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RESEARCH

Role of echocardiographic views adapted for lung evaluation in diagnosis of cardiogenic pulmonary edema in Dogs

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Abstract

The objective of this study was to determine whether echocardiographic views adapted for lung evaluation may aid in diagnosis of dyspnea in dogs. Fifteen chronic valvular heart disease (CVHD) dogs without cardiac remodeling, 30 CVHD dogs with cardiac remodeling, 15 CVHD dogs with cardiogenic pulmonary edema and 15 dogs with pulmonary disease were prospectively enrolled. Loop recordings of pericardial-lung ultrasound were gathered during echocardiographic evaluation, and four videos of 4 different adapted views were recorded for each dog. Chest X-rays were used as reference-standard for pulmonary edema and/or disease. The videos were classified based on the number of B- lines as NEGATIVE (0, 1, 2 or 3) or POSITIVE (> 3 or confluent). Accuracy of a POSITIVE classification in identifying pulmonary edema and/or disease was calculated. Multivariate analyses were performed using echocardiographic variables that reflect increased left ventricular filling pressure (LVFP) to distinguish pulmonary edema from disease. Results showed that a POSITIVE classification distinguished dogs with pulmonary edema or disease from asymptomatic CVHD dogs in all four views. The best views were right parasternal short axis at papillary muscle level and long axis 4- chamber view, both with the same sensitivity (86.7%) and a specificity of 95.6% and 82.2%, respectively. Multivariate analyses showed that adding cutoff values of peak E wave > 130, E/IVRT > 2.5 or LA/Ao > 2.0 distinguished pulmonary edema from disease with 100% specificity. In conclusion, echocardiographic views adapted for lung evaluation, in addition to conventional echocardiography, may help identify the cause of dyspnea in dogs.

Keywords Lung ultrasound · B lines · Heart failure · Dyspnea · Pneumonia

Introduction

Dyspnea is a common cause of admittance in small animal practice, and thoracic radiography is currently considered to be the clinical standard for diagnosis (Rozanski & Chan 2005; Dear 2020; Atkins et al. 2009). However, thoracic x-rays are of unspecified accuracy, especially when it comes to combined heart and lung disease (Balbarini et al. 1991) In addition the demand for multiple recumbences and physical restrain may exacerbate respiratory distress in unstable patients. The use of bedside lung ultrasound (LUS) has been validated and gained acceptance in veterinary medicine over the past decade, and can be an alternative for identifying pulmonary and pleural space disease in patients in severe respiratory distress (Rademacher et al. 2014; Lisciandro et al. 2017; Ward. et al. 2017; Lisciandro et al. 2014). The LUS technique uses a high frequency curvilinear US probe and relies upon the observation of ultrasonographic artifacts (horizontal A-lines versus vertical B-lines) to differentiate between dry and wet lung patterns (Lisciandro et al. 2014; Baad et al. 2017; Lichtenstein et al. 1997 ; Louvet & Bourgeois 2008). Nevertheless, although LUS is considered a reliable and useful tool for detecting cardiogenic pulmonary edema (CPE) in dogs, there is consistent overlapping with parenchymal pulmonary disease (Ward et al. 2017). Therefore, heart size and function should be assessed in addition to LUS, to increase diagnostic accuracy.

