Journal of Veterinary Cardiology (2019) **21**, 18—27

Journal of Veterinary Cardiology
ESVC

www.elsevier.com/locate/jvc

Association between atrial fibrillation and right-sided manifestations of congestive heart failure in dogs with degenerative mitral valve disease or dilated cardiomyopathy☆

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Received 19 June 2018; received in revised form 8 October 2018; accepted 10 October 2018

KEYWORDS
Canine;
Arrhythmia;
Ascites;
Pleural effusion;
Heart disease

Abstract *Introduction:* To determine whether dogs with atrial fibrillation (AF) are more likely to develop right-sided manifestations of congestive heart failure (R-CHF) than dogs without AF.
Animals: Two hundred twenty dogs diagnosed with congestive heart failure (CHF) secondary to degenerative mitral valve disease (DMVD, n = 155) or dilated cardiomyopathy (DCM, n = 65) at a referral institution.
Methods: Medical records were reviewed to extract relevant clinical and echocardiographic data.
Results: Fifty dogs had AF at the time of CHF diagnosis, including 17/155 (11.0%) dogs with DMVD and 33/65 (50.8%) dogs with DCM. Sixty dogs had R-CHF evidenced

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https://doi.org/10.1016/j.jvc.2018.10.006

by cavitary effusions. Among DMVD dogs, R-CHF occurred in 13/17 (76.5%) dogs with AF compared with 10/138 (7.2%) dogs without AF; among DCM dogs, R-CHF occurred in 24/33 (72.7%) dogs with AF compared with 13/32 (40.6%) dogs without AF. Dogs with AF were more likely to manifest R-CHF signs than dogs without AF ($p < 0.0001$ for DMVD; $p = 0.0125$ for DCM). The presence of AF, diagnosis of DCM, and moderate to severe tricuspid regurgitation were associated with R-CHF in multivariate analysis. AF was the strongest predictor of R-CHF (odds ratio, 14.44; 95% confidence interval, 5.75—36.26).
Conclusions: Dogs with AF are more likely to manifest R-CHF than dogs without AF. Cavitary effusions are an expected finding in approximately three-quarters of dogs with AF and CHF secondary to either DCM or DMVD.

Abbreviations

AF	atrial fibrillation
CHF	congestive heart failure
DCM	dilated cardiomyopathy
DMVD	degenerative mitral valve disease
LA	left atrium/atrial
L-CHF	left-sided congestive heart failure
PAH	pulmonary arterial hypertension
PCEFF	pericardial effusion
PLEFF	pleural effusion
R-CHF	right-sided congestive heart failure
RA	right atrium/atrial
RV	right ventricle/ventricular
TR	tricuspid regurgitation

Introduction

Atrial fibrillation (AF) is the most common supraventricular tachyarrhythmia in dogs [1,2]. AF is most commonly noted in dogs with advanced structural heart disease and severe atrial enlargement [3—5]. The most common underlying heart diseases associated with AF in dogs are dilated cardiomyopathy (DCM) and degenerative mitral valve disease (DMVD) [3,6—9]. These diseases lead to both structural and electrical remodeling of the atria that provide a profibrillatory substrate for initiation and propagation of AF [4,10,11]. Hemodynamic consequences of AF include decreased diastolic filling time and loss of atrial contraction, both of which result in decreased cardiac output and increased atrial filling pressures [2,3,12]. Because of these negative hemodynamic effects, onset of AF in patients with underlying structural heart disease is often accompanied by cardiac decompensation and congestive heart failure (CHF) [3,4,13]. Indeed, case series and large-scale clinical studies suggest that 63%—100% of dogs with AF have concurrent CHF [1,3,6—9,13—16].

In dogs, classification of CHF is generally dichotomized as 'left-sided' (L-CHF), referring to elevated left atrial (LA) pressure causing increased pulmonary venous pressures and resultant pulmonary edema; or 'right-sided' (R-CHF), referring to elevated right atrial (RA) pressure causing increased systemic venous pressures and resultant cavitary effusion (ascites, pleural effusion [PLEFF], and/or pericardial effusion [PCEFF]). When considering the two most common cardiac diseases in dogs, DMVD primarily affects the left heart and is reported to result almost exclusively in L-CHF [17,18]; DCM can have biventricular involvement, but L-CHF generally predominates [19—22].

