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ULTRASOUND AND X-RAY EXAMINATION AT LUNG EDEMA OF DOMESTIC CAT

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The aim: *This study aims to determine the diagnostic value of lung ultrasound compared with radiography for respiratory distress in cats.*

Materials and methods: *The database of the veterinary center was analyzed. 130 animals diagnosed with pulmonary edema were selected. The lungs of sick cats were examined ultrasonographically; The line was counted in 4 anatomical sections on each hemithorax. A site was evaluated as positive when > 3 "B-lines" were detected. Animal treatment protocols were studied to clarify the final diagnosis (reference standard), and the sensitivity and specificity of lung ultrasound and chest X-ray for the diagnosis of pulmonary edema were calculated.*

Result: *Cats with a final diagnosis of cardiogenic pulmonary edema had a greater number of positive areas on ultrasound than those, in which respiratory distress was caused by non-cardiogenic pulmonary edema. The overall sensitivity and specificity of US for the diagnosis of pulmonary edema were 87 % and 89 %, respectively, and these values were similar to those of chest radiography (85 % and 86 %, respectively). The use of ultrasound led to a false diagnosis of cardiogenic pulmonary edema (ie, a false-positive result) in animals with diffuse interstitial or alveolar changes.*

Conclusions: *Ultrasound examination of the lungs in cats with respiratory distress syndrome is a promising diagnostic method. Emergency diagnosis of pulmonary edema in cats is difficult, especially in patients with severe shortness of breath, and limits the diagnostic evaluation. Chest x-rays are considered the standard diagnostic test, but the results are sometimes ambiguous and the process of obtaining the x-rays can increase respiratory distress in the animal.*

According to the results of the study, it was established, that ultrasound examination of the lungs can be used to differentiate the causes of shortness of breath (cardiogenic and non-cardiogenic) with sufficiently high sensitivity and specificity and less influence of the iatrogenic factor on the development of respiratory distress in cats, compared to chest radiography

Keywords: *respiratory failure, interstitial pattern, respiratory distress syndrome, ultrasound diagnosis of lungs, iatrogenic factor*

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1. Introduction

Ultrasound examination of the lungs is a simple and useful diagnostic method for respiratory tract pathologies. It is used to clarify the diagnosis of pulmonary edema, consolidation, atelectasis, embolism, neoplasia, pneumonia, pneumothorax, interstitial lung diseases, especially fibrosis, as well as any other signs of respiratory tract damage [1]. This method is relatively inexpensive, portable, easily accessible and does not affect the patient's body with ionizing radiation. In addition, it does not require anesthesia or a special position of the patient, which causes discomfort, so it is a common method in intensive care units.

Special protocols for rapid examination of animals in terminal conditions are known: veterinary ultrasound examination of the lungs (Vet BLUE) and (TFAST) [2]. They make it possible to establish a preliminary or even a final diagnosis very quickly, usually in less than 3 minutes. This speeds up diagnosis and allows earlier treatment, which can be important in saving the animal's life.

Basic ultrasound examination of the chest allows to recognize such artifacts as: lung-pleural line, A- and B-lines. The pulmonary-pleural line is a horizontal, hyperechoic line that moves back and forth with respiratory movements. A-lines are an artificial repetition of the lung-pleural line, which is displayed through the equal spaces of the pleura in the form of bright horizontal lines. They are mainly visible in normally aerated lungs. B-lines ("ultrasonic lung rockets") are visualized with interstitial-alveolar edema. They are the result of multiple movements of ultrasound beams back and forth between air and fluid, forming a long vertical hyperechoic artifact that begins at the pleural line and extends down the screen, moving along the pleural line in synchrony with respiration [2]. They occur due to the accumulation of a small amount of fluid in the lung tissue, surrounded by air, which creates a high impedence gradient. Their number and width correlate with the intensity of the pathology.

However, the presence of B-lines is not enough to establish a final diagnosis, since they are the result of interstitial-alveolar fluid, which can occur both with cardiogenic and non-cardiogenic pulmonary edema, as well as with acute respiratory distress syndrome, pulmonary bleeding of various etiologies, pneumonia, lung contusion. During the study, it is important to determine the number of B-lines, because a larger number of bands during a follow-up examination will indicate the progression of the disease, and a smaller number will confirm the effectiveness of treatment. The presence of a single B-line may be physiological, but more are indicative for lung pathology. The above-mentioned artifacts are easy to investigate, so basic ultrasound is highly reproducible – 92–97 % of researchers, depending on their experience, detect B-lines during ultrasonography in the corresponding lung pathology [3].

In recent decades, ultrasound has become a common diagnostic procedure in small animal clinical medicine. Although the use of ultrasound during chest examination has limitations due to excessive aeration of the lungs in clinically healthy animals [4, 5]. An acoustic window is created in the presence of pleural effusion and non-aerated lungs in sick patients [6, 7]. For cats with respiratory distress, ultrasound examination of the lungs is an easily accessible tool both for the initial assessment of the state of the respiratory system and in the intensive care unit [8, 9]. The presence or absence and characteristics of artifacts in the form of "comet tails", "lung rockets" or "B-lines" during the ultrasound examination of the lungs in cats make it possible to differentiate: lung contusion, pneumothorax, cardiogenic or non-cardiogenic pulmonary edema and alveolar-interstitial syndrome [10, 11].

