Radiographic features of cardiogenic pulmonary edema in dogs with mitral regurgitation: 61 cases (1998–2007)

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Objective—To evaluate radiographic distribution of pulmonary edema (PE) in dogs with mitral regurgitation (MR) and investigate the association between location of radiographic findings and direction of the mitral regurgitant jet (MRJ).

Design—Retrospective case series.

Animals—61 dogs with cardiogenic PE and MR resulting from mitral valve disease (MVD; 51 dogs), dilated cardiomyopathy (9), and hypertrophic cardiomyopathy (1).

Procedures—Thoracic radiographs of dogs with Doppler echocardiographic evidence of MR were reviewed for location (diffuse, perihilar, or focal) of PE. Also, direction (central or eccentric) of the MRJ, as evaluated by Doppler color flow mapping (DCFM), and distribution (symmetric or asymmetric) of radiographic findings were evaluated.

Results—Diffuse, perihilar, and focal increases in pulmonary opacity were observed in 11 (18.0%), 7 (11.5%), and 43 (70.5%) of 61 dogs, respectively. Radiographic evidence of asymmetric PE in a single lung lobe or 2 ipsilateral lobes was found in 21 dogs, with involvement of only the right caudal lung lobe in 17 dogs. Doppler color flow mapping of the MRJ was available for 46 dogs. Of 31 dogs with a central MRJ, 28 had radiographic findings indicative of symmetric PE. Of 15 dogs with eccentric MRJ, 11 had radiographic evidence of asymmetric PE, and all of these dogs had MVD.

Conclusions and Clinical Relevance—In dogs with cardiogenic PE, a symmetric radiographic distribution of increased pulmonary opacity was predominantly associated with a central MRJ, whereas an asymmetric radiographic distribution was usually associated with eccentric MRJ, especially in dogs with MVD. (*J Am Vet Med Assoc* 2009;235:1058–1063)

Pulmonary edema is defined as an abnormal accumulation of transudate fluid in the extravascular space of the lung, and it is one of the most frequent causes of respiratory distress in dogs.[1,2] Different pathophysiologic mechanisms are responsible for PE, including increased vascular hydrostatic pressure, decreased plasma oncotic pressure, increased vascular permeability, and impaired lymphatic drainage.[1] Cardiogenic PE is caused by an increase in pulmonary venous hydrostatic pressure mainly resulting from an increased left atrial pressure, with more interstitial fluid being produced than the lymphatic vessels can accomodate.[2] Mitral regurgitation is the most common and clinically important valvular disorder in domestic carnivores, leading to increased left atrial pressure and, eventually, PE.[1–3] The most common causes of acquired MR in dogs include MVD, mitral valve prolapse, dynamic outflow tract obstruction with systolic cranial motion of the mitral valve, ruptured chordae tendinae, DCM leading to dysfunction of the mitral valve apparatus and secondary MR, and bacterial endocarditis.[3,4]

Abbreviations

DCFM	Doppler color flow mapping
DCM	Dilated cardiomyopathy
HCM	Hypertrophic cardiomyopathy
MR	Mitral regurgitation
MRJ	Mitral regurgitant jet
MVD	Mitral valve disease
PE	Pulmonary edema

Radiographically, PE manifests initially as a hazy unstructured interstitial pulmonary pattern that may progress to an alveolar pattern, characterized by tiny nodular or acinar areas of increased opacity that tend to coalesce.[5–8] In humans, distribution of radiographic findings indicative of cardiogenic PE is usually diffuse and random, although a so-called bat-wing appearance of increased pulmonary opacity is sometimes found in subjects with rapidly developing severe cardiac failure.[7] However, asymmetric distribution of increased pulmonary opacity, mainly localized to the right upper lobe, has also been reported in humans with MR.[9–18] An eccentric direction of the MRJ is considered responsible for this radiographic feature in humans.[11–18] In dogs, cardio-

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genic PE typically manifests in the hilar and caudodorsal perivascular lung regions usually with a symmetric distribution in the caudal lung lobes.[5,6,8] Asymmetric distribution of cardiogenic PE in dogs has anecdotally been described.[5] To our knowledge, no systematic study aimed at describing the distribution of radiographic findings of PE in a large group of dogs with MR or investigating the cause of asymmetric distribution has been reported. The purposes of the study presented here were, first, to correlate radiographic location of PE in dogs with MR secondary to different cardiac disorders and, second, to determine whether the direction of the MRJ had an effect on the location of PE.