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Echocardiography is the gold-standard tool to identify and stage chronic valvular heart disease (CVHD) (Atkins et al. 2009; Chetboul & Tissier 2012). Volume overload and increased left atrial size and left ventricular filling pressure (LVFP) are underlying conditions associated with the development of CPE, and may be suspected upon the visualization of acknowledged echocardiographic variables of cardiac remodeling and pulmonary congestion (Ohno et al. 1994; Schober et al. 2008, 2010). Morphologic and Doppler-derived parameters however, although useful in refining diagnosis, do not give precise information regarding pulmonary parenchyma. Thoracic radiographs can be performed, but may be challenging in patients with respiratory distress. Bedside LUS is generally safe in unstable patients, but gives no information regarding heart size and function, and has marked overlapping with pulmonary disease such as pneumonia (Ward et al. 2017; Lisciandro et al. 2014). An integrated approach evaluating the lungs, pleural space, and heart should lead to an improved accuracy of diagnosis. In this study the authors hypothesized that additional information regarding pulmonary edema and/or disease could be obtained during standard echocardiography, limiting the need of multiple exams in challenging conditions. Therefore, the purposes of this study were (1) to test if a sector probe, as opposed to a curvilinear probe, is useful in identifying wet lung patterns during echocardiographic examination, in a similar fashion as the LUS technique, when focused on the pericardial-lung interface; (2) to identify the best adapted echocardiographic views for such purpose; and (3) to determine if the combination of cardiac remodeling, doppler-derived indices of elevated left ventricular filling pressure (LVFP) and wet lung pattern, obtained from echocardiography alone, may refine the diagnosis of the underlying cause of dyspnea in dogs.

Materials and methods

Dogs recruited for this prospective multicenter cross-sectional study were selected among patients admitted for veterinary care at a wide range of private veterinary clinics. All procedures received client consent and were previously approved by UFPR's institutional Animal Use Committee and complied with the National Institutes of Health Guide for the Care and Use of Laboratory Animals.

In order to be included in the study, the diagnosis and staging of CVHD in dogs was required, which was based on clinical history, echocardiographic identification of impaired valvar anatomy, presence or not of cardiac remodeling and clinical manifestation or absence of respiratory distress (Atkins et al. 2009; Chetboul & Tissier 2012; Borgarelli & Haggstrom 2010). Dogs presenting with respiratory signs

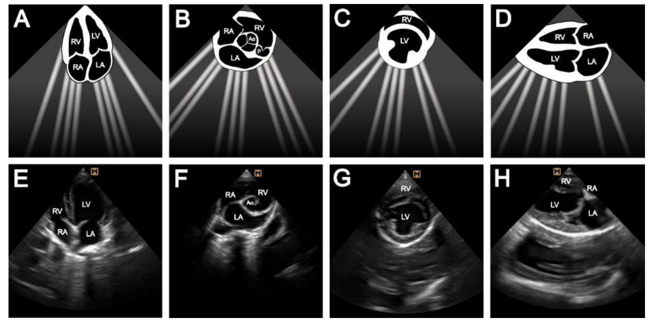

Fig. 1 A schematic illustration of the 4 adapted echocardiographic views used in this study, with B lines arising from the pericardial-lung interface, above each corresponding echocardiographic image. A and E: Left parasternal apical 4 chambers view (LPA4C); B and F: Right parasternal short axis at aortic level (RPSAo); C and G: Right parasternal short axis at papillary muscle level (RPSPM); and D and H: Right parasternal long axis 4 chambers view (RPL4C). Ao: aorta; LA: left atrium; LV: left ventricle; RA: right atrium; RV: right ventricle

and with a medical history, physical examination and blood work indicative of primary pulmonary disease of multiple causes were also gathered to compose a pulmonary disease (PD) group. Dogs with another concomitant heart disease in addition to CVHD, or clinically debilitated dogs due to other systemic underlying conditions were not enrolled in the study. For asymptomatic CVHD dogs with and without cardiac remodeling, and for dogs with CPE or PD, two-view thoracic radiography was used as the reference standard for pulmonary findings. Dogs that could not tolerate radiographic or echocardiographic examination within 3 h of admittance were also excluded from the study. A diffuse distribution of interstitial to alveolar pulmonary infiltrates, along with left cardiac enlargement and a positive clinical response to diuretic therapy was considered diagnostic of CPE (Diana et al. 2009). Echocardiography was carried out by either one of two operators, with over 7 years of experience (BCB and ATG) using an ultrasonography system (MySono U6 – Samsung, Suwon, South Korea) equipped with 3.0–8.0 MHz and 2.0–4.0 MHz sector probes (P2-4 and P3-8 reference – Samsung, Suwon, South Korea).