Other sonographic features that have also been described as abnormalities on chest ultrasound in cats include the presence of: pleural effusion, subpleural nodules, masses, consolidation, atelectasis, and diaphragmatic rupture [12, 13]. The diagnostic value of ultrasound-guided fine-needle aspiration/biopsy of consolidated lung lesions or thoracocentesis for effusion drainage has been outlined in previous studies and case reports [14, 15].

Chest ultrasound has been widely studied and clinically applied in patients with various types of respiratory problems [16]. In patients with pleural effusion, it has been found, that the sonographic appearance of a complex, compartmentalized, or echogenic effusion may indicate an exudative process, whereas two-thirds of exudative effusions have been shown to be anechoic [17]. This indicates that a clinical decision based on ultrasound findings still needs to be carefully evaluated with other clinical studies. However, ultrasound helps detect more pulmonary pathologies than chest radiography, and sonographic features of a consolidated lung, such as an air-liquid bronchogram, a vascular pattern, or the presence of "B-line" artifacts, can help differentiate pneumonia, pulmonary embolism, lung neoplasia or lung contusion. Sonographic signs of consolidation with an air bronchogram and an indistinct edge were observed in ~90 % of patients with pneumonia, while nodes with a well-defined edge and the absence of an air bronchogram were more often observed in patients with pulmonary pneumonia, neoplasia [17, 18].

X-ray examination is important for detecting lung pathologies. However, results are often nonspecific or may be limited by the presence of pleural fluid or pathology of multiple thoracic organs. The usefulness of ultrasound of the chest cavity is maximal if it is performed together with radiography. The location and type of disease, seen on radiographs, can help in the formation of a potential acoustic window. Ultrasound plays an increasingly important role in the diagnosis of diseases of the lungs, pleura and mediastinum, providing information on the location, size, degree and nature of the lesion [19, 20].

In modern veterinary literature, there is limited data on the diagnostic characteristics of various pathologies of the chest cavity during ultrasound in cats, except for "B-line" artifacts. Thus, the objectives of this study were to reassess the results of chest ultrasound in cats with radiographic changes in the lung parenchyma and pleural space and to determine the diagnostic performance of different sonographic characteristics corresponding to specific diagnoses.

2. Materials and methods

The evaluation of records from the electronic database of the veterinary center "Vet House", Vinnytsia in the period 2017–2022 was carried out. For the study, the indicators of cats that came to the "Vet House" center for stabilization of a severe condition due to pulmonary edema were used. The diagnosis was established on the basis of the data of the clinical examination of the animals, the results of the X-ray examination of the chest cavity, the data of echocardiography (EchoCG) and the results of ultrasound diagnostics of the lungs. During the period 2017–2022, 130 cats with a diagnosis of "pulmonary edema" were examined. The average body weight of the animals was 4.5 (1.1–7.4) kg. The average age of animals was 7 years (from 2 to 12 years). Sick animals were divided into two groups according to the form of pulmonary edema: the first group (cardiogenic edema) – 85 cats, the second group (non-cardiogenic edema) – 45 animals. In the cats of both groups, a number of parameters were evaluated for differential diagnosis based on the results of clinical examination, echocardiography, ultrasound examination of the lungs, radiographs, and blood parameters.

The study complies with the recommendations of ARRIVE and the guidelines of EU Directive 2010/63/EU on the protection of animals, used for scientific purposes, and was conducted in accordance with the UK Animals (Scientific Procedures) Act 1986 [21].

Special studies of the clinical condition of animals were conducted on the basis of the "Vet House" center, using an ultrasound machine (GE Logiq E9, country of manufacture USA) and an X-ray machine (GE 46-270615P2H, country of manufacture Japan). The ultrasound examination was performed using microconvex and linear transducers, however, just the microconvex transducer was used more often, mainly because of its small head, which technically simplifies the examination.

