Usefulness of pericardial lung ultrasonography for the diagnosis of cardiogenic pulmonary edema in dogs

Yasutomo Hori DVM, PhD

Yohei Yamashita DVM

Keiichiro Sakakibara DVM

Tadashi Sano DVM, PhD

Ai Hori DVM

Received July 28, 2019.
Accepted September 24, 2019.

From the School of Veterinary Medicine, Rakuno Gakuen University, Ebetsu, Hokkaido 069-8501, Japan (Y Hori, Sano, A Hori); Ebisu Animal Hospital, Sendai, Miyagi 982-0034, Japan (Yamashita); and North Animal Clinic, Sapporo, Hokkaido 064-0917, Japan (Sakakibara).

Address correspondence to Dr. Yasutomo Hori (y-hori@rakuno.ac.jp).

OBJECTIVE
To investigate whether lung ultrasonography (LUS) performed around the heart, where the lungs are in contact with the pericardium (ie, pericardial LUS), could be used for the diagnosis of cardiogenic pulmonary edema (CPE) in dogs with degenerative mitral valve disease (DMVD).

ANIMALS
15 control dogs with healthy hearts and 26 dogs with DMVD.

PROCEDURES
In a prospective multicenter study design, dogs with DMVD were assigned to 2 groups: those with CPE (n = 11) and those without CPE (15). Thoracic radiography, echocardiography, and pericardial LUS were performed for all dogs. For pericardial LUS, the left ventricular short-axis view was obtained with a sector probe (dog positioned in right parasternal recumbency) and the number of B lines was recorded. Accuracy of pericardial LUS for the diagnosis of CPE was calculated, with thoracic radiography used as the reference standard.

RESULTS
On thoracic radiography, all dogs with CPE had a diffuse distribution of interstitial to alveolar pulmonary infiltrates. On pericardial LUS, most control dogs (14/15) and dogs with DMVD but no CPE (13/15) had ≤ 2 B lines, whereas all dogs with DMVD and CPE had ≥ 3 B lines. The presence of ≥ 4 B lines had high sensitivity (91%; 95% confidence interval, 62% to 98%) and excellent specificity (100%; 95% confidence interval, 89% to 100%) for the diagnosis of CPE, and the area under the receiver operating characteristic curve was 0.99.

CONCLUSIONS AND CLINICAL RELEVANCE
Results suggested that identification of ≥ 4 B lines extending from the epicardium of the left ventricle into the lung field on pericardial LUS may be useful in the diagnosis of CPE in dogs with DMVD. Additional research is needed to determine whether pericardial LUS allows differentiation between CPE and pneumonia. (*Am J Vet Res* 2020;81:227–232)

Degenerative mitral valve disease is the most common acquired heart disease in dogs. Advanced DMVD can result in severe complications, including CPE, pulmonary hypertension, and cachexia.[1–3] Because of the life-threatening nature of CPE, rapid and accurate diagnosis and emergency care are required.

Auscultation and thoracic radiography are standard methods for the detection of CPE in dogs. Auscultation allows evaluation of heart murmurs as well as the presence or absence of pulmonary edema through the detection of abnormal inspiratory sounds such as crackles. Additionally, thoracic radiography is considered a high-yield test for the presence of CPE, which manifests as an interstitial or mixed interstitial-alveolar pattern in the lung fields in addition to cardiac enlargement.[4,5]

Lung ultrasonography has recently attracted attention in emergency and intensive care settings in human and veterinary medicine.[5–8] Compared with thoracic radiography, LUS has several advantages in that it is radiation free, can be performed bedside in a few minutes, and can be used for the diagnosis of lung and thoracic diseases in real time. In human medicine, LUS can be used to rapidly diagnose the underlying cause of acute respiratory failure, such as pleural effusion, pneumothorax, and pulmonary interstitial disease.[6,9] With LUS, healthy lungs have evidence of horizontal repetition artifacts, with hyperechoic lines arising from the pleural line (ie, A lines), indicating that the pulmonary capillary wedge pressure is < 18 mm Hg (ie, dry lungs).[10] By contrast, lungs with interstitial