During echocardiographic examination, loop recordings with increased depth, placement of the heart in the upper 1/3 of the screen and positioning of the focal point at the lung plane were used for image gathering and posterior post-acquisition evaluation in the following standard echocardiographic views: left parasternal apical 4-chamber view (LPA4C), right parasternal short axis at the level of aortic valve (RPSAo), right parasternal short axis at the level of papillary muscles (RPSPM) and right parasternal long axis 4-chamber view (RPL4C). A schematic figure of the adapted views, along with the corresponding echocardiographic images is shown in Fig. 1.

The videos were recorded immediately after routine evaluation of each window, not adding significant amount

Table 1 Demographic data and echocardiographic variables in 15 control dogs, 15 mitral valve disease dogs with cardiac remodeling (RM), 15 mitral valve disease dogs with increased left ventricular filling pressure (RM&CONG), 15 dogs in pulmonary edema (CPE) and 15 dogs with pulmonary disease (PD).

	Control		RM		RM&CONG		CPE		PD		p-value between groups*
	M	SD	M	SD	M	SD	M	SD	M	SD	
Age	5.6[a]	3.7	12.2[b]	3.3	12.3[b]	2.4	12.3[b]	2.4	13.1[b]	2.0	< 0.001
Weight	7.8[a]	5.4	6.8[a]	3.4	6.8[a]	4.0	5.7[a]	2.6	6.6[a]	3.2	0.908
LA:Ao	1.1[a]	0.1	1.7[bc]	0.1	2.0[bd]	0.3	2.2[d]	0.4	1.3[ac]	0.2	< 0.001
LVdn	1.4[a]	0.2	1.8[b]	0.1	2.1[b]	0.2	2.0[b]	0.3	1.3[a]	0.4	< 0.001
E peak	68.3[a]	13.3	88.3[a]	20.0	156.0[b]	20.4	141.4[b]	26.8	64.0[a]	22.8	< 0.001
E:IVRT	1.4[a]	0.4	1.8[a]	0.5	6.6[b]	3.2	6.4[b]	3.0	1.2[a]	0.6	< 0.001

M:mean; SD: standard deviation; LA:Ao: left atrium to aortic ratio; LVdn: normalized left ventricle diameter in diastole ; Epeak: peak mitral E wave; E:IVRT peak mitral E wave to isovolumic relaxation time ratio.

*ANOVA ; different letters means significant differences in multiple comparisons

of time to the exam. Also, echocardiographic parameters including left atrium aortic root ratio (LA/Ao)(Hansson et al. 2002), normalized left ventricular internal diameter in diastole (LVIDDn) (Cornell et al. 2004), peak velocity of E wave of transmitral flow (Emax), isovolumic relaxation time (IVRT) and peak velocity of E wave isovolumic relaxation time ratio (E/IVRT) were either measured or calculated for each dog for the sorting of groups, and posterior statistical analyses. During the exam, most dogs were placed in lateral recumbence and maintained in position by gentle physical restraint. In dogs presenting with respiratory distress, the exam was executed under oxygen administration, and the right parasternal views were performed with the dogs in standing position, with no relevant loss of quality of the data obtained. Most of the dogs in unstable conditions received a bolus of 2–4 mg/kg of furosemide at admittance, and an individualized protocol of treatment was initiated immediately after diagnosis. Dogs considered too unstable to tolerate physical restraint despite these measures were not admitted in the study.