Deeper structures are better visualized with the microconvex transducer, but the pleural line is usually less visible. Thus, the linear transducer was used when imaging the pleural line was most important. A basic ultrasound device, equipped with a microconvex and linear transducer with a frequency of 4.0–10.0 MHz, was used for the ultrasound examination of the lungs. This made it possible to carry out examinations both in a critical situation (when there is no time to switch the transducer) and during "routine" ultrasound diagnostics of the lungs in stable patients. During the examination, the animal was in a standing position or lying on the sternum, the hair was not cut, but separated after applying the appropriate amount of gel, the transducer was placed directly on the chest wall. The probe was positioned across the ribs to visualize the "alligator sign" (pleural line and two ribs). Four areas were examined on each thoracic side (caudodorsal, perigillar, middle, and cranial ones) with one scan for each area. The presence of A-lines with lung sliding was considered a sign of physiological aeration of the lungs. Interstitial-alveolar edema was recognized by the presence of B-lines. Additional ultrasound abnormalities, detected during the study: shred sign (air bronchogram), tissue-like sign (consolidation without aeration, hepatization) and "nodule" sign. Shred sign is a manifestation of partial consolidation of the lungs. The deeper border of the consolidated lung tissue, connected to the aerated lung, is crushed and uneven. A tissue-like sign – the lung resembles the liver tissue and is the result of translobar consolidation. The "nodule" sign is limited, completely surrounded by an aerated lung. B-lines extend from the distal border of each type of consolidation down the screen. The appearance of B-lines was described on a 5-point scale: absence of B-lines – 0 points (Fig. 1), single B-line – 1 point (Fig. 2), double B-line – 2 points (Fig. 3), numerous noticeable B -lines – 3 points (Fig. 4), as well as numerous indistinguishable B-lines – 4 points (Fig. 5).

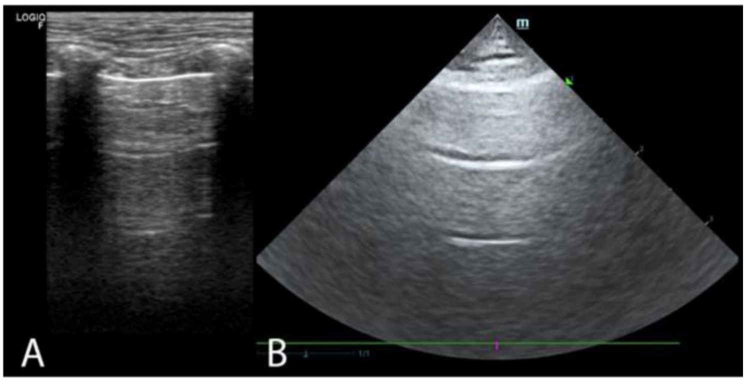

Fig. 1. A-lines. (A). Linear probe (B). A probe with a phased array

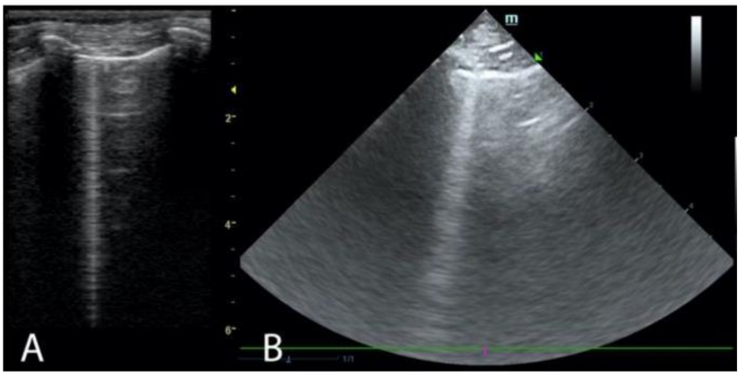

Fig. 2. One B-line (A). Linear probe (B). A probe with a phased array

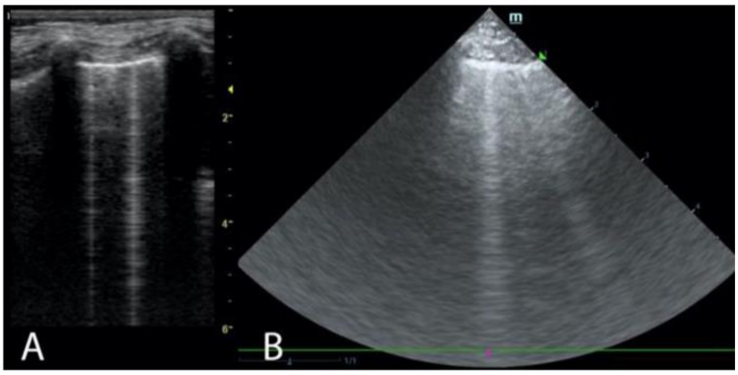

Fig. 3. Two B-lines. (**A**). Linear probe (B). A probe with a phased array

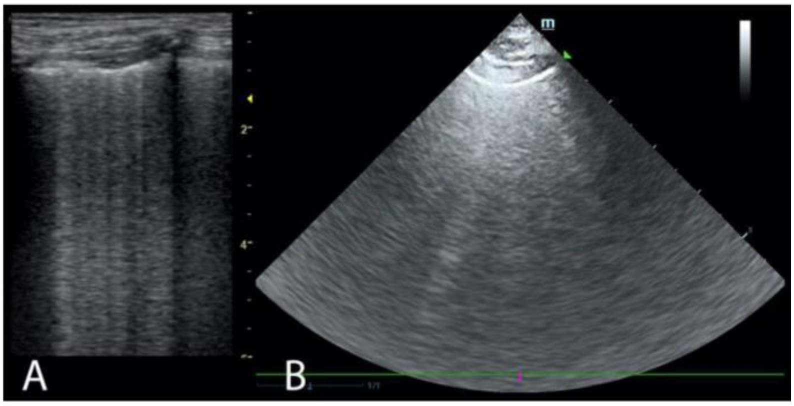

Fig. 4. Numerous noticeable B-lines. (**A**). Linear probe (B). A probe with a phased array