Materials and Methods

Criteria for selection of cases—Medical records of dogs admitted to the Internal Medicine Section of the Department of Veterinary Clinical Sciences of the Universities of Bologna and Teramo from January 1998 through March 2007 with a diagnosis of cardiogenic PE were retrospectively reviewed. The diagnosis of cardiogenic PE and the disease causing it was based on combined clinical (ie, tachypnea, dyspnea, cough, tachycardia, and abnormal lung sounds with or without an audible heart murmur), radiographic (ie, increased pulmonary opacity resulting from unstructured interstitial or mixed interstitial-alveolar pattern associated with enlarged cardiac silhouette), and echocardiographic and Doppler echocardiographic (ie, dilated left atrium and MR, respectively) findings. Only dogs with at least 2 orthogonal radiographic images of the thorax were included in the study.

Procedures—Evaluation of lateral and ventrodorsal or dorsoventral radiographic views of the thorax was performed by the same radiologist (MC) who was blinded regarding echocardiographic and Doppler echocardiographic findings. The evaluation of the pulmonary parenchyma was performed by first considering the presence of an interstitial or a mixed (ie, interstitial and alveolar) pattern indicative of PE. These radiographic patterns were then classified according to location as follows: diffuse, when all the lung fields were involved; perihilar, when the region surrounding the lung hilus was involved; or focal, when a single area of 1 or more lung lobes was involved. Asymmetric radiographic distribution of PE was considered when only a single lung lobe or 2 ipsilateral lobes were involved; all other distributions were considered symmetric.

Echocardiographic and Doppler echocardiographic examinations—All dogs underwent complete echocardiographic and Doppler echocardiographic examinations, which included transthoracic 2D, M-mode, spectral Doppler imaging, and DCFM with continuous ECG monitoring. Two echocardiographic machines[a,b] equipped with a 2.8- to 3.8-MHz and 4.5- to 6.5-MHz, and a 2.5- to 3.5-MHz and 5.0- to 7.5-MHz, respectively, phased array transducer were used. Standard echocardiographic scan planes were used to obtain a definitive diagnosis for each dog.[19] The direction of the systolic MRJ was assessed from the right parasternal, long-axis, 4-chamber view or from the left apical, 4-chamber view with DCFM. Still images and cine loops were analyzed, and the direction of MR in the left atrium was classified as central or eccentric. A central MRJ was defined as one in which all the displayed MRJ turbulence was contained within the left atrial cavity, with a clearly defined fluid layer between the margins of the MRJ and the walls of the left atrium. An eccentric MRJ was one that contacted the walls of the left atrium immediately after the MRJ emerged from the regurgitant orifice.

Statistical analysis—Frequencies of symmetric and asymmetric distributions of PE observed in dogs with central or eccentric directions of the MRJ were compared by use of the χ^2 test. The odds ratio was calculated to evaluate the association between the distribution of radiographic findings of PE and the direction of MRJ into the left atrium. Data analysis was performed by use of a statistical software package,[c] and a value of $P < 0.05$ was considered significant.

Results

Sixty-one dogs met the inclusion criteria for the study. Forty-three (43/61 [70.5%]) were male, and 18 (18/61 [29.5%]) were female. Ages ranged from 3 to 15 years (mean ± SD age, 10 ± 2.1 years), and body weights ranged from 2 to 50 kg (4.4 to 110.2 lb) with a mean body weight of 17.6 ± 11.4 kg (38.8 ± 25.1 lb).

