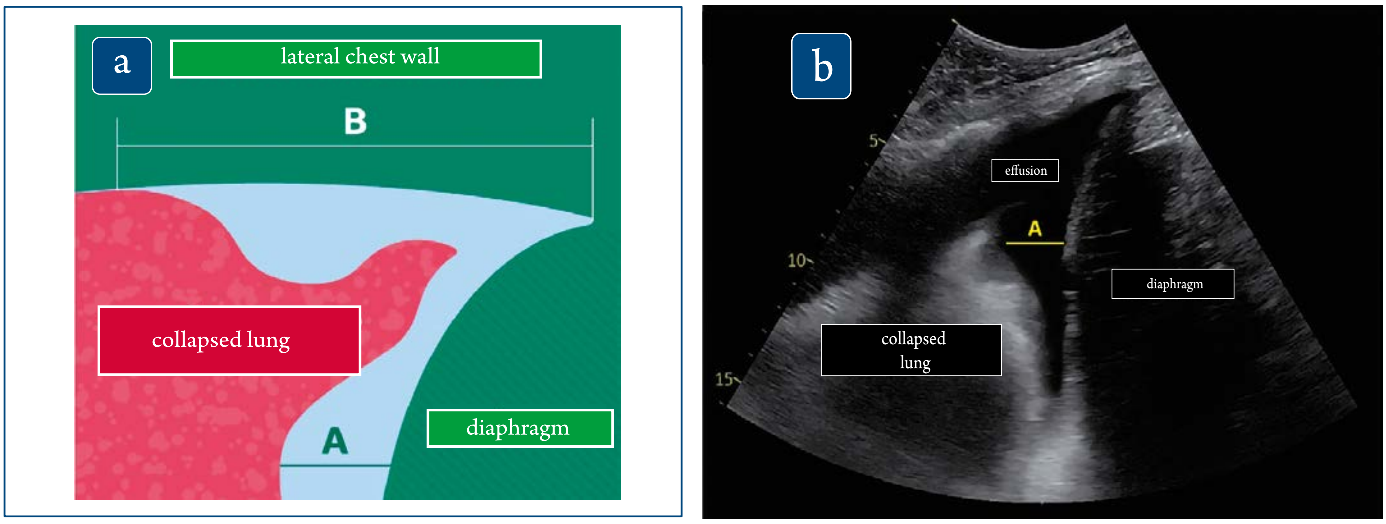
Figure 8. Measurements to calculate the volume of pleural effusion. a – diagram. b – echogram.
A – distance from the collapsed lung base to the top of the diaphragm. B - the height of the pleural effusion. Adapted from Hassan et al. [96]



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Annex 1. Possible protocol of focus echocardiography

1.	Hospital/facility
2.	Department in which the examination was performed
3.	Setting of the examination (mechanical ventilation; supine position, sitting position, etc.; nature of the heart rhythm – tachycardia, bradycardia, atrial fibrillation, etc.)
4.	Date, time
5.	Device used for the examination
6.	Mandatory clarification that the focus protocol is implemented
7.	Patient (name, age)
8.	Diagnosis at admission/visit and/or goal of the examination
9.	Narrative
10.	Conclusion

The protocol can be recorded separately and as a part of a diary/round report/initial examination.

Depending on the goal of focus ultrasound examination of the heart, the narrative of the protocol can include the following parameters:

- Diameter of the aortic root at the sinus level from the left parasternal view along the LV long axis. The maximum diameter of the tubular ascending aorta is additionally measured, if necessary. In this case, the position can be modified and/or the right parasternal view can be added for optimal imaging of the aorta at this level. Measured in mm.
- Movement of the aortic valve leaflets: restricted /not restricted.
- Aortic regurgitation: yes/no (if yes, mild, moderate, or severe).
- LA dimensions from the parasternal view along the LV long axis. Measured in mm.
- Movement of the mitral valve leaflets: restricted /not restricted.
- Mitral regurgitation: yes/no (if yes, mild, moderate, or severe).
- Movement of the tricuspid valve leaflets: restricted /not restricted.
- Tricuspid regurgitation: yes/no (if yes, mild, moderate, or severe).
- Movement of the pulmonary valve leaflets: restricted /not restricted.
- Pulmonary regurgitation: yes/no (if yes, mild, moderate, or severe).
- RV end-diastolic dimension at the basal and median levels from the apical four-chamber view. Measured in mm.
- IVS thickness from the parasternal view along the LV long axis. Measured in mm.
- LV posterior wall thickness from the parasternal view along the LV long axis. Measured in mm.
- LV end-diastolic dimension from the parasternal view along the LV long axis. Measured in mm.
- LV end-systolic dimension from the parasternal view along the LV long axis. Measured in mm.
- Reduced LV wall motion: yes/no; assessed from the parasternal view along the LV long/short axis, apical two-/four-chamber views.
- Reduced RV wall motion: yes/no; assessed from the apical four-chamber view.
- Pericardial fluid: yes/no (if yes, the maximum diastolic layer thickness /fluid level in mm).
- IVC diameter from the subcostal view. Measured in mm.
- Inspiratory IVC collapse: yes/no>50% of the initial diameter.
- Hepatic vein blood flow: normal/abnormal.
- Diameter of the main pulmonary artery. Measured in mm. Many focus examination protocols have been developed and validated recently for various clinical scenarios (Appendix 2).

