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Original article

Transthoracic lung and pleura ultrasonography as a diagnostic tool of pulmonary edema in dogs and cats

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Abstract

Despite the consensus on the role of lung and pleura ultrasound in human medicine, veterinary medicine questions credibility of the pulmonary evaluation in ultrasound examination, based on the analysis of artifacts in animals with clinical signs of respiratory failure and possibility of pulmonary edema diagnosis with recognition of the degree of its severity. The study was conducted on 47 animals (29 dogs and 18 cats) of different breeds, age and sex. In all of animals prior to the transthoracic lung and pleura ultrasound examination (TLPUS), all animals were subjected to a clinical examination and hematological blood test as well as chest radiography examination in three projections. Ultrasound imaging of the chest in each animal was performed at designated four defined segments. TLPUS in dogs and cats based on an analysis of artifacts allows recognition of pulmonary edema, to the degree comparable to chest X-ray examination. The number of depicted B-lines artifacts is proportional to the degree of pulmonary edema. These results allow to reduce the number of radiographs and allow the shortening of the diagnostic process for patients in life-threatening condition.

Key words: dog, cat, respiratory failure, pulmonary edema, lung ultrasound

Introduction

Due to the physical properties of ultrasound, ultrasonographic evaluation of the lung tissue is possible by the analysis of artifacts and not the image on the screen (Lichtenstein 2012, Volpicelli et al. 2012, Lisciandro et al. 2014). Most of the artifacts comes from the pleura, which makes it one of the key elements of the ultrasound of the chest. Artifacts are the result of the interaction of ultrasound and penetrated tissues but not depicting anatomical structures of examined part of the body. In transthoracic lung and pleura ultrasonography

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(TLPUS) in animals the intercostal spaces (IS) are used as acoustic windows to apply the probe. Publications on ultrasound diagnosis of lung in humans discuss the normal lung image in transthoracic ultrasound and artifacts used to assess lung disorders (Lichtenstein 2012, Volpicelli et al. 2012). The ultrasound images of particular artifacts are well known and described in available literature, thus in this publication they are not described.

There are only few publications on TLPUS in dogs and cats (Lisciandro et al. 2008, Lisciandro 2011, Boysen and Lisciandro 2013, Lisciandro et al. 2014, Rademacher et al. 2014). In order to evaluate the ultrasonographic signs of pulmonary edema (in comparison to properly aerated lungs) we analyzed A-lines, B-lines, Z-lines and bat sign, sliding sign (gliding sign), color doppler sign and seashore sign. According to literature reports, the diagnosis of interstitial lung disease using ultrasound is possible by assessing not only the presence but also the number of B-lines artifacts generated by the reflection of ultrasound from the thickened subpleural interlobular septa. So far TLPUS is not used for diagnosis of the very specific changes but only to determine the general category of lung disease. Due to reports of a positive correlation between the number of artifacts in B-lines and the degree of interstitial-alveolar syndrome of lung (defined as pulmonary edema) an attempt to analyze the diagnostic capabilities of pulmonary edema using ultrasound was undertaken (Copetti et al. 2008). Only small number of documented research in lung ultrasound in dogs and only few reports in cats suggest the need for polemics on the issue of evaluation and analysis of individual artifacts to help diagnose pulmonary edema. In this study etiology of pulmonary edema was not considered. The aim of study is the assessment of the diagnostic TLPUS utility in dogs and cats with clinical symptoms of respiratory failure as a cause of pulmonary edema and comparison to chest radiography. Other purpose of this study is the evaluation of the possibility of using TLPUS based on artifacts in clinical practice and possibility to reduce number of radiograms accelerating diagnostic procedure in the emergency and critical care unit in patients with pulmonary edema.

Materials and Methods

The study was conducted on 29 dogs and 18 cats of different breeds, age and sex. All of animals were divided in two groups: control group (I) and clinical group (II). Control group consisted of healthy animals showing no clinical signs from the respiratory system and without clinically relevant changes in chest X-ray radiography. The control group (I) consisted of 20 animals (12 dogs and 8 cats) of different breeds and sex, 7 months – 11 years of age. The results of the blood morphology of animals in group I were within reference standards. The average age of the group was 6 years. The average weight for dogs was 27 kilograms (kg), for cats 4.5 kg.