Table 1—Observed radiographic patterns (unstructured interstitial or mixed interstitial-alveolar) and location (diffuse, perihilar, or focal) of increased pulmonary opacity on thoracic radiographic views of 61 dogs with MR and cardiogenic PE.

			Focal	
Variable	**Diffuse**	**Perihilar**	**1 lobe**	**≥ 2 lobes**
Interstitial	6	7	18	10
Interstitial-alveolar	5	0	2	13
Total (%)	**11 (18.0)**	**7 (11.5)**	**20 (32.8)**	**23 (37.7)**
Lung lobe involvement	NA	NA	17 RCa* 3 LCa*	20 RCa, LCa 1 RM, RCa* 1 LCr, RCr 1 LCr, RCr, RCa, Acc

Values are the number of dogs with each radiographic pattern and location.
*Asymmetric radiographic distribution of PE.
Acc = Accessory lung lobe. LCa = Left caudal lung lobe. LCr = Left cranial lung lobe. NA = Not applicable. RCa = Right caudal lung lobe. RCr = Right cranial lung lobe. RM = Right middle lung lobe.

Thirty-four (34/61 [55.7%]) dogs were purebreds, and 27 (27/61 [44.2%]) were mixed breeds.

Radiologic features consistent with cardiac enlargement were present in all dogs. Pulmonary edema was evident radiographically as an interstitial pattern in 41 of 61 (67.2%) dogs and as mixed interstitial-alveolar pattern in 20 of 61 (32.8%) dogs (**Table 1**). In terms of location, diffuse (**Figure 1**), perihilar, and focal PE was observed in 11 (11/61 [18.0%]), 7 (7/61 [11.5%]), and 43 (43/61 [70.5%]) dogs, respectively. Among dogs with radiographically focal PE, a single lung lobe was involved in 20 (20/61 [32.8%]) dogs and 2 or more lung lobes were involved in 23 (23/61 [37.7%]) dogs, mainly the caudal lung lobes (**Figure 2**). Twenty-one (21/61 [34.4%]) dogs had an asymmetric radiographic distribution of PE, 17 with involvement of only the right caudal lung lobe (**Figure 3**), 3 with involvement of only the left caudal lung lobe, and 1 with concurrent involvement of the right middle and caudal lung lobes.

Of the 61 dogs with PE, 51 (83.6%) had MVD, 9 (14.8%) had DCM, and 1 (1.6%) had HCM. A symmetric radiographic distribution of PE was observed in 40 (65.6%) dogs; 30 dogs with MVD and all dogs (n = 9) with DCM and HCM (1). An asymmetric radiographic distribution of PE was found in 21 (21/61 [34.4%]) dogs with MVD but not in any of the dogs with DCM or HCM.