ABBREVIATIONS

AUC	Area under the receiver operating characteristic curve
CPE	Cardiogenic pulmonary edema
DMVD	Degenerative mitral valve disease
LA:Ao	Left atrial diameter-to-aortic root diameter ratio
LUS	Lung ultrasonography
LVIDDn	Left ventricular end-diastolic internal diameter normalized to body weight
NT-proBNP	N-terminal pro-B–type natriuretic peptide
ROC	Receiver operating characteristic

diseases have vertical hyperechoic lines that emerge from the surface of the pleura, extending to the distal edge of the ultrasonograph screen (ie, B lines), which erase the A lines.[6,10] The presence of B lines suggests the presence of alveolar or interstitial pulmonary diseases such as CPE and pneumonia.[6] Indeed, LUS is considered a reliable and useful tool for the assessment of CPE in humans and dogs.[5,7,8,10–12]

Lung ultrasonography is commonly used to examine the pleura beneath the thoracic wall; however, abnormalities in the lung parenchyma around the mediastinum cannot be evaluated as typically performed because the ultrasound beam does not propagate in the air-filled alveoli. Because a B line is created by the high impedance gradient between small fluid-filled alveoli and surrounding gas, we considered that LUS performed around the heart where the lung makes contact with the pericardium (ie, pericardial LUS) may be useful in the diagnosis of CPE when performed with a sector probe and dogs positioned in right lateral recumbency. The purpose of the study reported here was to investigate whether pericardial LUS could be used to detect B lines in dogs with CPE and to determine its clinical usefulness for the diagnosis of CPE caused by DMVD.

Materials and Methods

Animals

Dogs with treated or untreated DMVD examined between September 2018 and February 2019 at the authors' facilities (1 veterinary teaching hospital and 2 private veterinary practices) were eligible for inclusion in this prospective study. Dogs with healthy hearts as determined by physical examination and echocardiography were also recruited from the same clinics during this period for inclusion in a control group. All owners provided informed consent before their dogs participated in the study.

To qualify for inclusion in the DMVD group, dogs were required have the diagnosis confirmed by detection of a grade 3/6 or greater systolic heart murmur over the mitral area and color flow Doppler echocardiography (ie, characteristic valvular lesions of the mitral valve apparatus and mitral valve regurgitation). Those with echocardiographic evidence of an LA:Ao ≥ 1.6 and LVIDDn ≥ 1.7 (ie, stage B2 disease) and dogs with past or current clinical signs of congestive heart failure (ie, stage C or more severe disease) as indicated by American College of Veterinary Internal Medicine guidelines[13,14] were included in the study. Dogs that did not meet these criteria (eg, those with stage B1 disease) were excluded. The study was conducted in accordance with the guidelines for experimental use of animals of the Japanese Ministry of Education, Culture, Sports, Science, and Technology.

Examination

All included dogs underwent physical examination, thoracic radiography, echocardiography, and pericardial LUS. Blood samples for plasma NT-proBNP measurement were collected by jugular venipuncture (23-gauge needles) and immediately placed into tubes containing EDTA. Dogs with DMVD were classified as having CPE if they had an interstitial pattern or mixed interstitial-alveolar pattern[4] in addition to cardiac enlargement noted on thoracic radiographs, clinical signs of CPE (ie, 1 or more of tachypnea, dyspnea, cough, and cyanosis), and moist rales and an audible heart murmur detected by auscultation as determined by an experienced veterinary radiologist (AH) and veterinary cardiologist (YH). Dogs with DMVD were further grouped on the basis of these findings as to whether they had or did not have CPE.

Thoracic radiographs were also used for assessment of vertebral heart score, as described elsewhere.[15] Transthoracic echocardiography was performed by an experienced echocardiographer (YH), who used an ultrasonographic unit with a 7.5- to 12-MHz sector probe. For nondecompensated dogs, radiography and echocardiography were performed within 1 hour of each other. The LA:Ao was measured with the 2-D method on the right parasternal short-axis view.[14] M-mode echocardiography was also performed in the right parasternal short-axis view. The LVIDDn was calculated as left ventricular end-diastolic internal dimensions (cm)/(body weight [kg]$^{0.294}$).[14] The mean values of 3 cardiac cycles were calculated.

