Review

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The Role of Ultrasound in Diagnosing Community-Acquired Pneumonia

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BACKGROUND The literature review is devoted to an urgent problem of the diagnosis of pneumonia in the practice of an anesthesiologist-resuscitator using ultrasound. The literature review describes the methodological foundations of this method, its advantages and disadvantages, sensitivity and specificity for the diagnosis of severe community-acquired pneumonia in the practice of an anesthesiologist-resuscitator.

AIM OF STUDY The analysis of the most modern domestic and foreign evidence base based on the information content of lung ultrasound in CAP in the practice of an anesthesiologist-resuscitator.

MATERIAL AND METHODS Russian publications were searched in the elibrary.ru database, foreign publications were searched in the PubMed database. Publications (literature reviews, observational studies, double-blind randomized trials) were searched for the period 2010–2020. A total of 1379 publications were initially selected, identified through database searches. After removing duplicates, the number of publications was reduced to 695. Of this number, 503 publications were excluded. The remaining 192 full-text articles were evaluated for text acceptability. Due to inconsistency with the main sections of the review, 77 articles were deleted from them. The remaining 115 ones were included in the qualitative synthesis and 67 ones were selected in the quantitative synthesis.

RESULTS The ultrasound is a promising and worthy alternative to other imaging modalities. According to the results chest X-ray was inferior to lung ultrasound in diagnosing the presence of fluid in the pleural cavities. The sensitivity of ultrasound in assessing pleural effusion reaches 100%, the specificity is 99.7%. Pulmonary ultrasonography plays an important role in the diagnosis of pneumonia and is a promising alternative to chest X-ray and chest CT.

DISCUSSION Since POCUS is performed at the patient's bedside, the results are available to the doctor in real time, which helps in diagnosis and treatment. Sequential examinations can be performed to monitor disease progression and response to treatment. However, many facilities do not have the ability to store ultrasound images, so other healthcare professionals cannot see them.

FINDINGS The ultrasound examination of the lungs is unlikely to replace computed tomography of the chest, as it does not have 100% specificity, however, it is indispensable in bedside examination and is the doctor's sonographic "stethoscope", which significantly expands diagnostic capabilities.

Keywords: community-acquired pneumonia, lung ultrasound, ultrasound

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CAP - community acquired pneumonia
CT - computed tomography
ARF - acute respiratory failure
PCT - procalcitonin
CRP - C -reactive protein
LR - likelihood ratio
PSI - Pneumonia Severity Index
FDA - Food and Drug Administration
BLUE - bedside lung ultrasound in emergency

"We must, of course, strive for technological progress in medicine,
but in such a way as not to lose the precious qualities of a doctor such as kindness,
love for people, and humanity. Despite the technical equipment,
medicine does not cease to be the medicine of the individual.

A.F. Bilibin

INTRODUCTION

Pneumonia is an acute polyetiological infectious disease/complication characterized by the development of inflammation (focal, lobar, total), clinical and laboratory signs of high accuracy and reproducibility. Pneumonia is one of the most common respiratory diseases with high mortality. The mortality in Russia is approximately 4 cases per 1,000 people of the adult population, and in elderly people with concomitant diseases, mortality can reach 40-50%. This category of patients requires close attention with deeper monitoring of the inflammatory infiltrate [1–3]. Community-acquired pneumonia is considered to be pneumonia that developed outside the hospital, or diagnosed in the first 48 hours after hospitalization [1, 2]. In the elderly, the disease is severe and often fatal. Community-acquired pneumonia (CAP) kills more people than all other infectious diseases in the world, which in total reaches up to 3 million per year [4]. The ideal, reference diagnosis of pneumonia is based on the detection of pathogenic agents in the lung parenchyma, but this is not always possible in routine clinical practice. Thus, for the differential diagnosis of pneumonia and other respiratory diseases, a comprehensive assessment is used, including a physical examination, a laboratory blood test (including an assessment of inflammation markers), imaging methods (such as computed tomography (CT), chest X-ray and ultrasound of the lungs [5].

The aim of this literature review is to analyze the modern domestic and foreign evidence base based on the information content of lung ultrasound in CAP in the practice of an anesthesiologist-resuscitator.