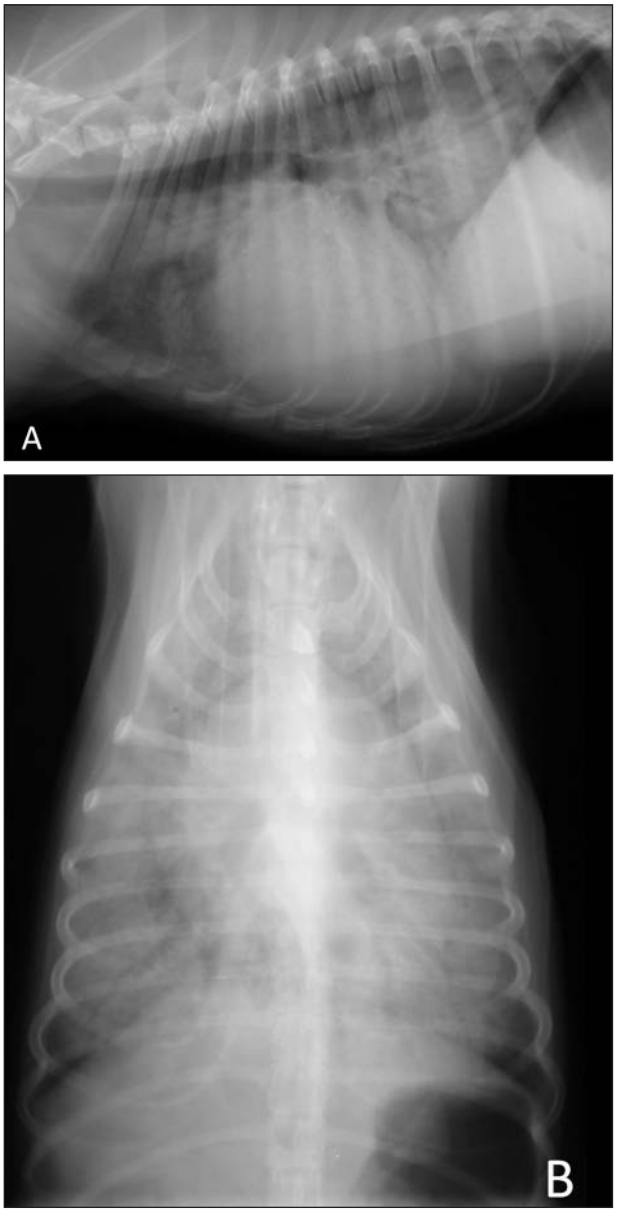

Figure 1—Right lateral (A) and ventrodorsal (B) radiographic views of the thorax of a dog with diffuse cardiogenic PE. Notice the increased pulmonary opacity that involves all lung lobes.

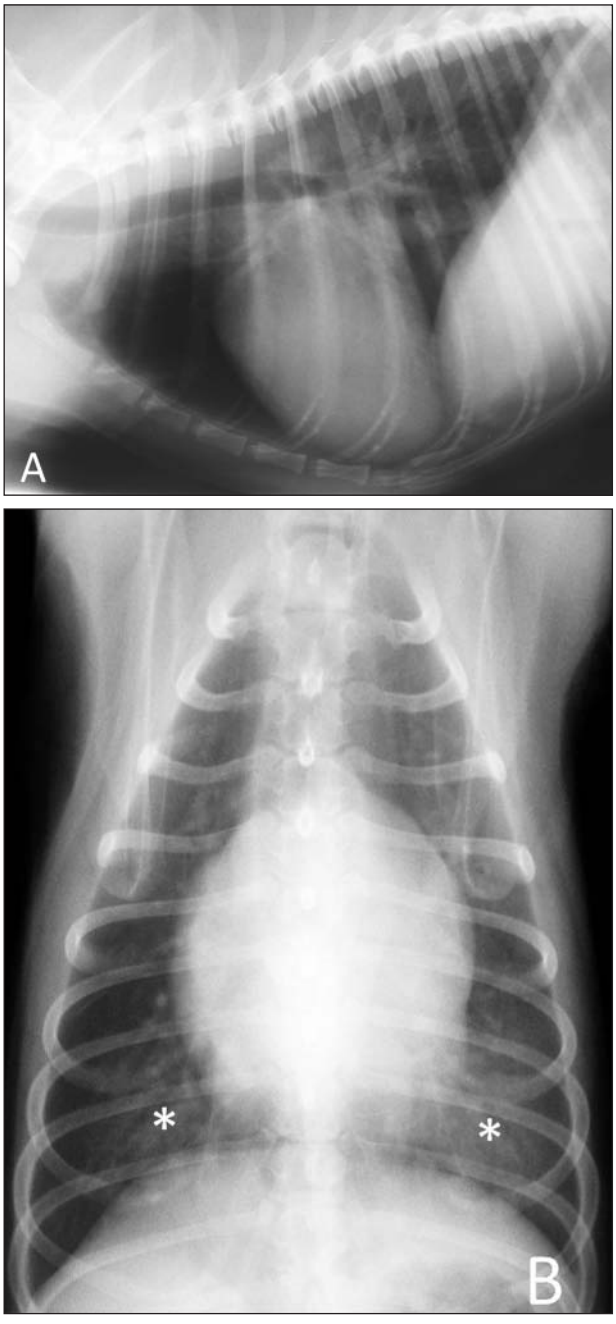

Figure 2—Right lateral (A) and ventrodorsal (B) radiographic views of the thorax of a dog with symmetric cardiogenic PE. Notice the increased pulmonary opacity that is localized in the left and right caudal lung lobes (asterisks).