Several case series have reported higher-than-expected prevalence of R-CHF or biventricular CHF in dogs with AF [3,7,15,16,20,23]. In these studies, R-CHF was noted in 42—80% of dogs with AF and CHF, despite the majority of these dogs being diagnosed with either DCM or DMVD. However, many of these studies were small ($n < 20$), and presentation of results often did not allow direct correlation between the presence of AF, manifestation of CHF, and type of underlying heart disease. In other studies involving dogs with AF and CHF, the distinction between R-CHF and L-CHF was not discussed [6,8,9,13,14,24]. To the authors' knowledge, there has been no systematic investigation of the relationship between AF and manifestation of CHF (R-CHF versus L-CHF) in dogs.

The objective of this study was to determine whether the presence of AF is associated with increased occurrence of R-CHF in a large population of dogs with CHF secondary to DCM or DMVD. A secondary objective was to determine if target clinical or echocardiographic variables are

associated with the presence of either AF or R-CHF in this patient population.

Animals, materials, and methods

Data collection

A retrospective medical record search was performed to identify all dogs diagnosed with CHF secondary to DCM or DMVD at the Iowa State University Lloyd Veterinary Medical Center between January 1, 2007 and January 1, 2018. Inclusion in this study required confirmation of clinical signs compatible with CHF, as well as radiographic, ultrasonographic, and/or post-mortem confirmation of fluid accumulation (pulmonary edema or cavitary effusion). Dogs with congenital heart disease were excluded from this study.

Medical records were reviewed, and the following information extracted for each patient: signalment; body weight; diagnosis of underlying heart disease (DCM or DMVD); date of diagnosis of CHF; location(s) of fluid accumulation (radiographic pulmonary edema; ultrasonographic abdominal, pleural, or pericardial effusion); heart rate on presentation; systolic blood pressure; presence or absence of AF; and presence and characterization of other arrhythmias noted on electrocardiogram. For patients with AF and suspected ventricular premature complexes, aberrant ventricular conduction (Ashman's phenomenon) was excluded as an explanation for QRS complexes with bundle branch block morphology either by the presence of complex ventricular ectopy (couplets, paroxysms of ventricular tachycardia) or by the absence of the typical 'long-short' cycle length pattern preceding the wide QRS complexes. The following parameters were extracted from the most contemporaneous echocardiographic report for each patient: date of echocardiogram; LA-to-aorta ratio (measured in two-dimensional or M-mode right parasternal views at the level of the heart base) [25,26]; fractional shortening (measured in M-mode right parasternal views of the left ventricle at the level of the chordae tendineae); subjective RA and right ventricular (RV) size (normal, mildly enlarged, moderately enlarged, or severely enlarged); presence and subjective severity of tricuspid regurgitation (TR; none, trace, mild, moderate, or severe); transtricuspid pressure gradient calculated using the modified Bernoulli equation for estimation of systolic pulmonary arterial pressure; and presence and severity of pulmonary arterial hypertension (PAH; pressure gradient $<$ 35 mmHg = none, 35–50 mmHg = mild, 50–75 mmHg = moderate, $>$75 mmHg = severe) [27]. In dogs with CHF, an echocardiographic diagnosis of DMVD was based on the presence of characteristic mitral valve lesions, severe mitral regurgitation on color Doppler, and secondary LA and left ventricular enlargement [17]; an echocardiographic diagnosis of DCM was based on decreased left ventricular systolic function and left ventricular dilation in the absence of significant valvular disease [28].

Statistical analysis

Statistical analysis was performed using commercial software.,[c,d] Normality of data was assessed using a combination of visual inspection and the Shapiro–Wilk test. Comparisons of variables between the groups of dogs (AF versus no AF; R-CHF versus no R-CHF) were performed using Student's t-tests for continuous normally distributed variables, Mann–Whitney log-rank tests for continuous non-normally distributed variables, and Fisher's exact tests for categorical variables. Univariate logistic regression analysis was performed to assess variables that were associated with occurrence of AF or R-CHF. Parameters significant in univariate analysis were subsequently entered into a multivariate stepwise logistic regression analysis. Variables demonstrating quasi-complete separation in the univariate logistic analysis were not incorporated in the multivariate analysis. Statistical significance was set at $p < 0.05$ for all analyses.