Similar to transthoracic echocardiography, pericardial LUS was performed with a 7.5- to 12-MHz sector probe with the dog positioned in right lateral recumbency. The left ventricle at the level of the papillary muscle was visualized by means of the 2-D method on the right parasternal short-axis view. The depth was adjusted such that the 3- to 5-cm lung region beneath the heart was visible. B lines were defined as hyperechoic, narrow-based reverberation artifacts originating from the epicardium of the left ventricle and spreading to the bottom edge of the ultrasonograph screen. The maximum number of B lines was recorded as 0, 1, 2, 3, ≥ 4, or confluent (too many to count). In dogs with suspected decompensated heart failure (eg, those with dyspnea and cyanosis), radiography and ultrasonography were rapidly performed during oxygen administration (via a mask) to obtain a diagnosis and to discriminate the condition from pulmonary or thoracic disease. Treatment was initiated immediately after diagnosis. No LUS of the thoracic wall was performed because the focus of the study was pericardial LUS.

Plasma NT-proBNP measurement

Collected blood samples were centrifuged at 1,500 X *g* and 4°C for 10 minutes. Plasma was harvested, and plasma samples were stored at –20°C and then shipped in a frozen state to a commercial laboratory[a] within 3 days after collection. The detection range of the assay used to measure NT-proBNP concentration was 250 to 10,000 pmol/L. Plasma samples with an NT-proBNP concentration higher than the

Table 1—Median (interquartile [25th to 75th percentile] range) values of selected characteristics of control dogs with healthy hearts (n = 15), dogs with DMVD but no CPE (15), and dogs with DMVD and CPE (11).

Characteristic	Control	DMVD but no CPE	DMVD and CPE
Age (y)	8.3 (5.3–11.8)	12.5 (11.3–13.2)*	12.3 (11.8–13.0)*
Body weight (kg)	6.4 (4.2–8.5)	4.2 (3.0–6.0)	3.5 (2.8–5.4)
Respiratory rate (breaths/min)	34 (24–45)	45 (28–59)	66 (51–95)
Heart rate (beats/min)	115 (103–135)	150 (134–166)†	135 (126–162)
Vertebral heart score	10.7 (10.2–11.1)	11.3 (10.8–12.1)	11.7 (10.4–12.1)
NT-proBNP (pmol/L)	539 (496–1,870)	2,576 (1,785–4,589)	9,307 (2,201–9,696)†
LA:Ao	1.5 (1.3–1.6)	2.2 (2.1–2.6)‡	2.0 (1.7–2.7)*
LVIDDn (cm/kg$^{0.294}$)	1.45 (1.40–1.59)	2.15 (2.03–2.15)‡	1.85 (1.65–2.31)†

Values for plasma NT-proBNP concentration represent 28 dogs (7 control dogs, 14 dogs with DMVD but no CPE, and 7 dogs with DMVD and CPE).

†‡Value differs significantly (P < 0.01, †P < 0.05, and ‡P < 0.001) from the respective value for the control group.

assay detection limit were assigned a concentration of 10,000 pmol/L for statistical analysis.

Statistical analysis

Statistical analyses were performed by use of statistical software.[b,c] Normality of continuous data was assessed with the Kolmogorov-Smirnov test, and results indicated a nonnormal distribution for most variables. Therefore, all data are reported as median (interquartile [25th to 75th percentile] range). The Kruskal-Wallis test was used to compare the clinical, radiographic, and echocardiographic variables and plasma NT-proBNP concentrations among the 3 groups. Post hoc analysis was performed with the Dunn test.