The above parameters are the main indicators, the combination of which is determined in a protocol by a specific clinical situation and is sufficient for the ultrasound semiotics of a certain range of nosologies (e.g., if hemopericardium is suspected, it is advisable to measure the pericardial layer separation caused by fluid accumulation and the presence or absence of tamponade signs).

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Annex 2. Focus ultrasound protocols that include echocardiography and terms used to discuss focus ultrasound

Protocol	Description
Focus ultrasound protocols that include echocardiographic examination	
BEAT (Bedside Echocardiographic Assessment in Trauma/critical care) [98]	Echocardiographic examination at the patient's bedside used to assess trauma in intensive care units
BLEEP (Bedside Limited Echocardiography by Emergency Physician) [99]	Emergency echocardiographic examination at the patient's bedside (developed for pediatric patients). It is a focus protocol, despite the term "limited" is used
CAUSE (Cardiac Arrest UltraSound Exam) [100]	Ultrasound examination for cardiac arrest
CLUE (Cardiopulmonary Limited Ultrasound Exam) [101]	Protocol for the ultrasound examination of the heart and lungs at the patient's bedside. It is a focused protocol, despite the term "limited" is used
EGLS (Echo-Guided Life Support) [102]	Intensive care under ultrasound guidance (protocol designed for the management of patients with a shock of unknown origin)
FAST (Focused Abdominal Sonography in Trauma) [103]	Focused abdominal ultrasound examination used to assess trauma
FATE (Focus-Assessed Transthoracic Echocardiography) [104]	Focus transthoracic echocardiography protocol (used in the perioperative period, intensive care units, in trauma, and for resuscitation)
FEEL (Focused Echocardiographic Evaluation in Life Support) [105]	Focused ultrasound examination of the heart used in life support
FEER (Focused Echocardiographic Evaluation in Resuscitation) [106]	Focused echocardiographic examination used for resuscitation
RUSH (Rapid Ultrasonography for Shock and Hypotension) [107]	Emergency ultrasound examination in shock and hypotension
RUSH-HIMAP (Rapid Ultrasound for Shock and Hypotension – Heart, Inferior vena cava, Morrison pouch with FAST exam view and hemothorax windows, Aorta, and Pneumothorax) [108]	Emergency ultrasound protocol used in shock and hypotension, including examination of IVC, hepatorenal recess (free fluid), FAST protocol, assessment of pleural cavities for hemothorax and pneumothorax, and assessment of the abdominal aorta, as well as echocardiography
Terms used to discuss focused ultrasound examinations	
Cardiac POCUS (Point-Of-Care UltraSound)	The term "POCUS" refers to the diagnostic and navigational use of ultrasound examination for various areas and tasks using several protocols (examination of the lungs, upper respiratory tract, heart, abdominal cavity, large vessels, etc.). The term "cardiac POCUS" refers to a bedside ultrasound examination using a limited set of approaches and positions used to detect or exclude a specific disease or condition (e.g., rule out cardiac tamponade) [25]. "POCUS" is synonymous with focused ultrasound. This term is more common for the consensus papers in US.
FoCUS (Focus Cardiac UltraSound)	Focused point-of-care ultrasound examination of the heart in cardiologic practice (the abbreviation is used in the European consensus papers)
UAPE (Ultrasound Assisted Physical Examination)	Clinical examination using ultrasound

Annex 3. Differential diagnosis of ultrasound profiles [65]

Ultrasound signs/artifacts	Normal lung	Cardiogenic interstitial syndrome	Pneumothorax
Lung sliding	Yes	Yes	No
A-lines	Yes	No/yes	Yes
B-lines	No / yes (<3)	Yes (≥3 per slice), bilateral	No
Seashore sign	Yes	Yes	No
Lung point	No	No	Yes
Barcode sign	No	No	Yes

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