For analyses and statistical purposes, dogs were divided into 5 different groups based on cardiac remodeling according to the American College of Veterinary Internal Medicine (ACVIM) classification scheme (Atkins et al. 2009) (stage B defined as subclinical heart disease without (B1) or with (B2) evidence of left cardiomegaly, defined as both LA/Ao ≥ 1.6 and LVIDDn > 1.7), presence or absence of increased LV filling pressures and radiographic evidence of pulmonary edema or disease (interstitial and/or alveolar lung patterns) (Atkins et al. 2009; Ward et al. 2018). The groups were named as follows: (1) Control (CVHD stage B1 patients); (2) Remodeled (RM) CVHD stage B2 patients presenting low evidence of increased left ventricular filling pressure (LVFP) (Emax < 1.0 m/s and E/IVRT < 2.0); (3) Remodeled and Congested (RM&CONG) (CVHD stage B2 with strong evidence of increased LVFP and congestion of pulmonary veins (Emax > 1.3 m/s and E/IVRT > 2.5); 4): Cardiogenic pulmonary edema (CPE); and 5) Pulmonary disease (PD). For each dog, four video loops were obtained (LPA4C, RPSAo, RPSPM and RPL4C) for post-acquisition assessment. In each video, the number of B lines (hyperechoic vertical lines extending without fading from the pericardial-lung interface to the far aspect of the ultrasound screen) was tabulated. The analyses were performed individually by 2 veterinary cardiologists, blinded to the dogs' clinical, echocardiographic, and radiographic data. The number of B lines was classified as 0, 1, 2, 3, > 3 or confluent (too many to count), and each video was marked as NEGATIVE (0, 1, 2 or 3) or POSITIVE (> 3 or confluent).

Statistical analyses

Statistical analyses were performed using commercially available software. All data underwent the Shapiro-Wilk normality test. Mean and standard deviation (SD) were used to provide descriptive statistics for normally distributed continuous variables, such as age, weight, and relevant echocardiographic variables. Breeds were presented as relative frequencies. An analysis of variance followed by Tukey´s multiple comparison test was used to investigate differences between groups. To evaluate the accuracy of a POSITIVE/NEGATIVE classification in distinguishing CPE and PD from the other three groups, relative frequencies were estimated for these results, in each one of the four adapted views. The association between these classifications was checked with a chi-square test. Based on these frequencies, sensitivity, specificity, positive and negative predictive values, accuracy and the odds-ratio of each view were obtained. The level of agreement between two investigators was further examined by calculation of Cohen's kappa. Levels of agreement based on kappa values were interpreted as poor (0.00–0.20); mild (0.21–0.40); moderate (0.41–0.60); good (0.61–0.80); very good (0.81–1.00).

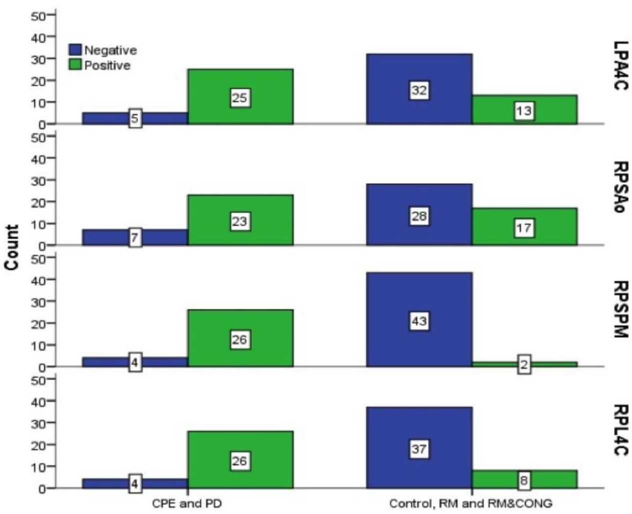

Fig. 2 Bar chart depicting the number of POSITIVE and NEGATIVE classifications in each one of the 4 views tested, when putting together groups with the same expected results (Control, RM and RM&CONG Vs. CPE and PD) LPA4C = Left parasternal apical 4 chambers view; RPSAo = Right parasternal short axis at aortic level RPSPM = Right parasternal short axis at papillary muscle level; RPL4C = Right parasternal long axis 4 chambers view

Finally, multivariate analyses was performed, with predetermined cutoff values of Emax, LA/Ao and E/IVRT, to distinguish POSITIVE CPE dogs from PD dogs. For all analyses, statistical significance was set at $P < 0.05$.