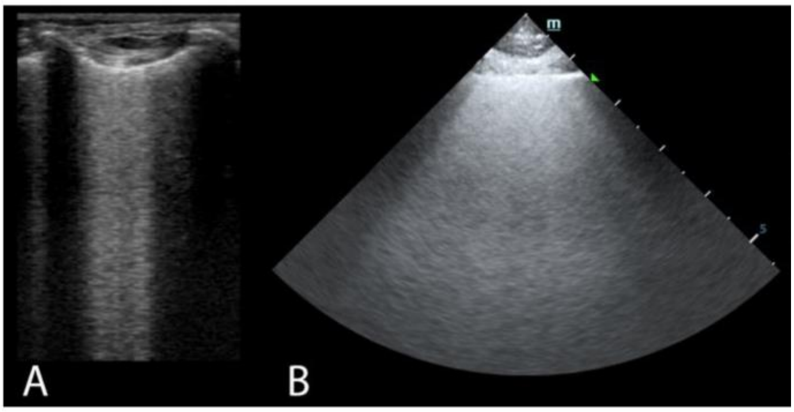

Fig. 5. Numerous indistinguishable B-lines. (**A**). Linear probe (B). A probe with a phased array

All patients also underwent an echocardiographic examination to rule out congenital or acquired heart diseases, cardiac neoplasms, pericardial effusion, etc. Cardiac ultrasound diagnosis was based on two different two-dimensional echocardiographic methods: left atrial (LA) and aortic root (Ao) diameter measurements in early diastole from the right parasternal short-axis projection at the base of the heart to calculate the LA:Ao ratio and LA diameter measurements from the right parasternal four-chamber view along the long axis at the end of systole.

Based on the results of echocardiography, the cats were divided into separate groups. The first group "hypertrophic cardiomyopathy (HCM) phenotype" – the maximum end-diastolic thickness of the wall of the left ventricle (LV) on the projection along the short axis at the level of the papillary muscle or on the projection from four chambers along the long axis and the LV outflow tract was ≥6 mm. The second group "phenotype of dilated cardiomyopathy (DCM)" – LV myocardial wall thickness ≤5 mm, increased LV internal diameter (i. e. LV diameter in diastole >14 mm) and partial shortening <28 %. The third group "restrictive cardiomyopathy (RCM) phenotype" – LA dilatation or biatrial dilatation with or without mild left ventricular wall thickening.

The size of the animal and the thickness of the area to be radiographed were taken into account when setting parameters for radiological examination. Three radiographic projections (right lateral (RLL), left lateral (LLL) and ventrodorsal (VD) were performed for all patients, excluding animals with dyspnea, in which only dorsoventral and one lateral positioning were performed. The silhouette of the heart, pulmonary vessels and lung parenchyma was evaluated. Interstitial and/or alveolar patterns were classified according to their distribution (ie, diffuse, multifocal, or focal).

3. Research results

We established breed characteristics among the examined cats with signs of pulmonary edema. These are cats of various breeds and mixed breeds, including: British Shorthair – 50 animals, mixed breed – 30, Sphynx – 28, Maine Coon – 22. The average body weight of the animals is 4.5 (1.1–7.4) kg. The average age of animals was 7 years (from 2 to 12 years). Cardiomyopathy was found in 65 % of cats with symptoms of pulmonary edema, among them: 43.6 % had hypertrophic cardiomyopathy (HCM), 10.7 % – restrictive cardiomyopathy (RCM), 7.7 % – dilated cardiomyopathy (DCM), 3 % – unclassified cardiomyopathy (UCMP). Non-cardiogenic pulmonary edema was found in 35 % of the animals.

Changes (noise, galloping rhythm, arrhythmia) were detected in animals diagnosed with pulmonary edema during auscultation of the lungs and heart. Tachypnea or orthopnea, respiratory distress and cough were noted most often. Arrhythmias, murmurs, weak/filament pulses, and prolongation of the capillary refill time (CRT) were found in patients with primary heart disease. During the examination, pale mucous membranes, weak pulse, and sometimes a decrease in body temperature during rectal measurement were revealed. To confirm the diagnosis, special research methods were used (chest radiography, ultrasound diagnostics of the lungs, and echocardiography). Thus, respiratory distress was the primary clinical sign for all animals, examined for pulmonary edema, as reported in a previous study [22].

Performing lung ultrasound was technically possible (all images, obtained at all 4 anatomical sites in each hemithorax) for all patients. The average interval ± standard deviation between ultrasound and chest radiography was 1.5±2 hours.