The clinical group (II) consisted of 27 animals (17 dogs and 10 cats) of different breeds and sex, 6 months-17 years of age, in which chest radiography examination showed pulmonary edema of different degree. Radiologically visible symptoms of the trachea collapse excluded animal from the study. Group II also encompassed animals with changes in the lung parenchyma accompanied by a trace amount of free fluid in the pleural cavity. The average age of the group was 8 years. The average weight was 18.6 kg for dogs and 4.3 for cats.

In all of animals, prior to the ultrasound examination (US), the clinical examination, a hematological blood test and a radiography chest examination in three projections (right side, left side and dorsal-ventral) were done. All radiographs were taken using Konica Minolta Regius 110S, Siemens lamp 3D Vertix 75 kV. All ultrasound scans of lung and pleural cavity were conducted using Philips ultrasound En Visor C. The time between the tests was no more than 20 min. All animals were examined without premedication.

The type of ultrasound probes in the examination were used: microconvex (5-8 MHz) and linear probe (3-12 MHz). Most examinations were performed with use of microconvex probe to unify the image of many studies and because in most publications it is preferred type of probe (Lichtenstein 2010, Volpicelli et al. 2012). Patients were predominantly in the sternal recumbency position. Methodology is analogous to the method of scanning the lung and pleural cavity as described in the literature (Soldati et al. 2009). To carry most of the studies it was sufficient to cover the skin with an alcohol solution and gel for ultrasound.

Ultrasound imaging of the chest in each animal was performed at four designated segments: area between the intercostal spaces I-VI and VII-XII on the left and right chest side along each IS. The segmentation of the chest of the tested animals was a modified method described by Rademacher et al. 2014. Lung US was started with the B-mode presentation followed by the M-mode. The study was carried out in transverse and longitudinal plane, moving the probe along each IS. Doppler examination was performed secondarily. After setting the Doppler gate on the pleura line, in order to unify study, amplification of echo Doppler parameters was set for each patient in the same range of values (GAIN 75-85). For statistical purposes, modified scale division was used, differentiating the degree of radiological changes and incidence of selected artifacts. Analogous to the tests described in the available literature, dogs and cats were not divided into species subgroups, but it was decided to divide the groups due to the pathogenesis of the disease.

Scale used in this work to assess the degree of alveolar-interstitial changes shown on x-ray, is the modified version applied in the work of Brown et al. (Brown et al. 2013). The modification was to use scale from 0 to 3, instead of 1 to 3 as used by Brown. In addition, assessment of the radiographic vascular and pleural cavity visualization for more detailed analysis of the changes was used. In this work scale from 0 to 3 was used to differentiate severity of edema on X-ray, maintaining the same division of the chest in 4 segments as in the US. Grade 0 was used for the area of the lung with normal radiographic findings. Single small foci of lung tissue mineralization and/or bronchial walls as well as gentle reaction of an interstitial tissue were allowed, seen in older or obese animals, feature appropriate to the age. Vascular visualization was well seen and correct. Pleural cavity and trachea showed no radiographic changes. Grade 1 characterized lung area of mild edema changes. The changes were weakly expressed, lung area was predominantly aerated (small generalized increased opacities of lung tissue). Pleural cavity and trachea were correct. Bronchial reaction component was admissible. Vascular visualization was well seen. Grade 2 was used to qualify an area of moderate intensity changes. Pulmonary edema was in the middle stage, which was expressed by the partial reduction of lung aeration (moderately increased opacities of lung tissue). The changes were clearly visible in at least two X-ray projections. Unambiguous assessment of pulmonary vessels was not possible due to the poor visibility. Presence of a small amount of free fluid in the pleural cavity was visible. Grade 3 was characterized by an area of strongly expressed radiological features of pulmonary edema, often covering most of the lung area (strongly increased opacities of lung tissue). Significant reduction in lung aeration was observed. Changes were clearly visible in all three projections, often bronchogram was present. Vascular signs were not sufficient to evaluate. Free fluid in the pleural cavity was observed.

Examination covered sonographic assessment of various artifacts. In each animal the maximum number of separated artifacts of B-lines in each segment of IS was also evaluate. It was assumed, based on literature reports, that ultrasonography picture visible in at least 50% of examined intercostal spaces was considered possible to reliably assess the condition and provide the basis for classification according to the adopted scale (Soldati et al. 2009). B-lines artifacts in a two-dimensional imaging were counted using uniform scale described by Lisciandro et al. (Lisciandro et al. 2014). The scale for assessing the degree of edema in the TLPUS was adopted from 0 to 3 where 0 – no visible B-lines artifacts, 1 – 1 to 3 B-lines well separated from each other, 2 – above 3 B-lines, 3 – numerous, countless, consolidated B-lines (i.e. white lungs).