Results

Seventy-five client-owned dogs that met all inclusion criteria among the total of animals recruited by the end of the study were enrolled. The age and body weight of the animals ranged from 6 to 16 years and 1.7–21.7 kg, respectively. There was no difference between groups regarding weight (P = 0.908), but a significant difference in age was documented between the control group and every other group (P < 0.001). Several breeds were included, but mixed-bred (n = 13, 17.3%), Miniature Poodles (n = 10, 13.3%) and Lhasa apsos (n = 10, 13.3%) were overrepresented. Descriptive statistics of the studied population is shown in Table 1.

Of the fifteen dogs with confirmed CPE, five (33.33%) were previously diagnosed stage C patients, in chronic use of pimobendan, furosemide, benazepril and spironolactone, whereas two (13.33%) were stage B2 dogs, in chronic use of pimobendan alone. The remaining eight (53,33%) dogs in CPE group had no previous diagnosis of cardiac disease, and were not taking any chronic medication.

Of the thirty dogs with remodeled hearts without CPE at the time of examination, nine (30%) were known stage B2 patients, in chronic use of pimobendan as monotherapy. The

Table 2 Values of sensitivity, specificity, positive and negative predictive values and correct and incorrect classifications in dogs with cardiogenic pulmonary edema (CPE) or pulmonary disease (PD)

	Groups CPE and PD				
	Sn(%)	Sp(%)	PPV(%)	NPV(%)	Accuracy(%)
LPA4C	83.3	71.1	65.8	86.5	76.0
RPSAo	76.7	62.2	57.5	80.0	68.0
RPSPM	86.7	95.6	92.9	91.5	92.0
RPL4C	86.7	82.2	76.5	90.2	84.0

CPE: cardiogenic pulmonary edema; PD: pulmonary disease; Sn: Sensitivity; Sp: Specificity; PPV: Positive predictive value; NPV: Negative predictive value; LPA4C: Left parasternal apical 4- chamber view; RPSAo: Right parasternal short axis at aortic level RPSPM: Right parasternal short axis at papillary muscle level; RPL4C: Right parasternal long axis 4- chamber view

remaining 21 (70%) dogs had no previous history of cardiac disease, so no medication had been prescribed before.

Regarding the dogs in the respiratory group, twelve (46%) were diagnosed with pneumonia, five (33.3%) with chronic bronchitis, two (13.33%) were diagnosed with pulmonary metastasis, and one (6.66%) was diagnosed with neurogenic edema attributable to cluster seizures, based on clinical and radiographic findings and response to treatment, according to follow-up given by the DVM in charge. None of the dogs were in chronic use of medication at the time of diagnosis.

When arranging together groups with the same expected results based on positive radiographic findings (CPE + PD), 25 out of 30 (83,33%), 23/30 (76,66%), 26/30 (86,66%) and 26/30 (86,66%) videos were correctly classified as POSITIVE for views LPA4C, RPSAo, RPPM and RPL4C, respectively. Similarly, with groups Control, RM and RM&CONG, 32 out of 45 (71.11%), 28/45 (62.22%), 43/45 (95.55%) and 37/45 (82.22%) were correctly classified as NEGATIVE when using images LPA4C, RPSAo, RPAP and RPL4C, respectively (Fig. 2).

A positive classification based on each of the four adapted echocardiographic views (> 3 or confluent B lines) was able to differentiate dogs with cardiogenic edema or pulmonary disease from animals without radiographic pulmonary infiltrates. Sensitivity, specificity, positive and negative predictive values, accuracy and the odds ratio are show in Table 2.

Best interobserver agreement was obtained when RPSP and RPL4C images were used (kappa 0.88 and 0.86, respectively). An illustrative image of how the B lines behave in all 4 adapted views between groups is shown in Fig. 3.