Overall, 65 % of patients had a final diagnosis of cardiogenic pulmonary edema, whereas 35 % of patients had a diagnosis of noncardiogenic pulmonary edema. Causes of cardiogenic pulmonary edema in cats: 57 (43.6 %) – HCM, 14 (10.7 %) – RCM, 10 (7.7 %) – DCM, 4 (3 %) – UCM. Causes of non-cardiogenic pulmonary edema in cats: 12 (9.4 %) – neoplasia, 9 (7 %) – pneumonia, 8 (6.2 %) – brain injury, 6 (4.6 %) – electric shock, 4 (3.2 %) – poisoning by toxic substances, 3 (2.3 %) – anaphylactic reaction, 3 (2.3 %) – airway obstruction.

At least 1 positive area (> 3 B-lines in one area) was found on lung ultrasound of patients with cardiogenic pulmonary edema in 75 of 85 with a mean of 5.2±2.5 positive areas per patient, which is 88.2 %. Ultrasonography of cats with noncardiogenic pulmonary edema showed positive areas in 30 of 45 patients with an average of 2.5±2.8 positive areas per patient, which is 66.6 %. Therefore, the number of positive areas during ultrasound at cardiogenic pulmonary edema is significantly greater compared to their number during ultrasound at non-cardiogenic pulmonary edema.

Overall, positive US findings were more common at all areas in patients with cardiogenic pulmonary edema than in patients with noncardiogenic pulmonary edema, and the overall distribution of positive areas was significantly different between the 2 groups (Table 1). For patients with cardiogenic pulmonary edema, the most common positive areas were the right and left medial ones, whereas for patients with noncardiogenic pulmonary edema, only the right medial area was rated as positive. In both groups, the right and left caudal areas were least rated as positive.

Table 1

Frequency (%) of positive results (> 3 B lines in one area) in each of the 8 anatomical areas evaluated by lung ultrasound

Anatomic areas	Cardiogenic pulmonary edema		Non-cardiogenic pulmonary edema	
	Left thoracic side	Right thoracic side	Left thoracic side	Right thoracic side
Cranial (Cr)	75 %	69 %	34 %	39 %
Middle (Md)	77 %	76 %	49 %	34 %
Perigilar (Ph)	74 %	66 %	38 %	36 %
Caudodorsal (Cd)	43 %	59 %	27 %	27 %

B-lines are observed mainly for pulmonary edema during the ultrasound examination of the lungs. With cardiogenic pulmonary edema, the pleural line is smooth, while with non-cardiogenic edema, it is thickened and there are marked subpleural compactions (shred sign, tissue-like sign, and nodules). These lesions, accompanied by the presence of B-lines, are strongly suggestive of noncardiogenic pulmonary edema. In addition, cardiogenic B-lines are mainly on both sides of the chest, are more diffuse, and disappear after several hours of diuretic therapy. B-lines with tissue-like signs were noticeable mainly for pneumonia, and signs of nodules – for neoplasia.

The result of ultrasound was a highly significant predictor of the final diagnosis. The sensitivity and specificity of ultrasound were 87 % and 89 %, respectively. The overall sensitivity and specificity of chest radiography for the diagnosis of pulmonary edema were 85 % and 86 %, respectively. A positive ultrasound result was defined as at least 2 of 4 anatomic areas that were considered positive (>3 B lines/in one site) for each hemithorax. A ratio >1 indicates an increased likelihood that pulmonary edema is present, and a ratio <1 indicates a decreased likelihood that pulmonary edema is present.

The diagnosis of pulmonary edema (considered the reference standard for the aforementioned calculations) was made by reviewing the history, clinical examination, laboratory test results, response to treatment; results of echocardiography, ultrasound diagnostics of the lungs and results of interpretation of radiological data for each patient.

12 cases of non-cardiogenic pulmonary edema were identified as cardiogenic pulmonary edema during the ultrasound examination. False positive results were obtained for 4 animals with pneumonia, 3 animals with craniocerebral trauma, 3 animals with electric shock, 2 animals with toxic substance poisoning.

Additional patient characteristics at initial evaluation (heart rate, respiratory rate, rectal temperature, presence and severity of heart murmurs) were investigated for the potential to increase the diagnostic accuracy of US. The specificity of ultrasound for cats will improve if the heart rate is taken into account during the initial evaluation. When all patients with an initial heart rate <150 bpm were reclassified as having noncardiac disease, the specificity of US improved to 88 %, although the sensitivity decreased to 52 %. Other patient parameters, such as respiratory rate, rectal temperature, and murmurs characteristics, did not have a significant impact on the diagnostic accuracy of ultrasound.

During the x-ray examination, a qualitative and quantitative radiographic evaluation of the silhouette of the heart was first performed. The subjective absence or presence of cardiomegaly (if present, classified as mild, moderate, or severe), concavity and/or presence of a notch at the level of the caudal edge of the cardiac silhouette, and the absence or presence of a "bulge" in the left atrial region were evaluated. The presence or absence of a "valentine-shaped" silhouette of the heart and a "double wall" at the level of the left atrial area were considered. The quantification of cardiac silhouette was performed by measuring cardiac long axis, cardiac short axis, vertebral heart to determine cardiomegaly.