Results

In the control group, there were no abnormalities observed, neither in M-mode nor in B-mode US. In all animals, pleural line was well visualized, in more than 50% intercostal spaces artifacts of A-lines, the sliding signs, color Doppler sign, and the seashore sign were clearly visible (Fig. 1). A-lines was visible in 70% of animals. Separated B-lines have been reported in 15% of the animals. In these cases, the B-lines were visible in only a few projections, and the number did not exceed 3 B-lines in a single plane.

All analyzes in this study were conducted in the Statistica 10 StatSoft Inc. program, at a significance level of 5%.

Due to the nonparametric data represented in the ordinal scales, to assess the dependence between findings in the X-ray and ultrasound, chi^2 independence test was used to check the dependence between variables and Spearman's rank correlation coefficient (Rs) to determine the strength of data convergence.

Comparison of radiological and ultrasound assessment in scale (0-3) for animals in the control group was carried out. Independence of variables has been shown in the chi^2 test (p=0.266); Spearman's rank correlation coefficient R=0.124 showed no statistical significance (p=0.272). Demonstrated independence of radiographic and ultrasound data for the animals in the control group is due to the very small variation of data in this test: 85% of the animals has in both cases a score of 0, and the remaining 15 potential combinations accounts for 12 cases.

In group II, both in B-mode and M-mode examination, in all animals pleural line was well demonstrated. In all animals tested there was clearly visible sliding sign and color Doppler sign was visible in more than 50% of them. Z- lines artifacts were clearly visible in 9 animals (33.3%). In approx. 22% of dogs and cats (6 animals) seashore signs and the A-lines were visible, but less distinguishable, visualized in less than half of the intercostal spaces. No patient had seashore sign see in more than 50% of spaces.

Comparison of radiological and ultrasound assessments in scale (0-3) for pulmonary cranial segments on the left side was carried out; dependence of the vari-

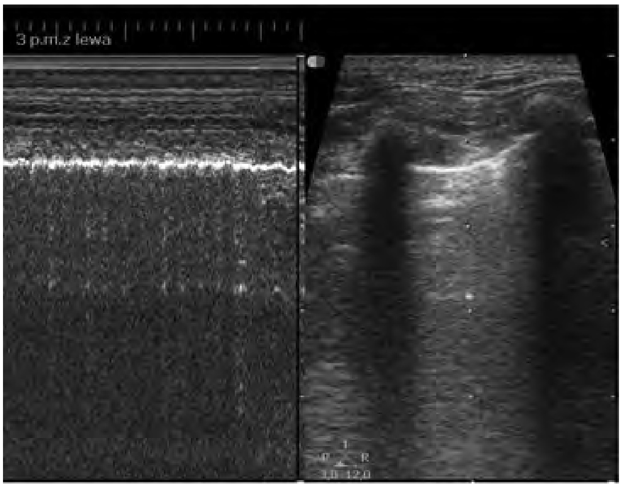

Fig. 1. Image showing normal lung and pleural cavity ultrasound appearance. On the left side is visible seashore sign in M-mode. On the right side bat sign and hyperechogenic pleural line movement visible in real-time as a sliding sign in the B-mode.

Fig. 2. Image showing rare, septal B-lines artifacts originating from hyperechogenic pleural line in the B-mode.

ables has been shown in the chi² test ($p<0.001$). Spearman's rank correlation coefficient Rs=0.813 showed statistical significance ($p<0.001$). Comparison of radiological and ultrasound assessments in scale (0-3) for pulmonary caudal segments on the left side was carried out; dependence of the variables has been shown in the chi² test ($p=0.009$). Spearman's rank correlation coefficient Rs=0.794 showed statistical significance ($p<0.001$). Comparison of radiological and ultrasound assessments in scale (0-3) for pulmonary cranial segments on the right side was carried out; dependence of the variables has been shown in the chi² test ($p<0.001$). Spearman's rank correlation coefficient Rs=0.861 showed statistical significance ($p<0.001$). Comparison of radiological and ultrasound assessments in scale (0-3) for pulmonary caudal segments on the right side was carried out; dependence of the variables has been shown in the chi² test ($p<0.001$). Spearman's rank correlation coefficient Rs=0.786 showed statistical significance ($p<0.001$).