Results

Demographic and clinical findings

Two hundred twenty dogs met the inclusion criteria, including 155/220 (70.5%) dogs diagnosed with DMVD (Table 1) and 65/220 (29.5%) dogs diagnosed with DCM (Table 2). Commonly represented breeds with DMVD were mixed breed dogs (n = 50), Cavalier King Charles spaniels (n = 19), miniature schnauzers (n = 10), Chihuahuas (n = 9), and Shetland sheepdogs (n = 8). Common breeds diagnosed with DCM included Doberman pinschers (n = 12), Great Danes (n = 10), Labrador retrievers

[c] GraphPad PRISM version 7.0, GraphPad Software, La Jolla, California, USA.
[d] MedCalc version 17.6, MedCalc Software, Ostend, Belgium.

Table 1 Clinical and echocardiographic data for dogs diagnosed with degenerative mitral valve disease (DMVD), comparing dogs with and without concurrent diagnosis of atrial fibrillation (AF). Data are expressed as mean ± standard deviation for normally distributed data and as median (range) for non-normally distributed data. Statistically significant differences between dogs with and without AF are indicated by an asterisk (*). Multiple P-values are reported for categorical variables when multiple Fisher's exact tests were performed. The number of dogs with data included is noted for variables with incomplete data sets.

Clinical parameter	DMVD + AF	DMVD, no AF	P-value
N	17	138	–
Age (years)	9.5 (6.0–13.1)	10.6 (6.1–15.9)	0.027*
Weight (kg)	24.2 (12.7–51.7)	7.5 (1.5–31.4)	<0.001*
Male (n, %)	14 (82.4)	72 (52.2)	0.020*
Heart rate (beats/min)	224 ± 42	136 ± 24	<0.001*
Blood pressure (mmHg) (n = 140)	114 ± 25	137 ± 32	0.055
Other arrhythmias (n)	VPCs: 0	VPCs: 2 SVPCs: 15	0.376
R-CHF (n, %)	13 (76.5)	10 (7.2)	<0.001*
Type of cavitary effusion (n)	Ascites: 10	Ascites: 5	0.221
	PLEFF: 2	PLEFF: 1	1.000
	PCEFF: 4	PCEFF: 4	0.685
Cavities affected per dog (n)	1: 10	1: 10	0.113
	2: 3	2: 0	
	3: 0	3: 0	
TR severity (n) (n = 148)	None/Trace: 1	None/Trace: 41	0.041*
	Mild: 6	Mild: 56	0.295
	Moderate–severe: 9	Moderate–severe: 34	0.299
PAH (n, %) (n = 124)	8/13 (61.5)	69/111 (62.2)	0.751
TR pressure gradient (n = 110)	41.2 (15.0–54.8)	42.9 (13.0–100.7)	0.405
LA:Ao	2.2 ± 0.7	1.9 ± 0.5	0.133
FS (%)	35.3 ± 10.9	49.9 ± 10.8	<0.001*
Right atrial enlargement (n, %) (n = 149)	12/16 (75.0)	15/133 (11.3)	<0.001*
Right ventricular enlargement (n, %) (n = 149)	7/16 (43.8)	14/133 (10.5)	0.0021*

FS, fractional shortening; LA:Ao, left atrium to aorta ratio; PAH, pulmonary arterial hypertension; PCEFF, pericardial effusion; PLEFF, pleural effusion; R-CHF, right-sided congestive heart failure; SVPC, supraventricular premature complex; TR, tricuspid regurgitation; VPC, ventricular premature complex.

(n = 10), and Boxers (n = 7, all diagnosed with the DCM phenotype variant of arrhythmogenic right ventricular cardiomyopathy). One hundred thirty-six dogs (136/220, 61.8%) were males 14 of which were intact; the remaining 84/220 (38.1%) were females, four of which were intact. Additional clinical variables describing the population are shown in Tables 1 and 2

Diagnosis of underlying heart disease was based on complete echocardiography in 206/220 (93.6%) dogs. In a minority of dogs, diagnosis was established on postmortem examination (n = 3) or abbreviated point-of-care echocardiogram (n = 5). In six dogs, diagnosis of DMVD was based on a combination of clinical and auscultatory findings (loud left apical holosystolic heart murmur in an older small-breed dog) and thoracic radiographs revealing cardiomegaly and severe LA enlargement. Echocardiography was completed within 1 day of CHF presentation in 179/206 (86.9%) dogs. In the remaining 41 dogs, echocardiography to confirm underlying heart disease occurred a median of 18 days after CHF (interquartile range 10–130 days).