To predict the accuracy of B line identification on pericardial LUS for the diagnosis of CPE, ROC[16] curves were constructed, with results of thoracic radiography used as the reference standard. The optimal number of identified B lines (ie, cutoff value) for this purpose was determined on the basis of the Youden index. The ROC curves were compared by a nonparametric method as described elsewhere.[16] On the basis of the identified optimal cutpoint, the frequencies of dogs with or without that number of B lines on pericardial LUS were compared among groups with the χ^2 test and Yates continuity correction. In all analyses, values of P < 0.05 were considered significant.

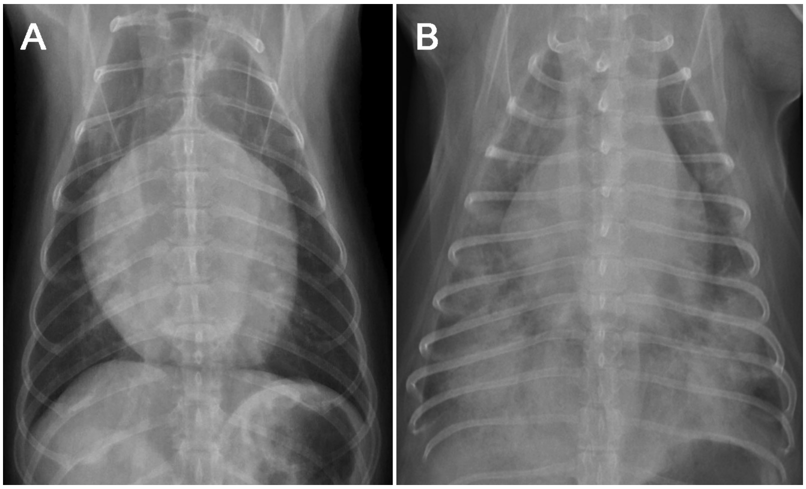

Figure 1—Representative radiographic images of the thorax in dogs with DMVD without (A) and with (B) CPE. A—An enlarged heart is visible, and radiolucency of the lung field appears unremarkable. B—An enlarged heart is visible as well as bilaterally enhanced radiopacity in the caudal lung lobes.

Results

A total of 41 dogs (23 males and 18 females), with an age range of 3.0 to 16.0 years and body weight range of 2.4 to 14.7 kg, were included in this study. Breeds included Chihuahua (n = 12), Shih Tzu (5), Beagle (4), Toy Poodle (3), Miniature Dachshund (2), Yorkshire Terrier (2), Miniature Schnauzer (2), Papillon (2), and various other breeds (1 dog each). Fifteen dogs with healthy hearts were included in the control group, and 26 dogs were included in the DMVD group. Eleven dogs in the DMVD group had CPE, and the remaining 15 had no CPE. Signalment data for each group were summarized **(Table 1)**. Dogs in both DMVD subgroups were significantly older than were control dogs.

Thoracic radiography of control dogs and dogs with DMVD but no CPE revealed no evidence of an interstitial pattern or mixed interstitial-alveolar pattern in the lung fields. On the other hand, dogs with DMVD and CPE had a diffuse distribution of interstitial to alveolar pulmonary infiltrates mainly in the caudodorsal area **(Figure 1)**. Alveolar pulmonary infiltrates were visible bilaterally in all lung lobes of 7 dogs, bilaterally in the caudal lobes of 1 dog, and in the right lobes of the remaining 3 dogs. Heart rate was significantly higher for dogs with DMVD but no CPE than for control dogs. Plasma NT-proBNP concentration, measured in 28 dogs (7 control dogs, 14 dogs with DMVD but no CPE, and 7 dogs with DMVD and CPE), was significantly greater for dogs with DMVD and CPE than for control dogs. On echocar-