The subjective assessment of pulmonary vasculature was performed by evaluating abnormalities of the pulmonary veins and pulmonary arteries, namely dilation, tortuosity, and dissection. These abnormalities were then classified according to the lobe of the lung involved.

Lung parenchyma was evaluated for the presence of an interstitial or mixed interstitial-alveolar pattern (increased lung opacity without or with obliteration of air spaces, respectively). These radiographic patterns were then classified according to distribution as follows: diffuse (all lung areas involved); multifocal (several areas of more than one lobe of the lung are involved); or focal (one area of one lobe of the lung is affected). Asymmetric distribution was considered when only one lobe of the lung or two ipsilateral lobes were involved, and all other distributions were considered symmetrical. Multifocal and focal patterns were further classified according to their location as craniodorsal, cranioventral, caudodorsal, caudoventral, or central.

The presence of a bronchial pattern and other various radiographic findings, such as subjective moderate pleural effusion, caudal vena cava dilatation, and aerophagia, were recorded.

Pulmonary edema was radiologically characterized by a decrease in the transparency of lung areas, and the images were not stable. X-rays of the examined cats showed signs of a granular interstitial pattern, an alveolar pattern, and an alveolar-interstitial pattern. Among the radiographs, on which a pronounced alveolar pattern was visualized, there were 42 animals with air bronchograms, and 33 with an increased diameter of pulmonary vessels and a bronchial pattern. According to the characteristics of the distribution of changes in the pulmonary pattern due to pulmonary edema, the radiographs were divided into groups: the pattern was considered diffuse/even in 48 animals (36.9 %); diffuse/uneven in 43 (33.1 %); multifocal in 22 (16.9 %) animals and focal in the remaining 17 (13.1 %) animals. According to the prevalence of the process in the lungs, changes were visualized in the areas: lobary in 37 animals, regionally in 67 animals, among them ventrally in 30 animals, caudally in 15 animals, peripherally in 10 animals, cranially in 5 animals and ventrally with further spread in 7 animals (Fig. 6). Radiological symmetry of lung structure damage, which was assessed by studying dorsoventral or ventrodorsal projections, could be determined for 68 (52.3 %) animals. Areas of reduced lung transparency were bilaterally symmetrical in 39 (57.3 %) animals. Lesions of the lung structure on radiographs were asymmetric in the remaining 62 (47.7 %) of the examined animals, and they were predominantly right-sided asymmetric in 23 (37 %) of them.

On lateral radiographic projections, the caudodorsal quadrant of the lung area was mainly involved. In general, animals with non-cardiogenic pulmonary edema due to airway obstruction had the greatest degree of radiographic damage to the lung structure, followed, in descending order, by animals with pulmonary edema, caused by craniocerebral trauma, and animals with pulmonary edema due to electric shock (Fig. 7).

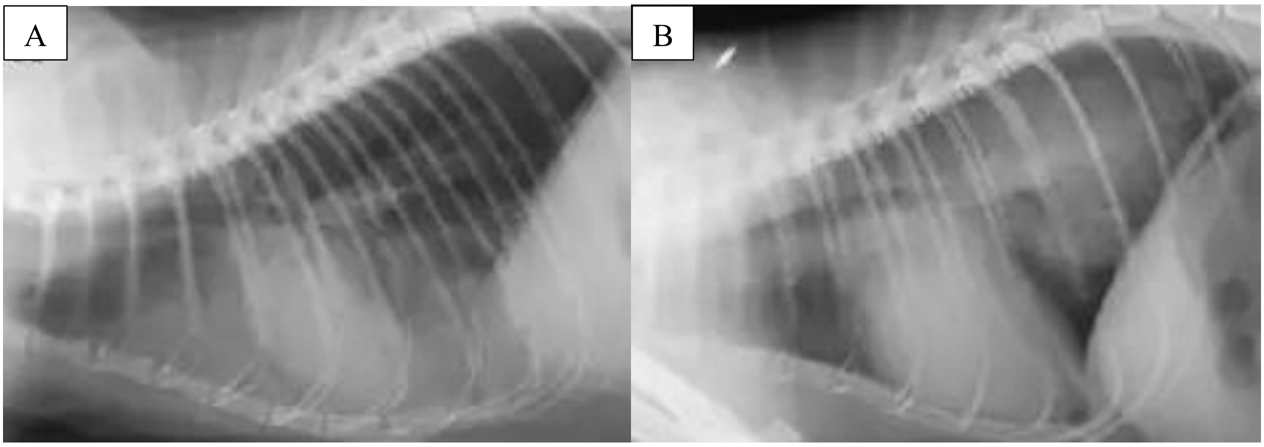

Fig. 6. Regional distribution of alveolar structures associated with pulmonary edema: A – ventral distribution; B – caudal distribution