Degenerative mitral valve disease versus DCM

Several clinical and echocardiographic variables differed based on the type of underlying structural heart disease. Compared with dogs with DMVD, dogs with DCM were younger (median age, 7.8 years [range 1.1–14.2 years] versus 10.5 years [range 6.0–15.9 years]; $p = 0.002$), larger (median body weight, 39.9 kg [range 6.7–73.0 kg] versus 7.8 kg [range 1.5–51.7 kg]; $p < 0.001$) and were more likely to be male (76.9% versus 55.5%, $p = 0.004$). Breeds diagnosed more commonly with DCM than DMVD were Doberman pinschers ($p < 0.001$), Great Danes ($p < 0.001$), Labrador retrievers ($p < 0.001$), Boxers ($p < 0.001$), and Saint Bernards ($p = 0.007$). Breeds diagnosed more

Table 2 Clinical and echocardiographic data for dogs diagnosed with dilated cardiomyopathy (DCM), comparing dogs with and without concurrent diagnosis of atrial fibrillation (AF). Data are expressed as mean ± standard deviation for normally distributed data and as median (range) for non-normally distributed data. Statistically significant differences between dogs with and without AF are indicated by an asterisk (*). Multiple P-values are reported for categorical variables when multiple Fisher's exact tests were performed. The number of dogs with data included is noted for variables with incomplete data sets.

Clinical parameter	DCM + AF	DCM, no AF	P-value
Number of dogs	33	32	—
Age (years)	6.3 ± 2.6	8.4 ± 3.0	0.027*
Weight (kg)	48.7 ± 15.3	35.2 ± 13.2	<0.001*
Male (n, %)	29 (87.9)	21 (65.6)	0.160
Heart rate (beats/min) (n = 64)	214 ± 35	152 ± 30	<0.001*
Blood pressure (mmHg) (n = 57)	121 ± 24	108 ± 30	0.068
Other arrhythmias	VPCs: 2	VPCs: 22 SVPCs: 3	<0.001*
R-CHF (n, %)	24 (72.7)	13 (40.6)	0.013*
Type of cavitary effusion (n)	Ascites: 16	Ascites: 9	1.000
	PLEFF: 16	PLEFF: 7	0.495
	PCEFF: 5	PCEFF: 0	0.140
Cavities affected per dog (n)	1: 12	1: 10	0.104
	2: 11	2: 3	
	3: 1	3: 0	
TR severity (n = 56)	None/trace: 8	None/trace: 9	0.783
	Mild: 14	Mild: 14	1.000
	Moderate: 3	Moderate: 8	0.108
PAH (n, %) (n = 32)	3/10 (30.0)	9/22 (40.9)	0.425
TR pressure gradient (mmHg) (n = 26)	32.8 (17.3—52.7)	33.6 (14.4—80.2)	0.693
LA:Ao	1.8 ± 0.5	1.7 ± 0.5	0.35
FS (%)	16.5 ± 7.7	16.3 ± 7.1	0.90
Right atrial enlargement (n, %) (n = 57)	20/26 (76.9)	17/31 (54.8)	0.101
Right ventricular enlargement (n, %) (n = 57)	16/26 (61.5)	19/31 (61.3)	1.000

FS, fractional shortening; LA:Ao, left atrium to aorta ratio; PAH, pulmonary arterial hypertension; PCEFF, pericardial effusion; PLEFF, pleural effusion; R-CHF, right-sided congestive heart failure; SVPC, supraventricular premature complex; TR, tricuspid regurgitation; VPC, ventricular premature complex.

commonly with DMVD were Cavalier King Charles spaniels ($p < 0.001$) and miniature schnauzers ($p = 0.036$). Compared with dogs with DMVD, dogs with DCM had higher heart rates (median 180 versus 140 beats per minute, $p = 0.012$), higher prevalence of ventricular premature complexes ($p < 0.001$), and lower LA to aorta ratios (1.7 ± 0.5 versus 1.9 ± 0.6, $p = 0.0146$). There were no differences between disease groups in terms of systolic blood pressure ($p = 0.096$), presence or severity of TR ($p = 0.533—1.000$), presence or severity of PAH ($p = 0.109—0.687$), or TR pressure gradient ($p = 0.425$).