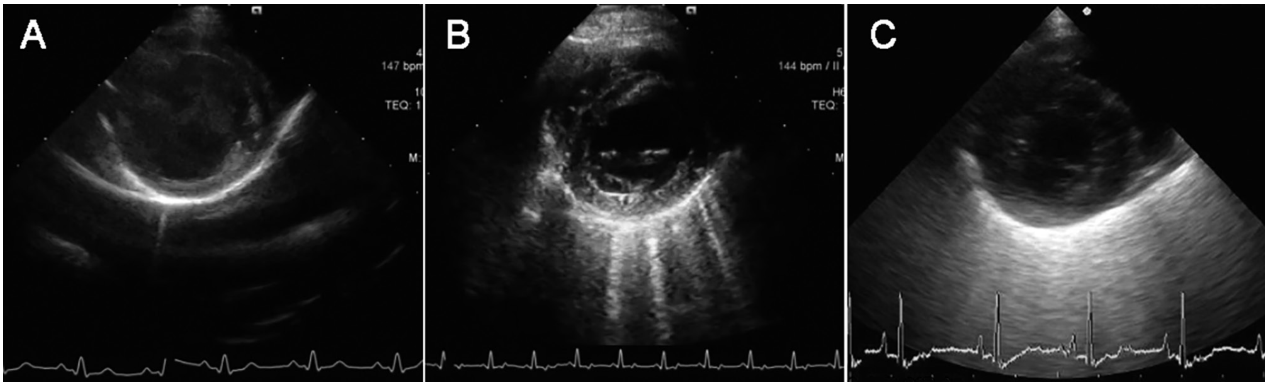

Figure 2—Representative pericardial LUS images (obtained with a sector probe and the dog positioned in right lateral recumbency) showing 2 or fewer B lines (A; as characteristic of control dogs and dogs with DMVD but no CPE) and multiple B lines (B) or confluent B lines (C) extending from the epicardium of the left ventricle into the lung field (downward; as prevalent in dogs with DMVD and CPE).

Table 2—Maximum numbers of B lines identified by pericardial LUS in the dogs of Table 1.

No. of B lines	Control	DMVD but no CPE	DMVD and CPE
0	8	4	0
1	5	9	0
2	1	0	0
3	1	2	1
≥ 4	0	0	1
Confluent*	0	0	9

*Too many to count.

diography, values for LA:Ao and LVIDDn were significantly higher for both subgroups of dogs with DMVD than for control dogs.

On pericardial LUS, most of the control dogs (14/15) and dogs with DMVD but no CPE (13/15) had ≤ 2 B lines from the epicardium **(Figure 2; Table 2)**. By contrast, dogs with DMVD and CPE had a high prevalence of confluent B lines. To discriminate between dogs with CPE and those without CPE, the optimal cutoff value was 4 B lines, which resulted in high sensitivity (91%), excellent specificity (100%), and an AUC of 0.99 **(Figure 3; Table 3)**. Results of the χ^2 test indicated that the presence of ≥ 4 B lines was significantly ($P < 0.001$) more common in dogs with CPE (91% [10/11]) than in dogs without CPE (ie, dogs with DMVD but no CPE and control dogs; 0% [0/30]). Finally, the AUC for the use of pericardial LUS to diagnose CPE at the optimal cutoff value was significantly greater than the AUCs for the use of the vertebral heart score, LA:Ao, LVIDDn, and plasma NT-proBNP concentration at their optimal cutoff values.

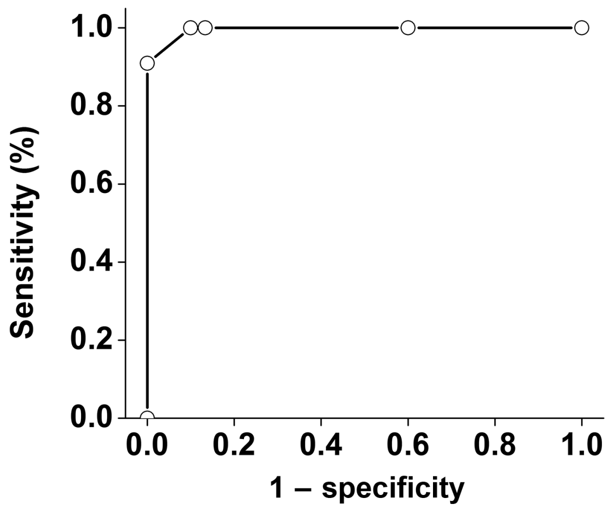

Figure 3—Receiver operating characteristic curve showing the usefulness of pericardial LUS in the diagnosis of CPE in dogs with DMVD, with the presence of CPE defined as ≥ 4 B lines (AUC, 0.99). The curve represents results for 15 dogs with healthy hearts, 15 dogs with DMVD but no CPE, and 11 dogs with DMVD and CPE. Thoracic radiography was used as the reference standard.