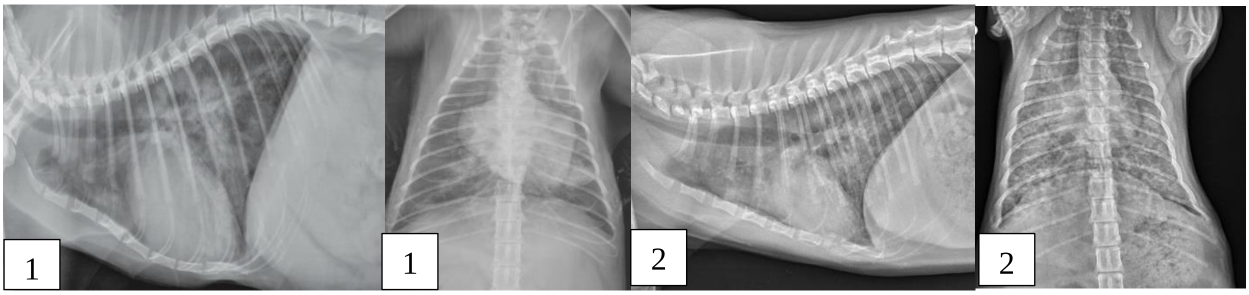

Fig. 7. Ventrodorsal and mediolateral radiographs of the chest cavity of cats with signs of cardiogenic (1) and non-cardiogenic (2) pulmonary edema

To assess the severity of lung lesions, the area of lesions was calculated on radiographs. Thus, local or diffuse lesions of the interstitial tissue of the lungs, which did not exceed 25 % of the lung area on the radiograph, were found in 30 animals; damage to the parenchyma covering up to 50 % of the lung area on the radiograph - in 45 animals; lesions of the lung parenchyma over 75 % of the lung area on radiographs – in 55 animals.

4. Research results discussion

In this study, the overall sensitivity of lung US for diagnosing pulmonary edema in cats with acute dyspnea was high (87 %) and similar to chest radiography (85 %). A previous study of lung ultrasound in cats revealed a large number of B-lines and positive areas with signs of pulmonary edema, which indicated 100 % sensitivity [23]. However, in these studies, lung ultrasound was performed on a selected small group of animals, in which the diagnosis of pulmonary edema had already been made by chest radiography, and no prospective assessment of diagnostic accuracy was performed.

The sensitivity of lung ultrasound for the diagnosis of pulmonary edema was slightly higher – 81.3 % to 98.3 % (average sensitivity 94.1 %) in the study by Smargiassi A. compared to the study in cats [24]. In this study, 8 patients with a final diagnosis of pulmonary edema did not have positive areas, identified by lung ultrasound (ie, had false-negative results). The diagnosis of pulmonary edema in these patients was made on the basis of these clinical signs, radiography, and echocardiography. The lower sensitivity of lung ultrasound in animals, compared to humans, may be related to differences in anatomical structure, performance, and pathophysiological mechanisms.

Previous lung ultrasound studies have found very low numbers of B-lines or positive areas in clinically healthy animals, indicating 100 % specificity in differentiating clinically healthy animals from animals with pulmonary edema [23]. All patients in this study had dyspnea and therefore had a high probability of lung disease that could potentially cause artifacts (eg, B-lines) on lung US images. The mean number of positive areas (> 3 B-lines/area) for animals with pulmonary edema (2.7) was higher than the mean total number of B-lines (sum of all areas), reported for clinically healthy animals (0.9).

The use of lung US resulted in the correct identification of B-lines and positive areas in those patients in whom interstitial or alveolar disease was confirmed radiographically, similar to the results of the previous study.

We also investigated whether taking into account the results of the initial clinical examination could improve the diagnostic accuracy of lung US. Because of the pathophysiological nature of the disease, congestive heart failure would be expected to cause a higher heart rate, lower rectal temperature, and louder heart murmurs than in cats without heart disease. Adding heart rate to the analysis slightly improved the specificity of lung US, but the difference in diagnostic accuracy was small. Rectal temperature and the presence or intensity of heart murmurs did not affect the diagnostic efficiency of lung ultrasound.

The Volpicelli criterion, used to define a positive lung ultrasound in this study, requires bilateral distribution of pulmonary edema (ie, at least 2 positive areas). Previous research in veterinary medicine has shown that the anatomical distribution of pulmonary edema differs depending on the type of pulmonary edema. Cats more often had a diffuse or multifocal distribution of pulmonary edema. The distribution of positive areas of pulmonary edema in this study suggests that the middle quadrants of the lungs were most frequently involved, regardless of whether patients had cardiogenic or noncardiogenic pulmonary edema. This differs from the results of a previous study of pulmonary edema in animals [24], which showed that the perigillar and caudodorsal quadrants were more often positive in a small number of animals. A possible explanation for these differences is that cranial and caudodorsal areas may be technically more difficult to image, and image quality may be lower in these locations. The midsections are often the easiest to map, given the heart's orientation. Another possible reason could be that lung ultrasound can detect only lesions that extend to the periphery of the lungs. Additional studies are needed for a more accurate correlation of lung ultrasound results from one to another location of lung lesions on chest X-rays.