Manifestation of CHF

Overall, 195/220 (88.6%) dogs had pulmonary edema indicative of L-CHF, comprising 145/155 (93.5%) dogs with DMVD and 50/65 (76.9%) dogs with DCM. Of these 195 dogs, 160 dogs displayed solely L-CHF, whereas 35 dogs also had evidence of R-CHF and were thus diagnosed with biventricular CHF. Overall, 60/220 (27.3%) dogs had cavitary effusions indicative of R-CHF, including 23/155 (14.8%) dogs with DMVD and 37/65 (56.9%) dogs with DCM. R-CHF signs were more common in DCM than in DMVD ($p < 0.001$). Of dogs with R-CHF, 40 had ascites, 26 had PLEFF, and 13 had PCEFF. Pleural effusion was a more common manifestation of R-CHF in DCM than in DMVD ($p = 0.002$), whereas there was no difference in occurrence of ascites or PCEFF between the disease groups. For individual dogs with R-CHF signs, the number of body cavities (peritoneal, pleural, and pericardial) containing fluid ranged from one to three. Average number of cavities with effusion was higher in dogs with AF versus no AF (1.43 versus 1.13, $p = 0.032$) but did not differ between DCM and DMVD ($p = 0.15$).

Presence versus absence of AF

Fifty dogs (50/220, 22.7%) were in AF at the time of CHF diagnosis, comprising 33/65 (50.8%) dogs with DCM and 17/155 (11.0%) dogs with DMVD. AF

was more common in DCM than DMVD ($p < 0.001$). Within the subgroup of dogs with DMVD, AF dogs were younger ($p = 0.027$), larger ($p < 0.001$), and more likely to be male ($p = 0.020$); had higher heart rates ($p < 0.001$) and lower fractional shortening ($p < 0.001$); were less likely to have moderate to severe TR ($p = 0.041$); and were more likely to have RA ($p = 0.001$) or RV ($p = 0.0021$) enlargement than dogs without AF (see Table 1). Within the subgroup of dogs with DCM, AF dogs were younger ($p = 0.027$) and larger ($p < 0.001$); had higher heart rates ($p < 0.001$); and were less likely to have ventricular premature complexes ($p < 0.001$) than dogs without AF (see Table 2).

Overall, dogs with AF were more likely to manifest R-CHF signs (37/50, 74.0%) than dogs without AF (23/170, 13.5%; $p < 0.001$). This trend persisted when considering subgroups of dogs based on heart disease diagnosis. Among DMVD dogs, patients with AF were more likely to manifest R-CHF signs (13/17, 76.5%) than those without AF (10/138, 7.2%; $p < 0.001$). Similarly, among DCM dogs, patients with AF were more likely to manifest R-CHF signs (24/33, 72.7%) than those without AF (13/32, 40.6%; $p = 0.013$).

Variables predictive of AF and R-CHF

All variables listed in Tables 1 and 2 were entered into logistic regression analysis for association with either AF or R-CHF. Univariate logistic regression demonstrated that the following variables were significantly associated with the presence of AF: younger patient age ($p < 0.001$), higher body weight ($p < 0.001$), male sex ($p < 0.001$), higher heart rate ($p < 0.001$), diagnosis of DCM ($p < 0.001$), lower fractional shortening ($p < 0.001$), RA enlargement ($p < 0.001$), RV enlargement ($p < 0.001$), and presence of R-CHF ($p < 0.001$). The only variables that remained significantly associated with AF in multivariate analysis were heart rate and body weight (see Table 3).

The following variables were significantly associated with R-CHF in univariate logistic regression: younger patient age ($p < 0.001$), higher body weight ($p < 0.001$), male sex ($p = 0.005$), higher heart rate ($p < 0.001$), lower systolic blood pressure ($p < 0.001$), diagnosis of DCM ($p < 0.001$), lower fractional shortening ($p < 0.001$), presence of TR ($p = 0.003$), moderate to severe TR ($p = 0.002$), RA enlargement ($p < 0.001$), RV enlargement ($p < 0.001$), and presence of AF ($p < 0.001$). Variables that remained significant in multivariate analysis were presence of AF, diagnosis of DCM, and moderate-to-severe TR (see Table 3).

Discussion

This study found that among dogs with CHF secondary to either DCM or DMVD, the presence of AF was associated with a greater likelihood of R-CHF. This association between AF and R-CHF was found whether considering the entire study population as a whole ($n = 220$, $p < 0.0001$) or analyzing subgroups of dogs with DMVD ($n = 155$, $p < 0.0001$) or DCM ($n = 65$, $p = 0.0125$).