Discussion

In the present study, a novel pericardial LUS technique was evaluated that could be used to assess the lungs of dogs simultaneously with echocardiography, without the need to change the position of the dog or type of probe used. Although 27 of the 30 (90%) dogs without CPE (ie, dogs with healthy hearts and dogs with DMVD) had ≤ 2 B lines, all dogs with CPE (and DMVD) had ≥ 3 B lines. As a result, the presence of ≥ 4 B lines was highly sensitive and specific for the diagnosis of CPE in the study sample. These data suggested that pericardial LUS may be useful for the diagnosis of CPE in dogs with DMVD.

Studies[17,18] have shown that LUS is useful for assessment of lung lesions in humans with acute respiratory failure. The number of B lines is correlated with pulmonary capillary wedge pressure and the presence of extravascular fluid in the lungs.[19,20] Generally, LUS has been performed with a convex probe and dogs positioned in sternal recumbency or standing[21] to evaluate abnormalities between the thoracic wall and lung surface. In humans, abdominal ultrasonography has revealed confluent B lines running from the dorsal aspect of the right hepatic lobe into the right side of the thoracic cavity.[18] This finding,

Table 3—Results of ROC analyses for the usefulness of pericardial LUS, plasma NT-proBNP concentration, vertebral heart score (VHS), LA:Ao, and LVIDDn for the diagnosis of CPE in the dogs of Table 1.

Variable	Pericardial LUS	NT-proBNP	VHS	LA:Ao	LVIDDn
Cutoff value used	4 B lines	7,708 pmol/L	11.5	1.67	2.23
AUC	0.99 (0.99–1.00)	0.74* (0.51–0.96)	0.59† (0.36–0.82)	0.61† (0.40–0.83)	0.66† (0.46–0.87)
Sensitivity (%)	91 (62–98)	67 (30–90)	50 (25–75)	36 (20–57)	40 (17–69)
Specificity (%)	100 (89–100)	86 (67–95)	80 (61–91)	86 (60–96)	97 (83–99)

Values in parentheses represent the 95% confidence interval. Thoracic radiography was used as the reference standard.
†Value differs significantly ($P < 0.05$; †$P < 0.01$) from the corresponding value for pericardial LUS.

termed the aurora sign, indicates a lung lesion in the inferior or accessory lobes on the right side. Unlike common LUS, pericardial LUS can be used to evaluate lung lesions in contact with the pericardium. To the authors' knowledge, ours was the first study to confirm that B lines occurred from the pleura where the lungs makes contact with the pericardium in dogs with CPE.

In humans, the presence of ≥ 3 B lines between the ribs in ≥ 2 thoracic areas indicates the presence of interstitial syndrome.[9–11,22] This occurs when the subpleural interlobular septa surrounded by air-filled alveoli develop interstitial edema, such as with CPE. Similarly, the presence of ≥ 3 B lines within a single intercostal space indicates CPE in dogs.[21] Lung ultrasonography is highly sensitive and specific for the diagnosis of pulmonary edema in humans and dogs with heart failure.[5,7,8,11] In dogs, reported values for sensitivity and specificity of LUS for the diagnosis of CPE are 90% and 93%, respectively.[7] In the present study, identification of ≥ 4 B lines on pericardial LUS served as a reliable cutoff for the diagnosis of CPE in dogs, with a sensitivity of 91% and specificity of 100%. It is possible that CPE-induced small fluid-filled alveoli caused the high-impedance gradient between pericardium and alveoli, which resulted in multiple B lines from the pericardium. Further research is required to determine whether pericardial LUS can be used to determine the severity of CPE or detect CPE before the development of radiographic abnormalities.