MATERIAL AND METHODS

ELibrary.ru database, foreign publications were searched in the PubMed database. The block diagram of inclusion in the literature review of publications is shown in fig. 1. Searched publications (literature reviews, observational studies, double-blind randomized trials) for the period 2010–2020. A total of 1,379 publications were initially selected, identified through database searches. After removing duplicates, the number of publications was reduced to 695. Of this number, 503 publications were excluded. The remaining 192 full-text articles were evaluated for text acceptability. Due to inconsistency with the main sections of the review, 77 articles were deleted from them. The remaining 115 were included in the qualitative synthesis and 67 were selected in the quantitative synthesis. To form a literature block, the following search queries were used: "pneumonia", "ultrasound examination of the lungs", "ultrasound", "pneumonia" , "ultrasound examination of the lungs" , "community acquired pneumonia ultrasound".

All sources of domestic and foreign literature were divided into main chapters: a) morphology of pneumonia, foci and substrates; b) comparative characteristics of diagnostic methods, including radiation; c) ultrasound picture of pneumonia, research methodology and characteristics of this method.

Fig. 1. The flowchart for inclusion in the literature review of publications

SEARCHING RESULTS

HISTORY AND PHYSICAL EXAMINATION

The history and physical examination should be aimed at recognizing the clinical syndrome of CAP, assessing its severity, complications, and assessing comorbidities that affect each patient's symptom complex. CAP is classically characterized by an acute onset of fever, cough (with or without sputum production), and dyspnea [6]. In some cases, chest pain may also be present. Less common are gastrointestinal symptoms (eg, nausea, vomiting, diarrhea, abdominal pain), loss of appetite, and changes in mental status. In elderly patients or with a weakened immune system, the symptoms may be erased. For example, in elderly patients, fever is often not observed, and the only symptom indicating the disease is a change in mental status [7].

Also, during physical examination, tachycardia, tachypnea, hypoxemia, or involvement of additional muscles involved in the act of breathing may occur. Chest auscultation reveals wet and dry rales along with other signs of consolidation (eg, voice trembling, bronchophony, dullness on percussion). As the infection progresses, sepsis and/or respiratory distress syndrome become the dominant clinical picture. Although the clinical features described above support the diagnosis of pneumonia, no combination of symptoms and signs has been found to support a definitive diagnosis [6, 8]. In a study of more than 28,000 adults presenting to primary care with an acute cough associated with a lower respiratory tract infection, independent predictors of radiologically confirmed pneumonia were fever, tachycardia, rales on chest auscultation, and oxygen saturation of less than 95% [6]. However, the positive predictive value of all four variables taken together was only within 67%. Similar results were obtained in other studies comparing clinical assessment of patients with the results of chest X-ray. For example, the study by van Vugt et al. involving more than 2,800 adults with acute cough estimates the positive predictive value of the clinical score at 57% [5]. McGee reviewed physical examination methods for more than 6,000 patients with acute fever, cough, sputum production, and dyspnea. As a result, each patient underwent chest X-ray, which was used as a reference for the diagnosis of pulmonary infiltrate. Several physical examination findings significantly increase the likelihood of a diagnosis of pneumonia: asymmetric chest enlargement (likelihood ratio (LR) = 44.1), egophony (LR = 4.1), cachexia (LR = 4), bronchial breathing (LR = 3.3), oxygen saturation less than 95% (LR =3.1) and dull

percussion sound above the lung surface (LR =3). Some signs found on examination only moderately increase the likelihood: respiratory rate over 28 (LR = 2.7), wheezing (LR = 2.3), decreased breathing (LR = 2.2), body temperature above 37.8° C (100°F) (LR =2.2) and impaired consciousness (LR =1.9). One sign greatly reduces the likelihood of a diagnosis of pneumonia - these are normal indicators of all vital parameters (LR = 0.3) [9].

Many of these symptoms alone do not contribute significantly to the differential diagnosis, but some of them may help in the definitive diagnosis. For example, the Heckerling scale combines 5 symptoms to improve the accuracy of bedside examinations:

- body temperature above 37.8°C (100°F);
- pulse rate more than 100 beats per minute;
- wheezing upon auscultation;
- weakening of breathing during auscultation;
- no history of bronchial asthma [9, 10].