LA/Ao, Emax and E/IVRT were the echocardiographic variables used in the multivariate analyses. Cut-off values of 1.6 and 2.0 for LA/Ao, 1.0 m/s and 1.3 m/s for Emax and 2.5 for E/IVRT were able to distinguish dogs with CPE from dogs with PD with 100% specificity, for animals that had > 3 B lines in views RPSPM and RPL4C. Values of sensitivity,

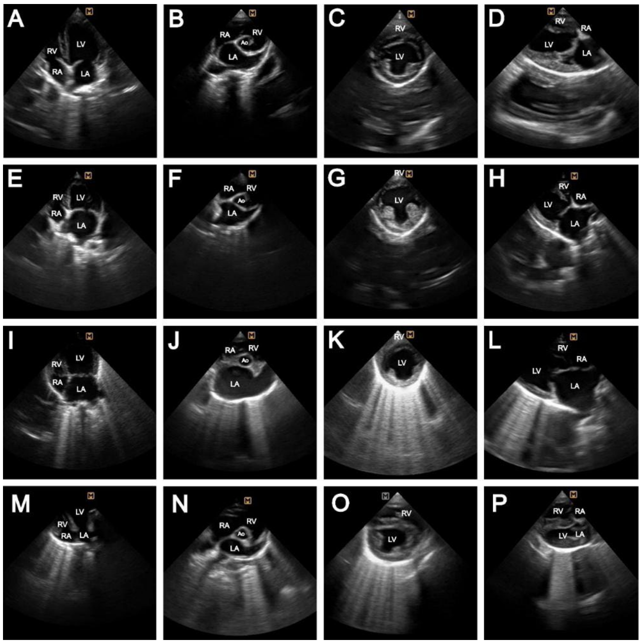

Fig. 3 Composition of 16 images showing the presentation of B lines in different clinical situations, in all 4 adapted echocardiographic views, from 4 dogs belonging to 4 different groups. A to D: Control; E to H: Remodeled (RM); I to L: Cardiogenic pulmonary edema (CPE); M to P: Pulmonary disease (PD); Ao: aorta; LA: left atrium; LV: left ventricle; RA: right atrium, RV: right ventricle

specificity, positive and negative predictive values and accuracy are show in Table 3.

Discussion

Differentiating causes of respiratory distress in dogs is challenging in clinical practice, especially if based solely on medical history and physical examination (Martindale et al. 2016). Unsurprisingly, the majority of diagnostic tests involve some degree of physical restrain and stress to the patient. In addition, most test results are not conclusive on their own, which can be time consuming and, for some clients, cost-prohibitive. This study assessed whether a single diagnostic tool might be enough for heart and lung evaluation during critical settings.

The results of this investigation show that echocardiographic views adapted for lung evaluation, in addition to standard echocardiographic findings, are a straightforward way of ruling in or out CPE as the cause of dyspnea in dogs. The technique consists of applying LUS techniques with sector probes during conventional echocardiographic examination, and analyzing the previously described wet/dry lung patterns on the pericardial-lung interface. Our study has shown that a POSITIVE classification usually matches the findings of interstitial to alveolar pulmonary infiltrates found in thoracic radiographs in dogs with CPE and lung disease, in every one of the four different views tested.

Even though the four different views were able to identify CPE and PD, RPL4C and RPSPM were the ones with best accuracies (92% and 84%, respectively) and less false positives. In contrast, LPA4C and RPSAo, were the adapted views with most false negatives, suggesting a higher number of artifacts arising from the cardiac base even in healthy individuals. In addition to having the highest sensitivity and specificity, RPSPM is considerably easy to obtain, even in patients in standing position, which may be more suitable for dogs in respiratory distress. Our findings are in accordance

Table 3 Values of sensitivity, specificity, positive and negative predictive values and accuracy of multivariate analyses when combining a positive classification (> 3 B- lines) and selected echocardiographic variables to distinguish dogs with cardiogenic pulmonary edema (CPE) from dogs with pulmonary disease (PD).