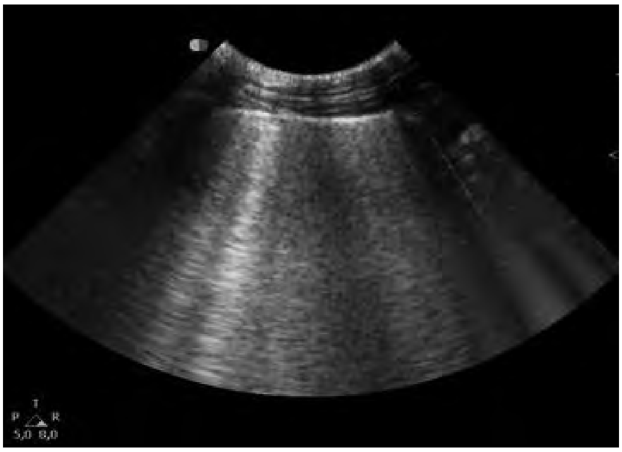

Fig. 3. Image showing multiple, quite well separated from each other, B-lines artifacts derived from the hyperechogenic pleural line in the B-mode (8MHz).

Fig. 4. Image showing numerous, countless, confluent B-lines (i.e. white lungs) between two ribs in B-mode.

Results of the rate frequency and nature of B-lines visualization in each chest segment in all animals with the characteristics of pulmonary edema shown in TLPUS:

In the cranial pulmonary segments on the left side in 44.4% of the animals have observed more than 3 B-lines, quite well separated from each other (Fig. 3.). In 33.3% of the animals we have seen from 1 to 3 B-lines well separated from each other, in 22.2% of the animals numerous, countless, consolidated B-lines were visible.

In caudal pulmonary segments on the left side in 37.1% of the animals we observed more than 3 B-lines, well separated from each other. In 44.4% of the animals there were either no B-lines or from 1 to 3 B-lines well separated from each other, in 18.5% of the animals numerous, countless, consolidated B-lines were visible. In cranial pulmonary segments on the right side in 44.4% of the animals there were numerous, countless, consolidated B-lines (Fig 4). In 29.6% of the animals were above 3 B-lines, quite well separated from each other, while in 22.2% of the animals from 1 to 3 B-lines well separated from each other and in 3.8% of the animals no B-lines were observed. In caudal pulmonary segments on the right side in 37% of the animals have observed above 3 B-lines, quite well separated from each other. In 26% of the animals there were observed numerous, countless, consolidated B-lines. In 22.1% of the animals there were from 1 to 3 B-lines well separated from each other (Fig. 2), and in 14.8% of the animals no B-lines were observed.

Discussion

In this research, selection of radiological examination, as the preferential method of comparison to ultrasound of lung and pleura in dogs and cats, was done based on the literature reports concerning veterinary medicine (Lisciandro et al. 2008). This is consistent with previous reports in human medicine where, among other things, was used as a precedence over the TLPUS chest radiography (Volpicelli et al. 2006, Copetti et al. 2008, Lichtenstein and Meziere, 2008). In this study, chest radiography was performed in three projections based on generally accepted principles of radiography, the experience of the author and conclusion drawn from the article of Lisciandro et al., that two projections may not be sufficient to clearly assess the lung and pleura (Lisciandro et al. 2014). Based on method described in the literature and also with a predilection of change at given IS in patients with pulmonary edema indicated by the chest radiography, technique of scanning along each intercostal space was adopted, allowing for accurate analysis of the changes observed (Soldati et al. 2009, Volpicelli et al. 2013).

