

## Echocardiographic Assessment of Cardiac Function by Conventional and Speckle-Tracking Echocardiography in Dogs with Patent Ductus Arteriosus

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**Background:** Patent ductus arteriosus (PDA) is one of the most common congenital heart defects in dogs. Advanced echocardiographic techniques such as speckle-tracking echocardiography (STE) have not been extensively used to evaluate cardiac function in affected dogs.

**Hypothesis:** Advanced echocardiographic techniques are more sensitive than standard echocardiographic techniques in analyzing systolic function in dogs with PDA.

**Animals:** Forty-four client-owned dogs: 34 dogs with PDA (preoperative evaluation) and 10 healthy sex- and weight-matched controls.

**Methods:** Prospective study. Dogs were recruited over a 2-year period. Complete echocardiographic evaluation was performed, including conventional (end-diastolic volumes indexed to body surface area in B and M-mode [EDVI<sub>B/M</sub>], end-systolic volumes indexed to body surface area in B and M-mode [ESVI<sub>B/M</sub>], allometric scaling in diastole and systole [AlloD/S], pulmonary flow to systemic flow [Qp/Qs], ejection fraction [EF] and fractional shortening [FS]) and speckle-tracking echocardiography ([STE]: global longitudinal, radial and circumferential strain [S] and strain rate [SR]).

**Results:** Dogs with PDA had significantly different EDVI<sub>B/M</sub>, ESVI<sub>B/M</sub>, AlloD/S, Qp/Qs and all STE-derived parameters (global longitudinal S and SR, global circumferential S and SR, global radial S and SR) compared to healthy dogs. No correlation was found between standard techniques (EDVI<sub>B/M</sub>, ESVI<sub>B/M</sub>, AlloD/S, Qp/Qs) and STE-derived parameters (global longitudinal, circumferential and radial S and SR).

**Conclusion and Clinical Importance:** Conventional parameters routinely used to assess systolic function (EF and FS) were not different between the groups; STE-derived parameters identified subtle changes in cardiac systolic function and contractility between the 2 groups of dogs. Based on these findings, STE may be a more appropriate tool to assess cardiac contractility in dogs with PDA.

**Key words:** Congenital heart disease; Dogs; Strain; Strain rate.

Patent ductus arteriosus (PDA) is 1 of the most common congenital heart defects in dogs and accounts for 21–32% of congenital heart disease in dogs.<sup>1–4</sup> Ductal patency has been related to the absence of smooth muscle tissue in the ductal wall, which prevents effective constriction shortly after birth.<sup>5</sup> The main hemodynamic effect of a left-to-right PDA (L-R PDA) is volume overload of the left ventricle, as indicated by the increase in preload (increase in end-diastolic volume), which in turn increases contractility following Starling's law.<sup>6,7</sup> The left ventricle compensates by increasing stroke volume and eventually may develop eccentric hypertrophy to normalize wall stress. Another common

### Abbreviations:

AlloD	allometric scale in diastole
AlloS	allometric scale in systole
EDVI <sub>B</sub>	end-diastolic volume index derived from B-mode
EDVI <sub>M</sub>	end-diastolic volume index derived from M-mode
EF	ejection fraction
ESVI <sub>B</sub>	end systolic volume index derived from B-mode
ESVI <sub>M</sub>	end systolic volume index derived from M-mode
FS	fractional shortening
PDA	patent ductus arteriosus
Qp/Qs	pulmonary flow to systemic flow ratio
SR	strain rate
S	strain
STE	speckle-tracking echocardiography
VVI	velocity vector imaging

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Where the work was performed: Dogs with patent ductus arteriosus were scanned at Clinica Veterinaria Gran Sasso, healthy control dogs were scanned at Università degli Studi di Milano. Post-processing was performed by the corresponding author at Università degli Studi di Milano.

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finding in dogs with PDA is the increase in end-systolic volume and aortic velocity. Left atrial enlargement also may occur as a consequence of volume overload, and PDA-related hemodynamic changes can lead to congestive heart failure and decreased survival if left untreated.<sup>8–10</sup>

Advanced echocardiographic techniques (also called “deformation imaging”) are echocardiography-based techniques that aim to quantify cardiac contractility and deformation by direct assessment of cardiac motion.<sup>11</sup>

Myofiber contraction can be evaluated by quantifying the deformation of a myocardial segment during the cardiac cycle. Strain (S, expressed as %) can be defined

as the deformation of a myocardial segment normalized to its original shape.<sup>11–13</sup> The velocity at which deformation occurs is called strain rate (SR,  $s^{-1}$ ). Different techniques are available to provide S and SR values, and currently in human cardiology speckle-tracking echocardiography (STE) is the most widely used. It is based on a software algorithm that tracks speckles (natural acoustic markers in the myocardium) during the cardiac cycle based on 2-dimensional (2D) images.<sup>12,13</sup> Systolic S and SR can be applied as an index of global performance of the LV, characterized by an average of the segments, or as a regional deformation indicator, conventionally by separately analyzing 6 myocardial segments.<sup>14</sup> The latter approach is targeted at identifying regional wall motion abnormalities that is of paramount importance in people affected by myocardial infarction or when a localized abnormality is suspected.