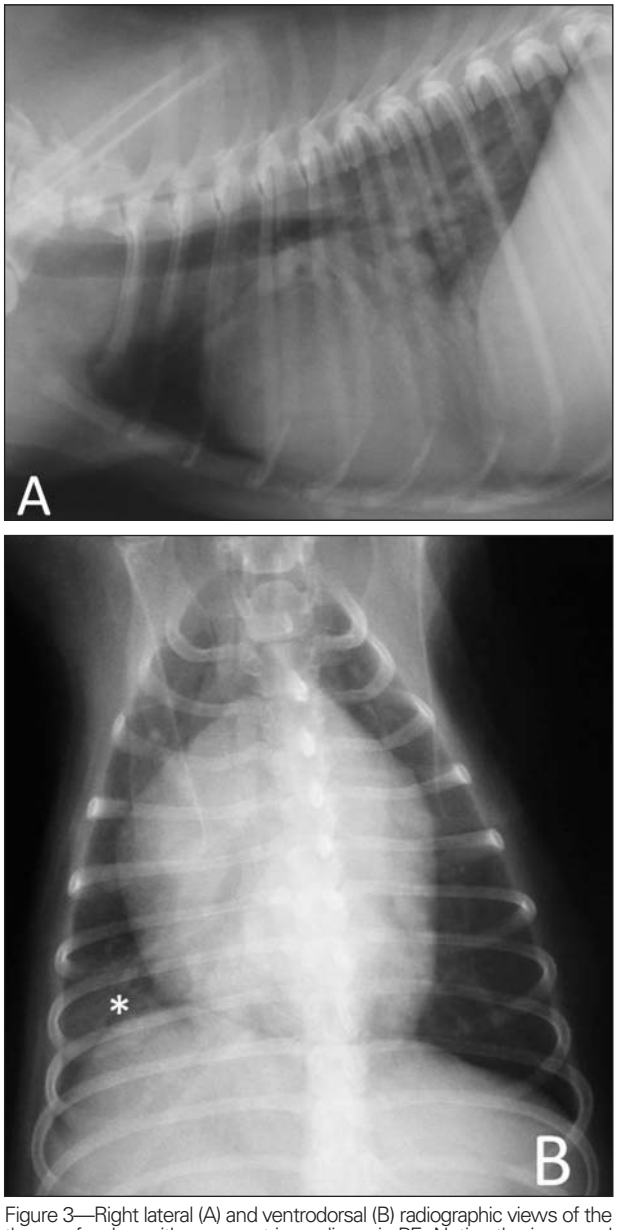

Figure 3—Right lateral (A) and ventrodorsal (B) radiographic views of the thorax of a dog with asymmetric cardiogenic PE. Notice the increased pulmonary opacity that is localized in the right caudal lung lobe (asterisk).

Results of DCFM were available for 46 dogs. A central and eccentric MRJ was found in 31 (31/61 [50.8%]; 22 dogs with MVD, 8 with DCM, and 1 with HCM) and 15 (15/61 [24.6%]; 15 dogs with MVD) dogs, respectively, on echocardiographic and Doppler echocardiographic examinations (**Figure 4**). Direction of the MRJ was not evaluated in the remaining 15 (15/61 [24.6%]) dogs. Of 31 dogs with a central MRJ, 28 had radiographic findings indicative of symmetric PE. Of 15 dogs with an eccentric MRJ, 11 had radiographic evidence of asymmetric PE, and all of these dogs had MVD. Finding an asymmetric radiographic pattern indicative of PE in dogs with an eccentric MRJ was 25.7 times as likely as finding the same radiographic pattern in dogs with a central MRJ. Similarly, finding a symmetric radiographic distribution of PE in dogs with a central MRJ was 25.7 times as likely as finding the same radiographic distribution in dogs with an eccentric MRJ (95% confidence interval of odds ratio, 4.9 to 133.8; $P < 0.001$).