McGee also showed that both low and high scores can be used to make a decision: a score of 0 to 1 is in favor of pneumonia (LR = 0.3) and a score of 4 to 5 is in favor of pneumonia (LR = 8.2) [9]. Examination and history taking, although not an accurate diagnosis of CAP, are key steps followed by chest imaging and treatment selection [8].

LABORATORY EVALUATION AND SERUM BIOMARKERS

In general, most patients with known or suspected CAP who are hospitalized or who may require hospitalization (depending on their age, comorbidities, vital signs, or clinical presentation) have a complete blood count. The most common finding is leukocytosis with a shift of the leukocyte formula to the left. Leukopenia (less than 4000 cells per mm^3) is less common, but usually means a poorer prognosis. Similarly, thrombocytopenia (platelet count less than 100,000 cells per mm^3) is a rare finding, but it suggests a worse outcome. The dynamics of the level of creatinine and blood urea nitrogen upward also indicates an unfavorable prognosis and is often an argument for hospitalization. These values, together with elevated values of liver function markers in the blood, can also be signs of sepsis, which requires immediate additional examination and treatment [11].

The use of studies of blood levels of C-reactive protein (RP) and procalcitonin (PCT) in the diagnosis of pneumonia, as well as studies that distinguish between bacterial and viral causes of CAP [5, 12, 13], is topical, although it remains questionable whether they can these tests reliably add value to the initial clinical and X-ray assessment [14–16]. Ebell M. et al. performed a meta-analysis, according to the results of which biomarkers such as CRP, PCT and white blood cell count have sufficient accuracy for diagnosing CAP in adults. The cut-off value chosen will determine whether the test is useful for exclusion (eg, CRP less than 10 or 20 mg/L) or for the diagnosis of pneumonia (eg, CRP greater than 50 or 100 mg/L). CRP is the most accurate of the three studied biomarkers currently used to diagnose CAP. Measurement of CRP is an inexpensive and readily available study, due to which it can be easily integrated into the clinical routine for diagnosing CAP in patients [17]. A low PCT level (less than 0.1 ng/ml) can be used as a negative predictor of 30-day mortality in patients with clinical and X-ray-confirmed CAP (92 % sensitivity, LR-0.22), even among patients with a high risk according to the Pneumonia Severity Index (PSI) and the British Thoracic Society CURB -65 scale (LR-0.09). Among patients admitted to the hospital, low PCT levels were associated with shorter hospital stays, fewer ventilated and intensive care unit admissions, and less severe sepsis [18].

Limitations of using PCT as a predictor include its cost and availability in many hospital laboratories. The FDA (Food and Drug Administration) has approved PCT analysis to determine by physicians the initiation and termination of antibiotic therapy in patients with suspected lower respiratory tract infection in the emergency department or hospital [19].

CHEST IMAGING METHODS

Any method of instrumental diagnosis of pneumonia is to verify the morphological substrate of the disease - the focus of infiltration. The term "infiltration" is commonly understood as a local decrease in the airiness of the lung tissue that occurs due to the accumulation of exudate in the respiratory sections of the lungs. The nature of the CAP is determined by the type of infiltration and the stage of the inflammatory process. If it is a consolidation (alveolar type), the alveoli, sacs, ducts and bronchioles are filled with inflammatory exudate. In this regard, the lung tissue becomes airless and is designated as a symptom of air bronchography. This feature is defined as pleuropneumonia, which most often occurs when infected with bacterial pathogens, especially pneumococci [20].

Another infiltration, of the "frosted glass" type, is characteristic of the interstitial type and is observed when the interalveolar spaces are filled with inflammatory exudate. In this case, its intensity is repeatedly reduced, and the affected area is characterized by a low intensity of the shadow, especially with chest X-ray. High-resolution CT is used to improve the visualization of bronchial walls and determine the vascular pattern in infiltration zones. Infiltration in this case will be defined as interstitial. Patients may be asymptomatic on examination, and infiltration may not be visible with classic chest X-ray. These features are most characteristic of viral pneumonias [20]. There is another type of infiltration - focal. It is characterized by a heterogeneous structure, consisting of many polymorphic foci with fuzzy contours, often merging with each other. This type of inflammation is characterized by bronchopneumonia: the transition of inflammation from small intralobular bronchi to the surrounding lung tissue. Unilateral and often bilateral lesions can also occur in non-bacterial infections of the lower respiratory tract [20]. Taking into account the peculiarities of infiltrations, in most cases it is not possible to establish the etiology of CAP according to the X-ray pattern (the nature of inflammation, the location of the infiltrate, etc.) [20].