TLPUS, to a very large extent, is based on an assessment of artifacts (Lichtenstein 2010, Lichtenstein 2012). Since in all animals in the control group well visible signs occurred: sliding, seashore, singular A-lines and no more than 3 B-lines artifacts in the IS, the author is inclined to the idea that the simultaneous occurrence of the above artifacts allows to identify properly aerated lungs and normal pleura cavity. In this study in 70% of animals from group I and only in 33% from group II multiple Z-lines were observed, which confirms the literature findings that Z-line artifact is a good indicator for normal lung in the US (Khosla, 2012). In our study, in 10% of the animals of the control group, x-ray showed mild interstitial reaction while US did not show B-lines. This may confirm lack of correlation of changes typical for pulmonary edema in dogs with poorly expressed changes in pulmonary perenchyma, particularly in older animals (mean age for this 10% of the animals was 10.5 years whereas for all control group was 6 years). In our study in 25% of the animals of the control group, only in a few IS single B-lines were observed (never more than 3 B-lines in a single projection). In those animals x-ray showed no abnormalities, and in 5% of animals with mild interstitial changes there were no clinical symptoms. This result can be seen as the credibility of the literature reports allowing the occurrence of individual B-lines not exceeding 3 in a single intercostal projection where x-ray showed no changes in the chest (Lisciandro et al. 2014). Compared to the publication of Lisciandro et al. in which in the animals without clinical symptoms and without any radiographic changes author describes frequent incidence of single B-lines on the left side of the chest, there were no comparable results in our study, in which there was no predilection to the side of the chest (Lisciandro et al. 2014). Our results are consistent with findings published by Lisciandro et al. describing B-lines as easily recognizable and detectable by ultrasound, enabling an objective assessment independent from the influence of noise arising from the environment or animal dyspnea (Lisciandro et al. 2014). According to the literature, numerous B-lines depicted in TLPUS in human medicine are seen in patients with radiologically diagnosed alveolar-interstitial syndrome testifying the pulmonary edema, where also numerous, consolidated B-lines are seen and described as "white (wet) lungs" (Copetti et al. 2008, Lichtenstein and Meziere 2008, Kosiak 2010, Rademacher et al. 2014). In our study we used a similar approach as Via did to classify changes allowing for a relative unification of the results. Comparably to the research discussed in the work of the Via et al. 2010, we demonstrated features of aggravated interstitial-alveolar syndrome in animals in which the TLPUS showed more than 3 B-lines in a single IS with varying degrees of mutual separation until the blurring their boundaries creating an image of "white lung" (Via et al. 2010). Noble et al. in their publication show the diagnostic capabilities of pulmonary edema when during examination more than three B-lines in the two areas were observed (Noble et al. 2009). There are also reports in the literature, that there is a linear correlation between the number of B-lines and the degree of radiologically visualized accumulation of extravascular fluid (Jambrik et al. 2004).

In our study statistical analysis assessing the degree of convergence between severity of interstitial-alveolar changes in x-ray and the evaluation of artifacts TLPUS, taking into account segmentation of lungs into four parts, showed statistical significance for all examined areas of the lung. This result confirms the literature reports, according to which the authors proof the credibility and legitimacy of US in the diagnosis of pulmonary edema in dogs and cats (Via et al. 2010, Rademacher et al. 2014). For this reason, TLPUS seems to be a promising examination technique in the diagnosis of pulmonary edema, regardless of its pathogenesis, enabling rapid and effective implementation of appropriate treatment.

It is worth to note that in veterinary medicine, lung ultrasound based on the analysis of B-lines artifacts, is not specific to disease, because B-lines on the screen reflect not only change of the nature of pulmonary edema but also pleural thickening and/or interlobar septum and pulmonary fibrosis (Koegelenberg et al. 2012). In human medicine there are reports describing pulmonary fibrosis associated with pleural thickening with visible B-lines artifacts (Gargani 2011). There are several advantages of TLPUS: this method is non-invasive, harmless, gives an instant result, relatively lower costs and greater availability in comparison with examination by computer tomography. Additional advantage is the possibility of repeated examinations during the therapeutic process. This allows for immediate verification of the effectiveness of implemented treatment and monitoring of disease symptoms (Andruszkiewicz and Sobczyk 2013). There are few restrictions of TLPUS shown both in our study and in the literature: subcutaneous emphysema, lack of contact of the lesion with pleura or chest wall, the patient's obesity, pleural adhesions, and (in the case of the assessment of some of the artifacts), strong respiratory movements of the chest (Stefanidis *et al.* 2011).

Conclusion: TLPUS in dogs and cats, based on an analysis of artifacts, is a very useful tool to recognize pulmonary edema comparable to chest X-ray examination. The number of B-lines artifacts is proportional to the degree of pulmonary edema thus allowing pulmonary edema diagnosis with the indication of the severity of the changes, regardless of the strong respiratory movements of the chest.

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