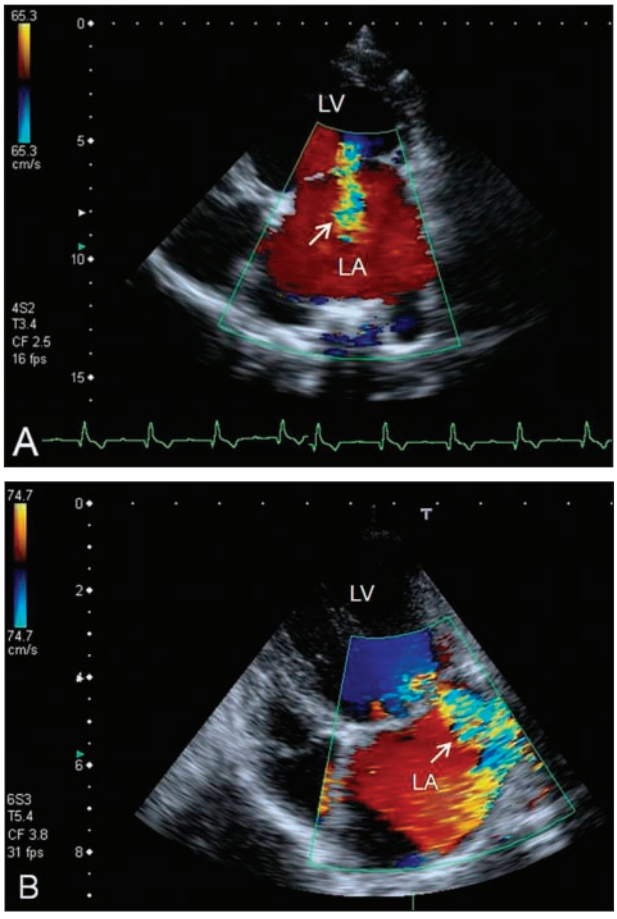

Figure 4—Images of DCFM of MR obtained from the left apical, 4-chamber view. A—Central direction of the MRJ in a dog with MVD. B—Eccentric direction of the MRJ in a dog with MVD. Notice the different position of the turbulent flow (arrows) into the left atrium. LA = Left atrium. LV = Left ventricle.

Discussion

Although it has been recognized that in dogs with MR the right caudal lung lobe is usually the location for the development of PE,[5] to our knowledge, the study reported here is the first to attempt to explain the location of PE in dogs with MR. In our study, the association between radiographic distribution of PE and the direction of the MRJ into the left atrium was evaluated with the aid of DCFM. In the present study, cardiac diseases that were associated with MR reflected the overall prevalence of acquired cardiovascular disorders in dogs, as MVD has been estimated to account for 75% to 80% of cardiac diseases in dogs and DCM is the most common form of myocardial disease in dogs.[20] Radiographically, increased opacity as an interstitial pattern was observed in most of the dogs with cardiogenic PE (41/61 [67.2%]) in our study, whereas the remaining dogs had a mixed interstitial-alveolar pattern. Interstitial accumulation of transudate fluid occurs in the initial phase of hydrostatic PE as a result of chronic MR, mainly in the perivascular spaces.[6,21] Therefore, an unstructured interstitial pattern reflects an early stage of pulmonary involvement during congestive heart failure. Indeed, transudate leaks into the alveolar spaces in the late phase of cardiogenic PE. Furthermore, the dis-

tribution of PE is determined by the hydrostatic forces across the pulmonary microcirculation and permeability of the pulmonary capillary bed.[6] Fluid usually accumulates at the perihilar area in the beginning phase of PE and typically manifests into an advanced phase with fluid accumulating in the caudal lung lobes.[6,21]