Lung ultrasound was available in all cats in this study, and we observed minimal evidence of additional stress in these patients. In many situations, lung ultrasound was performed through a small opening in the oxygen cage to minimize animal stress. Adequate images were obtained only using the gel to facilitate contact with the probe.

Limitations of the study. This study had several limitations. First, the number of patients was limited (n=130). Second, our patient population may have been biased by including more patients with cardiogenic pulmonary edema (65 %) compared with non-cardiogenic pulmonary edema (35 %). Third, we used the final clinical diagnosis as our reference standard in determining the diagnostic accuracy of lung ultrasound diagnostics.

Additional limitations of this study were the 6-hour maximum interval, allowed between lung ultrasonography and chest radiography, and the possibility that the pattern of pulmonary lesions may have changed during this period (especially if diuretics were used). Pulmonary ultrasonography was suggestive of cardiogenic pulmonary edema and chest X-ray findings were suggestive of non-cardiac disease in 9 of these patients, and chest X-ray findings were suggestive of cardiogenic pulmonary edema in the other 12, whereas lung US findings were suggestive of non-cardiogenic pulmonary edema. If these discrepant results were due to a prolonged interval between the 2 examinations or the administration of diuretics, one would expect that US-positive and radiographically negative results would appear before chest radiography (with diuretics in between), and US-negative, X-ray positive results after X-ray of the chest (with the introduction of diuretics in between). However, no such pattern was found for patients with discordant results; the mean interval between ultrasound and chest radiography for these patients was not longer, the order of examinations did not follow the above pattern, and none of the patients received diuretics between imaging modalities. Thus, despite a theoretical concern, the delay between examinations and diuretic administration did not affect our results. A possible explanation for the US-negative, radiographic-positive results could be that several animals had mild interstitial pulmonary edema, suggesting that US may not have been sensitive enough to detect very early and mild signs of pulmonary edema.

A general limitation of the ultrasound technique is the requirement for an ultrasound device at the point of care, which may not be available in clinical practice. The effectiveness of ultrasound can depend on several factors related to the equipment, including the ultrasound model, the probe, the software, and the quality of training of the ultrasound technician. Since ultrasonography is based on identifying artifacts rather than specific structures at high resolution, this method can be useful even with less expensive equipment.

In the study, providing point-of-care ultrasound to cats with dyspnea minimized additional patient stress. The accuracy of the technique for diagnosing pulmonary edema as a cause of dyspnea was quite high, with a sensitivity similar to chest radiography.

Prospects for further research. Due to the relatively small study group of animals, we could estimate the diagnostic accuracy of our algorithm with only moderate accuracy. Further research on a larger research group of animals is necessary, which will help in the development of an effective algorithm for diagnostic actions for pulmonary edema in domestic cats.

5. Conclusions

The results of this study provide information on the diagnostic effectiveness of various imaging characteristics of ultrasound and X-ray examination of the chest in cats. Common findings, such as consolidation artifacts, comet tail, and thickened/irregular pleura, are nonspecific. Although a definitive diagnosis cannot be made solely on sonographic data, some characteristics of chest ultrasound can help predict the etiology and establish the diagnosis.

All clinical cases in this study showed some lung parenchymal changes on chest radiographs and were therefore further evaluated. A chest radiograph is usually the first approach in clinical patients with signs of dyspnea. However, radiographic information may be reduced by the presence of effusion or severe alveolar-interstitial infiltration adjacent to neoplastic lesions, likely obscuring the underlying etiology. Although computed tomography can help elucidate the anatomic relationship between lesions and surrounding structures, the high cost and common need for general anesthesia in cats may limit its use. Ultrasound examination allows the use of a safe, inexpensive, radiation-free and easily reproducible imaging method to visualize a variety of etiologies in patients with signs of pulmonary edema.

Consequently, lung ultrasound has surpassed radiography as a diagnostic tool for acute respiratory failure in critically ill patients and often replaces conventional chest radiography and even CT. Ultrasound diagnosis of the lungs has significant advantages over conventional imaging methods, as the method is fast, noninvasive and does not generate ionizing radiation. Unlike computed tomography, ultrasound diagnostics of the lungs is an affordable method of diagnosis. Due to its high mobility, ultrasound can be used near the animal box and in conditions of emergency care. However, most importantly, ultrasound diagnostics is generally superior to conventional imaging methods in terms of accuracy (ie, sensitivity and specificity) and diagnostician training. However, a comprehensive approach should be taken for an accurate diagnosis, taking into account the indicators of a clinical examination, radiographic diagnosis, ultrasound diagnosis of the lungs and echocardiography.

Therefore, ultrasonography and lung radiography were useful in detecting and classifying the extent of alveolar or interstitial lung disease. Both modalities revealed differences in the distribution of alveolar-interstitial syndrome based on final diagnosis, suggesting that a regional approach to chest imaging may be diagnostically useful.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results, presented in this article.

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Data availability

The manuscript has no associated data.

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