	CPE vs. PD when RPSPM and RPL4C are POSITIVE					
	Sn (%)	Sp (%)	PPV (%)	NPV (%)	Accuracy (%)	P-value
RPSPM positive + LA:Ao > 1.6	100.0	83.3	87.5	100.0	92.3	< 0.001
RPL4C positive + LA:Ao > 1.6	100.0	83.3	87.5	100.0	92.3	< 0.001
RPSPM positive + LA:Ao > 2	64.3	100.0	100.0	70.6	80.8	0.002
RPL4C positive + LA:Ao > 2	64.3	100.0	100.0	70.6	80.8	0.002
RPSPM positive + peak E > 1.0 m/s	100.0	91.7	93.3	100.0	96.1	< 0.001
RPL4C positive + peak E > 1.0 m/s	100.0	91.7	93.3	100.0	96.1	< 0.001
RPSPM positive + peak E > 1.3 m/s	64.3	100.0	100.0	70.6	80.8	0.002
RPL4C positive + peak E > 1.3 m/s	64.3	100.0	100.0	70.6	80.8	0.002
RPSPM positive + E:IVRT > 2,5	100.0	100.0	100.0	100.0	100.0	< 0.001
RPL4C positive + E: IVRT > 2.5	100.0	100.0	100.0	100.0	100.0	< 0.001

CPE: cardiogenic pulmonary edema; PD: pulmonary disease; Sn: Sensitivity; Sp: Specificity; PPV: Positive predictive value; NPV: Negative predictive value; RPSPM: Right parasternal short axis at papillary muscle level; RPL4C: Right parasternal long axis 4- chamber view with a recently published study on pericardial-lung-ultrasound, which used a similar technique for the identification of CPE (Hori et al. 2020).

Differentiating cardiac from non-cardiac causes of dyspnea has long been of interest in various studies, especially due to the urgency that such situations require (Feissel et al. 2009). The clinical utility of biomarkers such as natriuretic peptides has been previously reported, owing to their relation with cardiac stretch (Fine et al. 2008). However, no test is optimal when used as a single modality approach, and the unavailability of a point-of-care canine NT-proBNP assay limits its utility in the emergency setting (Oyama et al. 2008).

Although LUS is well validated in dogs, with ≥ 3 B lines within a single intercostal space being a surrogate for CPE (Lisciandro et al. 2014), such technique could not differentiate CPE from other causes of alveolar-interstitial syndrome, since parenchymal pulmonary diseases produce the same wet-lung pattern (Ward et al. 2017; Lisciandro et al. 2014). For this reason, information regarding underlying cardiac disease and staging is of utmost clinical importance. Although the auscultation of a systolic apical murmur during physical examination in small dogs over 6 years of age is highly suggestive of CVHD, an echocardiogram is fundamental to confirm and stage the disease, as well as identify increased left ventricular filling pressure (LVFP) (Chetboul & Tissier 2012; Schober et al. 2008; Schober et al. 2010). Adding lung evaluation by means of the adapted RPSPM echocardiographic view proposed by the authors to a standard echocardiographic examination showed a high positive predictive value (92,9%) in the identification of wet lung pattern, in addition to reliably informing about cardiac condition, solving the inconvenience of pulmonary disease overlapping.

The interobserver agreement was very good for views RPSPM and RPL4C (kappa 0.88 and 0.86, respectively), which makes this technique repeatable for cardiologists and intensivists in the clinical setting. The method of classification, as it is with standard LUS, is very straightforward and not time consuming, allowing for immediate diagnosis and therapeutic management. In cases where cardiogenic edema is ruled out by lack of cardiac enlargement, but pulmonary disease is suspected upon the visualization of > 3 B lines, further diagnostic tools such as thoracic radiographs, bronchoscopy or computerized tomography scans should be considered (Johnson & Wisner 2007; Masseau & Reinero 2019). Nonetheless, for patients in respiratory distress it seems enough for the immediate therapeutic management, especially when it comes to deciding upon the use of diuretics.