Symmetric radiographic distribution of PE, including diffuse and simultaneous involvement of 2 contralateral lung lobes (mainly the caudal lung lobes), was the most prevalent feature in our dogs with cardiogenic PE, accounting for 65.6% (40/61) of dogs. However, more than a third of dogs had an asymmetric distribution of PE, mainly localized to the right caudal lung lobe. In a study performed by Drobatz et al[22] on 23 dogs and 3 cats with noncardiogenic PE, asymmetric radiographic distribution of lung infiltration was observed in 18 subjects, 13 with the right and 5 with the left side mainly involved. The cause for this asymmetry was not determined. Bilateral infiltration, with predominant distribution to the caudal lung lobes, was observed in Swedish hunting dogs with a particular form of noncardiogenic PE associated with hunting effort.[23]

In the present study, 27.9% (17/61) of dogs with MR had asymmetric involvement of the right caudal lung lobe, whereas only 4.9% (3/61) had asymmetric involvement of the left caudal lung lobe (Table 1). Echocardiographic examination and DCFM revealed a central MRJ in all dogs with DCM and HCM. In these dogs, only a symmetric radiographic distribution of PE was found. On the contrary, dogs with MVD had either a central (22 dogs) or an eccentric (15 dogs) MRJ. Of the 51 dogs with MVD, 30 had symmetric radiographic distribution of PE and 21 had asymmetric radiographic distribution of PE.

Functionally, the mitral valve apparatus consists of several components, including mitral valve leaflets, chordae tendinae, mitral annulus, papillary muscles and left ventricular myocardium underlying the papillary muscles, and the left atrial wall.[3,4,24,25] Mitral regurgitation may result from dysfunction or altered anatomy of any of these components. Incomplete apposition of thickened and smaller mitral valve leaflets together with elongated or ruptured chordae tendinae is the major determinant of MR in MVD.[3,4,25] Dilatation of the left ventricle and apical displacement of the papillary muscles leading to stretch of the mitral annulus is the major cause of MR in DCM, which is thus a secondary form of MR.[3,24] The former may lead to a central or an eccentric MRJ, whereas the latter is always associated with a central MRJ because of incomplete leaflet coaptation resulting from poor contraction.[24]

Incomplete evaluation of the MRJ direction is the main limitation of this study but does not detract from the main findings. Mitral regurgitation is a complex and dynamically changing process that may be impossible to characterize fully by use of a 2D imaging modality. Although veterinary cardiologists are fully aware of the possible different direction of the MRJ into the left atrium (ie, central or eccentric), this topic has received little consideration in the veterinary literature. Other aspects of MR, including size and width of the MRJ and proximal isovelocity surface area, are better suited to assess MR severity and therefore have been more thoroughly investigated.[26–30] Different scan planes are also necessary to determine the precise direction of the MRJ into the left atrium. For this purpose, transesophageal echocardiography offers major advantages, compared with transthoracic echocardiography, for the consistent evaluation of flow in all pulmonary veins.[31] However, the time required to perform a complete echocardiographic examination, including careful evaluation of pulmonary vein blood flow, may be risky in dogs with PE while in respiratory distress.

In summary, symmetric distribution of increased pulmonary opacity is the most common radiographic feature of cardiogenic PE in dogs, particularly in dogs with a central MRJ. However, asymmetric radiographic distribution of PE may be observed in about one-third of dogs with MR, particularly when caused by MVD. Eccentric direction of the MRJ is likely responsible for selective involvement of the right caudal lung lobe in dogs with MVD.

a. Aplio SSA-770A, Toshiba, Amsterdam, The Netherlands.
b. AU5 Epi, Esaote Biomedica, Florence, Italy.
c. MedCalc 7.3, MedCalc Software, Mariakerke, Belgium.

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