The AUC for the use of pericardial LUS for the diagnosis of CPE in dogs at the optimal B line cutoff value was significantly different from the AUCs for other assessed variables at their optimal cutoff values. This result may have reflected the stage of disease (stage B2 or C) in the included dogs with DMVD. Although values for vertebral heart score, LA:Ao, and LVIDDn were statistically equivalent between dogs with DMVD with and without CPE, the prevalence of ≥ 4 B lines was significantly higher among those with CPE. Furthermore, because thoracic radiography was used as the reference standard for the diagnosis of CPE, the diagnostic usefulness of pericardial LUS and radiography could not be compared. However, the accuracy of thoracic radiography and LUS for the diagnosis of CPE in dogs has been reported to be equivalent.[8]

Alveolar-interstitial syndrome occurs not only in association with CPE but also in dogs, cats, and humans with other pulmonary diseases, including acute respiratory distress syndrome, parenchymal lung disease, and pneumonia.[5,6] In the present study, most (90%) dogs without CPE had ≤ 2 B lines, but the remaining 3 dogs had 3 B lines. The presence of multiple B lines in dogs with no radiographic evidence of alveolar pulmonary infiltrates may have been attributable to the presence of mild CPE in 2 dogs with DMVD that were deemed to have no CPE and to diffuse pulmonary disease of unknown cause (which was not detected by thoracic radiography) in 1 control dog. Lung ultrasonography is reportedly useful for the differentiation of cardiogenic from noncardiogenic causes of dyspnea in humans,[9,23] but it could not be used to differentiate CPE from other causes of alveolar-interstitial syndrome in dogs and cats.[5] Because patients with pulmonary diseases may also have multiple B lines on pericardial LUS images, additional research is warranted to distinguish between dogs with respiratory signs that have CPE or other pulmonary diseases.

The present study was limited by the small sample size and significant differences in age between the groups. Therefore, large-scale age-matched studies are required to further explore the usefulness of pericardial LUS for the diagnosis of CPE. Second, performance of pericardial LUS on dogs positioned in right lateral recumbency only allows evaluation of the left lung and not the right lung because this position may cause lung atelectasis. Because the aim of our study was to investigate the diagnostic usefulness of pericardial LUS only, further research is needed to investigate the accuracy of a CPE diagnosis when using thoracic-wall LUS versus pericardial LUS. Nevertheless, our findings indicated that pericardial LUS may be useful as an additional method to thoracic radiography or thoracic-wall LUS for the diagnosis of CPE in dogs.

Acknowledgments

No third-party funding or support was received in connection with this study or the writing or publication of the manuscript. The authors declare that there were no conflicts of interest.

Footnotes

a. Idexx Laboratories Inc, Tokyo, Japan.
b. Statemate III, version 3.16, Avice Inc, Tokyo, Japan.
c. Excel Statistics, BellCurve for Excel, Social Survey Research Information Co Ltd, Tokyo, Japan.

References

1. Borgarelli M, Savarino P, Crosara S, et al. Survival characteristics and prognostic variables of dogs with mitral regurgitation attributable to myxomatous valve disease. *J Vet Intern Med* 2008;22:120–128.
2. Freeman LM. Cachexia and sarcopenia: emerging syndromes