Not surprisingly, DMVD dogs differed from DCM dogs in number of clinical and echocardiographic variables that reflect the distinct signalment and pathophysiology associated with each heart disease. Compared with dogs with DMVD, dogs with DCM were younger, larger, and more likely to be male; had higher heart rates and more ventricular arrhythmias; and demonstrated less dramatic LA dilation. Furthermore, compared with dogs with DMVD, dogs with DCM were more likely to be diagnosed with AF or R-CHF. Indeed, AF was noted in 50.8% of DCM dogs compared with 11.0% of dogs with DMVD, and R-CHF was diagnosed in 56.9% of DCM dogs compared with 14.8% of dogs with DMVD. These findings are consistent with previous studies describing clinical features of DCM [20–22] and DMVD [18,29,30]. The most

Table 3 Variables demonstrating statistical significance in multivariate logistic regression models for association with either atrial fibrillation (AF) or right-sided congestive heart failure (R-CHF).

	Variable	P-value	Odds ratio	95% CI
AF	Body weight	0.042	1.092	1.003–1.189
	Heart rate	0.001	1.123	1.038–1.204
R-CHF	AF	<0.001	14.438	5.750–36.255
	DCM	<0.001	4.327	1.869–10.015
	Moderate-severe TR	<0.001	5.111	2.166–12.060

CI, confidence interval; DCM, dilated cardiomyopathy; TR, tricuspid regurgitation.

important finding of the present study is that within each disease group, the presence of AF significantly increased the likelihood of R-CHF. In DCM dogs, R-CHF was found in 72.7% of patients with AF compared with 40.6% without AF; in DMVD dogs, R-CHF was noted in 76.5% of patients with AF compared with only 7.2% without AF. Therefore, approximately three-quarters of dogs with AF in this study displayed R-CHF, regardless of underlying heart disease. These findings suggest that in a dog with AF secondary to severe structural heart disease, R-CHF is an expected finding (rather than an exception to the rule) and suggests that additional diagnostic workup for noncardiac causes of cavitary effusion might not be warranted.

Results of this study are consistent with findings of several smaller case series, which reported R-CHF in more than half of dogs with AF and CHF [3,7,15,16,20,23]. The majority of dogs in these previous studies were diagnosed with DCM [3,7,20,23], although at least five dogs with DMVD were described as manifesting biventricular CHF [15,16]. However, it is difficult to compare published reports to the present study directly. Many prior studies of dogs with AF and CHF either fail to distinguish between R-CHF and L-CHF [6,8,9,13,14,24] or do not specifically correlate manifestation of CHF with the presence or absence of AF [2,23]. Other studies that report clinical findings in populations of dogs with AF lack a group of dogs without AF for comparison [3,7,15,16]. To the author's knowledge, this is the largest retrospective study of dogs with CHF secondary to DCM or DMVD and the only such study to correlate presence of AF with manifestation of CHF.

Both DMVD and DCM primarily affect the left heart. DMVD by definition involves acquired insufficiency of the left atrioventricular valve, causing LA and ventricular volume overload that subsequently leads to elevated LA pressure and causes almost exclusively L-CHF [17,18]. Dilated cardiomyopathy causes left ventricular systolic dysfunction and chamber dilation, ultimately leading to L-CHF in the majority of cases [31,32]. Several factors may contribute to the occurrence of R-CHF in dogs diagnosed with primarily left heart disease. First, some dogs develop variants of these structural heart diseases wherein the right heart becomes directly affected. For example, some dogs with DMVD also develop severe endocardiosis of the tricuspid valve, leading to hemodynamically relevant TR and secondary right heart enlargement [33]. Histopathologic changes in DCM can affect the right ventricle as well as the left; four-chamber dilation and biventricular CHF is a relatively common feature of advanced DCM, particularly in breeds other than Doberman pinschers [19—22]. In the present study, subjective RA and RV enlargement were associated with R-CHF in the subgroup of dogs with DMVD but not DCM, but were not significant predictors of R-CHF in multivariate analysis. In addition, among DMVD dogs, presence of TR was more common in dogs with concurrent AF, and presence of moderate-to-severe TR was a significant predictor of R-CHF in overall multivariate analysis. This suggests that among dogs with DMVD, concurrent tricuspid valve degeneration and hemodynamically relevant TR may be an independent pathophysiologic route to R-CHF. Particularly in dogs with DCM, it is difficult to determine a cause-and-effect relationship between severity of TR and severity of right heart dilation. Second, dogs with advanced left heart disease causing severely elevated LA pressure and L-CHF may develop postcapillary PAH, leading to RV pressure overload and potentially R-CHF [30,34]. However, in this study, echocardiographically estimated PAH was not a significant predictor of R-CHF in either univariate or multivariate models.