CHEST X-RAY

Since the discovery of X-rays in the late 19th century, chest X-ray has been the standard method for diagnosing pneumonia. The advantages of X-ray include ease of use, cost savings compared to more advanced techniques such as CT, and acceptance across all medical disciplines [21]. Thus, for the purpose of diagnosing CAP, it is recommended that all patients undergo chest X-ray in the frontal and lateral projections. chest X-ray is aimed at identifying the presence of pulmonary infiltration, determining the boundaries and its size, the prevalence of the process, as well as the presence of possible complications. The most important task of X-ray examination is the differential diagnosis with other pathological conditions [1, 2, 22]. Although some X-ray features indicate specific causes of pneumonia (eg, lobar consolidations indicate infection with typical bacterial pathogens), the X-ray pattern alone does not reliably differentiate the etiology of the disease [23]. There are also significant differences in the interpretation of chest radiographs in patients with possible pneumonia by different radiologists [24] and between emergency room physicians and radiologists [25]. The chest x-ray has a sensitivity of 38 to 64% for the diagnosis of pneumonia [26, 27], although clinicians often consider a negative chest X-ray to rule out pneumonia [21]. Quite often there are difficulties in interpreting the results of this study, for example, due to the constitutional features of the patient, as well as the “summation effect” due to impaired hemodynamics or pneumofibrosis [28, 29]. Of the limitations in the use of chest X-ray, it is worth noting the high radiation exposure, which becomes especially relevant when it is necessary to dynamically monitor a patient in critical condition. The authors separately carried out a comparative characteristic of chest X-ray in comparison with ultrasound of the lungs. According to the results, chest X-ray yielded to lung ultrasound in diagnosing the presence of fluid in the pleural cavities. The sensitivity of ultrasound in assessing pleural effusion reaches 100%, the specificity is 99.7%. It should be noted that the sensitivity of chest X-ray in the diagnosis of CAP remains very low, especially at the initial stages of the disease [30].

COMPUTED TOMOGRAPHY OF THE CHEST

According to Shah V.R. et al. (2013), the detection of an infiltrate up to 10 mm in size with the presence of a bronchogram on CT scan of the chest is regarded as focal pneumonia. CT scan of the chest can accurately detect small infiltrates and consolidations in the lungs [31]. In general, chest CT is the "gold standard" in the diagnosis of lung diseases [1]. High-resolution CT is more sensitive for detection of pneumonia than chest X-ray [27]. CT can help better characterize pneumonia and identify complications. This is especially true for immunocompromised patients who are at risk of being infected by a wide range of pathogens. The increased sensitivity and specificity of CT may help to establish the etiology of CAP (eg, invasive fungal infections, Pneumocystis pneumonia, bacterial pathogens) [32]. In patients with suspected CAP presenting to the emergency department, chest CT may also be useful to rule out pneumonia in case of questionable clinical syndromes and nondiagnostic chest X-ray results (opacities are present, but it is not clear whether they are due to pneumonia or pulmonary edema, atelectasis, chronic lung disease or have another etiology). It is most common in patients with multiple comorbidities presenting with non-specific syndromes. CT of the chest, supplementing chest X-ray, in such cases significantly affects both the diagnosis and clinical management of patients. In a study by Claessens et al . 319 patients with clinical symptoms of CAP who underwent CT within 4 hours of admission were included. Before and after the study,

physicians assessed the likelihood of a diagnosis of CAP as a) definite; b) probable; c) possible or ruled out the diagnosis and, depending on this, chose the tactics of treatment. A total of 187 patients (58.6%; 95% confidence interval (CI) 53.2–64.0) were reclassified based on the results of the CT study, resulting in 50.8% of cases of definite and 28.8% of cases of excluded CAP. Also, due to the results of CT, antibiotic treatment was started in 51 (16%) and discontinued in 29 (9%) patients, the decision to hospitalize was made in 22 patients, and 23 were discharged [26].