of importance in dogs and cats. *J Vet Intern Med* 2012;26:3–17.
3. Tidholm A, Hoglund K, Haggstrom J, et al. Diagnostic value of selected echocardiographic variables to identify pulmonary hypertension in dogs with myxomatous mitral valve disease. *J Vet Intern Med* 2015;29:1510–1517.
4. Diana A, Guglielmini C, Pivetta M, et al. Radiographic features of cardiogenic pulmonary edema in dogs with mitral regurgitation: 61 cases (1998–2007). *J Am Vet Med Assoc* 2009;235:1058–1063.
5. Ward JL, Lisciandro GR, Keene BW, et al. Accuracy of point-of-care lung ultrasonography for the diagnosis of cardiogenic pulmonary edema in dogs and cats with acute dyspnea. *J Am Vet Med Assoc* 2017;250:666–675.
6. Koenig SJ, Narasimhan M, Mayo PH. Thoracic ultrasonography for the pulmonary specialist. *Chest* 2011;140:1332–1341.
7. Vezzosi T, Mannucci T, Pistoresi A, et al. Assessment of lung ultrasound b-lines in dogs with different stages of chronic valvular heart disease. *J Vet Intern Med* 2017;31:700–704.
8. Ward JL, Lisciandro GR, DeFrancesco TC. Distribution of alveolar-interstitial syndrome in dogs and cats with respiratory distress as assessed by lung ultrasound versus thoracic radiographs. *J Vet Emerg Crit Care* (*San Antonio*) 2018;28:415–428.
9. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. *Chest* 2008;134:117–125.
10. Lichtenstein DA, Meziere GA, Lagoueyte JF, et al. A-lines and B-lines: lung ultrasound as a bedside tool for predicting pulmonary artery occlusion pressure in the critically ill. *Chest* 2009;136:1014–1020.
11. Aggarwal M, Gupta M, Vijan V, et al. Use of lung ultrasound for diagnosing acute heart failure in emergency department of southern India. *J Clin Diagn Res* 2016;10:TC05–TC08.
12. Rademacher N, Pariaut R, Pate J, et al. Transthoracic lung ultrasound in normal dogs and dogs with cardiogenic pulmonary edema: a pilot study. *Vet Radiol Ultrasound* 2014;55:447–452.
13. Boswood A, Haggstrom J, Gordon SG, et al. Effect of Pimobendan in dogs with preclinical myxomatous mitral valve disease and cardiomegaly: the epic study-a randomized clinical trial. *J Vet Intern Med* 2016;30:1765–1779.
14. Keene BW, Atkins CE, Bonagura JD, et al. ACVIM consensus guidelines for the diagnosis and treatment of myxomatous mitral valve disease in dogs. *J Vet Intern Med* 2019;33:1127–1140.
15. Buchanan JW, Bucheler J. Vertebral scale system to measure canine heart size in radiographs. *J Am Vet Med Assoc* 1995;206:194–199.
16. DeLong ER, DeLong DM, Clarke-Pearson DL. Comparing the areas under two or more correlated receiver operating characteristic curves: a nonparametric approach. *Biometrics* 1988;44:837–845.
17. Frassi F, Gargani L, Tesorio P, et al. Prognostic value of extravascular lung water assessed with ultrasound lung comets by chest sonography in patients with dyspnea and/or chest pain. *J Card Fail* 2007;13:830–835.
18. Kohzaki S, Tsurusaki K, Uetani M, et al. The aurora sign: an ultrasonographic sign suggesting parenchymal lung disease. *Br J Radiol* 2003;76:437–443.
19. Agricola E, Bove T, Oppizzi M, et al. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. *Chest* 2005;127:1690–1695.
20. Platz E, Lewis EF, Uno H, et al. Detection and prognostic value of pulmonary congestion by lung ultrasound in ambulatory heart failure patients. *Eur Heart J* 2016;37:1244–1251.
21. Lisciandro GR, Fosgate GT, Fulton RM. Frequency and number of ultrasound lung rockets (B-lines) using a regionally based lung ultrasound examination named vet BLUE (veterinary bedside lung ultrasound exam) in dogs with radiographically normal lung findings. *Vet Radiol Ultrasound* 2014;55:315–322.
22. Staub LJ, Mazzali Biscaro RR, Kaszubowski E, et al. Lung ultrasound for the emergency diagnosis of pneumonia, acute heart failure, and exacerbations of chronic obstructive pulmonary disease/asthma in adults: a systematic review and meta-analysis. *J Emerg Med* 2019;56:53–69.
23. Al Deeb M, Barbic S, Featherstone R, et al. Point-of-care ultrasonography for the diagnosis of acute cardiogenic pulmonary edema in patients presenting with acute dyspnea: a systematic review and meta-analysis. *Acad Emerg Med* 2014;21:843–852.