Although the technique discussed in this study is accurate in identifying wet-lung patterns, there was no way, as expected, to distinguish CPE from PD by the visualization of the B lines alone. For this reason, the authors recommend the technique to be used as an extension of the standard echocardiographic examination. In spite of doppler variables of increased left ventricular filling pressure (LVFP) demanding a higher degree of specialty, and being difficult to obtain from dogs in severe respiratory distress, LA/Ao performed well, and many studies have showed that non-specialists can obtain LA/Ao ratios consistently through focused echocardiograms in an acute care setting (Labovitz et al. 2010; Tse et al. 2013). Multivariate analyses in this study showed that adding known cutoff values of LA/Ao can increase the specificity of the B lines in diagnosing CPE up to 100% (Schober et al. 2008).

An important limitation of this research relates to the uncontrolled long-term medical treatment in patients in groups RM, RM&CONG and CPE, and the use of a 2-4 mg/kg bolus of furosemide prior to the imaging exams, which might have affected the amount of B lines. Nonetheless, positive classifications were still able to identify patients in CPE, as seen on thoracic radiographs. Another limitation is that the PD group is predominantly represented by pneumonia and chronic bronchitis (80%), which limits the extrapolation of these results to other pulmonary diseases, especially when it comes to focal pulmonary conditions. Furthermore, with the exception of a single patient where pulmonary metastasis was an unexpected finding, most patients presented some degree of respiratory distress at the time of the exam, which also might limit the applicability of our findings to patients with incipient diseases and mild respiratory signs. Although there was no difference between groups regarding weight, the effect of body condition over lung artifacts should be taken into consideration. In addition, although statistical analyses showed values of specificity up to 100% for the cutoff values used, one must not forget that this is a reflection of the studied population, where no marked overlapping of advanced cardiac remodeling and pulmonary disease was documented. Thus, one must keep in mind that these conditions may coexist as comorbidities, which may impact the accuracy of this technique when used in the clinical setting. It also should be pointed out that, although this study was directed to a population of CVHD dogs, there is no reason to believe this technique cannot be extrapolated to dogs or cats due to other clinical heart diseases. Future studies should be conducted in order to warrant this statement. Finally, the authors do not advise against the use multiple diagnostic techniques. However, pericardial-LUS, in addition to conventional echocardiographic exam, is appropriate for fast clinical decision-making, leading to an effective approach during the first critical hours of treatment.

Conclusion

This research showed that sector probes are efficient in the detection of wet lung patterns, with RPSPM and RPL4C performing as the most precise and repeatable adapted echocardiographic views. When used alone, pericardial LUS was not able to accurately differentiate CPE and PD. However, when combined with echocardiographic variables of cardiac remodeling and increased left ventricular filling pressure (LVFP), it was highly sensitive and specific for confirming CPE as the cause of respiratory distress. Adapting standard views for lung evaluation during echocardiography in dogs sufficiently stable to handle this exam is a simple, reliable, repeatable, and time sparing ancillary technique, that aides in the diagnosis of respiratory distress in dogs.

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Author contributions All authors contributed to the study conception and design. Material preparation and data collection were performed by Bruna Cristina Brüler and Amália Turner Giannico. Analyses were performed by Bruna Cristina Brüler, Amália Turner Giannico and Marcela Wolf. Figures were developed by Amália Turner Giannico. The first draft of the manuscript was written by Bruna Cristina Brüler and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Data Availability The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare no conflict of interest.

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Ethics approval The present study is in accordance with the precepts of Law no 11.794, of October 8th 2008, under Decree nº 6.899 of July 15th 2009, and with the edited rules from Conselho Nacional de Controle da Experimentação Animal (CONCEA), and approval was granted by the ANIMAL USE ETHICS COMMITTEE OF THE AGRICULTURAL SCIENCES CAMPUS OF THE UNIVERSIDADE FEDERAL DO PARANÁ (Federal University of the State of Paraná, Brazil), with degree 2 of invasiveness, in session of 05/12/2018. Protocol number: 094/2018.

Consent to participate Informed consent was obtained from all clinicians and tutors of the dogs included in the study.

Consent to publish The authors affirm that the tutors provided verbal consent for publication of any images and tables generated in this research.

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