However, the use of CT of the chest for continuous monitoring and evaluation of the dynamics of the inflammatory infiltrate is limited in use due to the high radiation exposure and the need to transport the patient [33, 34]. In China, Hu QJ, Shen Y.S. (2014) published the results of a study confirming that pulmonary ultrasound plays an important role in the diagnosis of pneumonia and is a promising and attractive alternative to chest X-ray and CT. But it is important to remember that its results should be interpreted in parallel with clinical data [35].

LUNG ULTRASOUND

Application possibilities

In recent years, a lot of data have appeared in the literature on the possibility of effective use of ultrasound as a bedside method in order to diagnose and monitor the effectiveness of CAP treatment. Non-invasiveness, accessibility, absence of ionizing radiation, speed of execution and simplicity of this technique makes lung ultrasound a possible alternative in comparison with traditional radiodiagnosis techniques, which is especially important in intensive care patients with severe CAP [2, 36–39]. When the ultrasound beam passes through the soft tissues of the chest, pleura and lung parenchyma, various ultrasound signals and artifacts coming from the pleura are detected, forming various ultrasound profiles corresponding to a particular lung disease [40]. The use of ultrasound in the diagnosis of lung diseases, namely pneumonia, pulmonary edema, emphysema, pathological peripheral formations and diseases of the pleura, and pneumothorax has proven to be effective [29, 41–44]. Volumetric formations, lesions, tumors of the pleura, including those located on the surface of the parietal pleura, are well visualized using ultrasound [45].

Ultrasound picture of pneumonia

In 2008, in France, Lichtenstein D. developed and implemented the BLUE (Bedside Lung Ultrasound in Emergency) ultrasound protocol for the diagnosis of acute respiratory failure (ARF). This protocol allows to establish the cause of ARF in 90.5% of cases. The detection of B -lines allows you to monitor the amount of fluid in the lungs; for this, the FALLS (Fluid Administration Limited by Lung Sonography) protocol was developed - the introduction of fluid based on the results of ultrasound. Monitoring of pulmonary edema using ultrasound allows timely adjustment of treatment tactics, which is especially important in the management of severe intensive care patients [3, 46]. Bedetti G. et al. showed that one of the main advantages of ultrasound is the ability to quickly learn and obtain reproducible, reliable results not only for experienced specialists, but also for beginners. It is also important that the quality of the device is of little importance [47] and does not affect the diagnosis of pulmonary edema [48, 49]. Reissig A. et al . (2012) in studies on the diagnosis of CAP suggest the following monitoring scheme: 1st, 5th, 8th, 13th and 16th days of treatment. According to the authors, these are the optimal days for monitoring the dynamics of the disease [50]. In the diagnosis of CAP, a polypositional method is used. Subcostal, parasternal, intercostal, paravertebral and supraclavicular approaches are used. The position of the patient in this case is sitting and lying down. Access, frequency, patient position, and other study factors are always determined on an individual basis [31, 39]. The focus of pneumonia is described as an inflammatory substrate, infiltration with a homogeneous or heterogeneous structure, mostly hypoechoic, which is no more than 20 mm in size [43]. When the lung tissue is damaged and a focus of inflammatory infiltrate forms in it, blood supply increases in the alveoli and exudate is formed. All this leads to the fact that the lung tissue becomes visible to ultrasound [51]. With pulmonary consolidations, the pleural line changes, it becomes thicker and has a characteristic "sign of a torn line" (Fig. 2). Sometimes in the infiltrate various hyperechoic inclusions can be determined, they are called "aerobronchograms". In essence, these are non-collapsing sections of the bronchi and bronchioles. However, if exudate is present, hyperechoic structures with anechoic layers inside are visualized - “fluid aerobronchograms”. They are characterized by "tubular" structures within the infiltration [52]. A characteristic ultrasound sign of pulmonary edema is the appearance of artifacts — B-lines — in the lungs due to thickening of the interlobular septa, in which fluid accumulates [53]. Their presence may also indicate in favor of interstitial pneumonia, and in the case of an increase in the number of B-lines to more than 5, it may be a nonspecific sign of incipient pulmonary edema [44, 54, 55].