Overall, the variable that was most predictive of R-CHF in this study was the presence of AF (odds ratio, 14.438; 95% confidence interval, 5.750—36.255). This suggests that hemodynamic effects of the tachyarrhythmia itself may contribute to development of biventricular or R-CHF. This notion is supported by experimental models of ventricular tachypacing in dogs causing tachycardia-induced cardiomyopathy and CHF. Ventricular tachypacing at rates of 220—240 beats per minute for 3 weeks causes a predictable increase in both LA and RA pressures [35—40], and is often characterized as a model of biventricular CHF [12]. In these reports, CHF is often based on clinical signs (lethargy, dyspnea, weight gain) rather than objective imaging; however, in the studies that specify the actual location of fluid accumulation in tachypaced dogs, cavitary effusions predominate over pulmonary edema [35,36,38]. These experiments suggest that the negative hemodynamic consequences of tachyarrhythmias, including decreased time for passive ventricular filling and elimination of the atrial kick, affect the RA at least as much as the LA. Therefore, a possible explanation for increased prevalence of R-CHF in dogs with AF and left-sided structural heart disease is that AF causes an acute increase in RA pressure that is more hemodynamically significant than the pressure increase within an already volume overloaded and dilated LA.

Interestingly, one of the early tachypacing experiments [36] describes initial pilot studies in

which dogs were paced at higher rates (260 beats per minute). The authors report that 'most' dogs paced in this manner died of fulminant pulmonary edema. Similarly, clinical reports of dogs with naturally occurring supraventricular tachycardia (heart rates ranging from 250 to 340 beats per minute) and secondary tachycardia-induced cardiomyopathy generally report dogs developing L-CHF [41—43]. It is theoretically possible that at extremely high heart rates, LA pressure quickly rises to critical levels; whereas at the more modest tachycardia typical of AF (mean 218 beats per minute in this study), the effects on RA pressure are more clinically relevant. Invasive hemodynamic studies would be required to confirm absolute and relative changes in RA versus LA pressure in dogs with CHF with and without various tachyarrhythmias.

In addition to establishing a correlation between AF and R-CHF, the present study also provided an opportunity to determine clinical and echocardiographic variables predictive of AF in a large population of dogs with CHF secondary to DMVD or DCM. As previously reported, AF was more common in dogs with DCM than those with DMVD [2,7,9,20]. Within disease subgroups, dogs with AF had higher body weight than dogs without AF, also consistent with prior studies [2,5], although relative LA size (based on LA to aorta ratio) did not differ based on the presence or absence of AF. These findings support the notion that increased absolute atrial size is a strong predisposing factor for AF [4]. Indeed, the only significant predictors of AF in multivariate analysis were higher body weight and higher heart rate. It is not surprising that dogs with AF had higher heart rates than those with underlying sinus rhythm, reflecting the pathologically elevated heart rates associated with this tachyarrhythmia.

This study had several limitations related to the retrospective nature of the investigation. Some data, particularly echocardiographic variables, were not recorded for all dogs. Echocardiographic examinations were not always performed on the day of CHF diagnosis, introducing possible effects of CHF treatment on clinical and echocardiographic variables. Echocardiographic descriptions of TR severity and right heart enlargement were based on subjective interpretation of two-dimensional and color Doppler images rather than objective measurements. Objective echocardiographic measurements of right ventricular systolic function, including tricuspid annular plane systolic excursion and right ventricular fractional area change, were not part of standard echocardiographic practice at the time of data collection. In addition, all dogs in this study were presented to a referral institution for diagnosis and treatment of CHF, introducing possible selection bias for dogs with more complex or severe disease.

Conclusions

In this large retrospective study of dogs with CHF secondary to either DMVD or DCM, the presence of AF was associated with a higher likelihood of R-CHF. In this population of dogs, AF was the strongest predictor of R-CHF in multivariate analysis. Cavitary effusion should be considered a common and expected finding in dogs with AF and CHF secondary to either DCM or DMVD.

Conflicts of Interest Statement

The authors declare no conflicts of interest.

Acknowledgments

This study was not supported by any grant or other funding source. The authors thank Imal Khelik for assistance with data collection.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jvc.2018.10.006.

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