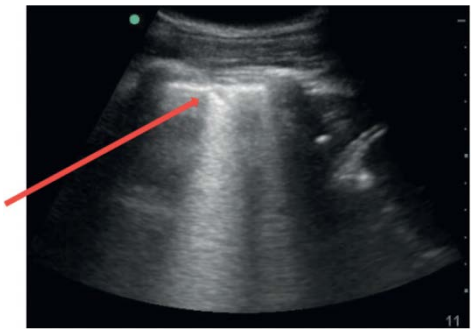

Fig. 2. Multiple, confluent B-lines. The arrow indicates the “sign of an interrupted line” and pulmonary consolidation

D. Lichtenstein et al. offered to differentiate these artifacts according to the principle of single and multiple, which corresponded to the presence of: a) less than 3 B -lines in one intercostal space; c) more than 3 B-lines, respectively [56]. In 2004, reports began to appear about the correlation of the number of these artifacts with the presence of extravascular fluid in the lungs, which was confirmed by chest X-ray [57]. Caiulo V.A. et al. (2013) noted that the appearance of several confluent B -lines is characteristic of focal pneumonia [39]. The appearance of B-lines does not always mean the presence of a pathological process. Normally, they can be observed on average in 15–30% of cases [58]. For ultrasound assessment of pneumonia, areas of airless tissue, their edges, the presence of destructive foci, as well as the phenomenon of "air bronchogram" are assessed [41]. The severity of the course of CAP directly depends on the number and distribution of the "air bronchogram". The sensitivity of ultrasound in the presence of a bronchogram reaches 90% [59].

Sensitivity and specificity of the method for the diagnosis of community-acquired pneumonia

In recent years, many authors have begun to study in more depth the issues of using ultrasound in the diagnosis of CAP and its complications [3, 60]. If pleurisy is suspected in patients with CAP, chest ultrasound is recommended [1]. Pleural effusion is a common complication of CAP in about 10–25% of cases. Ultrasound allows a high degree of sensitivity and specificity to determine the pleural effusion and its nature [1, 2]. The sensitivity of the method in the diagnosis of pneumothorax reaches 100%, the specificity is 96%. These indicators are much superior to the results of CT and chest X-ray [35, 61]. From the meta-analysis of Chavez M.A. et al . (2014) it is known that when diagnosing pneumonia using ultrasound, the sensitivity is 97%, and the specificity is 94% [62]. Several studies have demonstrated the superiority of ultrasound over chest X-ray and CT, finding a sensitivity of 97% and a specificity of 93% [63]. A 2019 systematic review and meta-analysis found that point-of-care ultrasound (POCUS) is superior to chest X-ray in diagnosing pneumonia and other lung diseases. This review of 14 pneumonia studies indicated the accuracy of each sonographic feature in determining the diagnosis. Many of these studies used different diagnostic standards (clinical opinion of the expert panel, X-ray and CT of the chest). On ultrasound, consolidation found in the anterior, lateral, or posterior regions had a better overall profile (LR +15.8, LR −0.18) [64]. Detection of either this pattern of consolidation or focal interstitial syndrome had the best sensitivity (0.96); detection of isolated focal interstitial syndrome or isolated anterior consolidation had the best specificity (0.97) [64].

Limitations of the method

Since POCUS is performed at the patient's bedside, the results are available to the doctor in real time, which helps in diagnosis and treatment. Sequential examinations can be performed to monitor disease progression and response to treatment. However, many facilities do not have the ability to store ultrasound images, so other healthcare professionals cannot see them. Without the ability to document the image, a bedside diagnosis cannot be substantiated. Another important limitation is the experience of the doctor who conducts and interprets the results of the examination. However, according to studies, competence is achieved after 9 hours of training [65].

Finally, the availability and cost of ultrasound machines for bedside examinations in healthcare settings remain in question. Each of these limitations precludes the clinical use of lung ultrasound and its findings for the diagnosis of pneumonia.

CONCLUSION

Ultrasound examination of the lungs is one of the most important methods in anesthesiology and resuscitation for solving the problems of diagnosing pneumonia. To date, both advantages and disadvantages of this method have been identified. Of the undoubted advantages, one can single out the high speed of the study and the sensitivity of the method, conducting the study directly at the patient's bedside, the absence of ionizing studies and the possibility of multiple repetitions. Ultrasound examination of the lungs is unlikely to replace computed tomography of the chest, as it does not have 100% specificity, however, it is indispensable in bedside examination and is the doctor's sonographic "stethoscope", which significantly expands diagnostic capabilities.

Thus, ultrasound is a promising and worthy alternative to other methods of radiation diagnostics.

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