Speckle-tracking echocardiography (STE) has been promoted as complementary and more sensitive tool to evaluate cardiac function in a wide variety of clinical conditions in humans, particularly with regard to physiological variations in healthy individuals such as growth,<sup>15</sup> pregnancy<sup>16</sup> as well as disease, such as sub-clinical heart disease, cardiomyopathy, and coronary artery disease.<sup>11–13,17,18</sup>

Recently, STE has been used to evaluate age-related changes in myocardial function<sup>19</sup> and to assess cardiac function in dogs with mitral valve disease and dilated cardiomyopathy.<sup>20–25</sup> Hemodynamic alterations related to PDA include increased preload, and previous studies have analyzed the consequences of ductal patency and its closure on cardiac indices of function by standard M- and B-mode parameters.<sup>9,26–29</sup>

To the authors' knowledge, no study has compared cardiac function and contractility by STE in dogs with PDA as compared to normal control dogs. The aim of our study was (1) to evaluate echocardiographic-related changes in conventional and advanced echocardiographic parameters in dogs with PDA compared to healthy control dogs, and (2) to determine whether or not a correlation exists between conventional and advanced echocardiographic parameters.

## Materials and Methods

Forty-four client-owned dogs were prospectively recruited, 10 of which were included in the normal healthy control group and were shown to be free from cardiovascular disease, and 34 of which were affected by PDA. Before inclusion, all dogs underwent a general physical examination and were found to be healthy except for those affected by PDA, in which a continuous heart murmur was identified and confirmed to be caused by a left-to-right shunting PDA using Doppler echocardiography. Written consent was obtained for both healthy control dogs and PDA dogs.

Inclusion criteria for PDA dogs included a complete medical record, complete preoperative echocardiography, electrocardiogram and thoracic radiographs. Healthy control dogs were included only if they were <2 years old, had no evidence of systemic or cardiac disease on general examination and blood testing; they were weight and sex matched to the affected dogs. Exclusion criteria were any additional congenital or acquired cardiac disease,

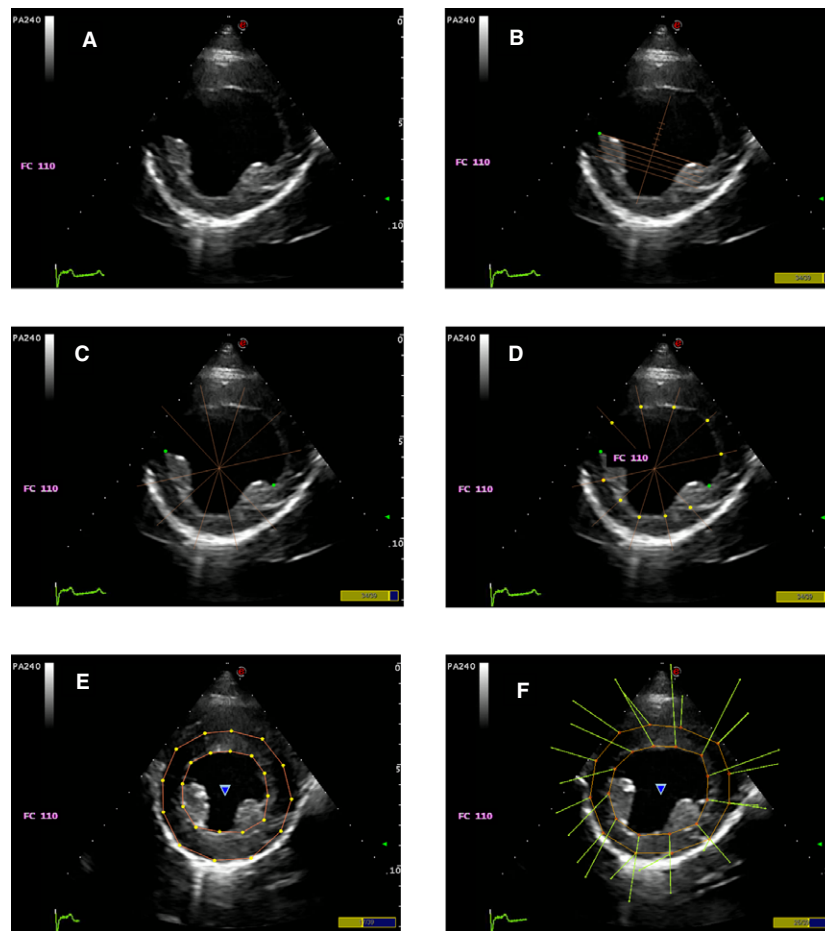
incomplete medical record, and incomplete echocardiographic study. No dog in the control group and in the PDA group was being treated with any medication. A complete standard echocardiographic examination was performed on all dogs in accordance with published human and veterinary medical guidelines.<sup>14,30,31</sup> All echocardiographic examinations were performed using commercial ultrasound equipment<sup>a</sup> with 2.5–10 MHz phase array ultrasound probes with the patient manually restrained. No sedation was performed in any dog.

Standard echocardiographic parameters included in the study were: end-diastolic volume and end-systolic volume indexed to body surface area (EDVI and ESVI), measured by Teichholz method on M-mode (EDVI<sub>M</sub>/ESVI<sub>M</sub>) and area-length method on B-mode (EDVI<sub>B</sub>/ESVI<sub>B</sub>) and allometric scaling in diastole and systole (AlloD and AlloS). Furthermore, fractional shortening in M-mode (FS) and ejection fraction (EF) in M- and B-mode were calculated. To provide further information about shunt severity, pulmonary flow to systemic ratio (Qp/Qs) was measured as described elsewhere.<sup>32,33</sup> Parameters considered to reflect systolic function based on literature review were FS, EF and ESVI.<sup>34</sup> No diastolic parameters were considered for this study.

In addition, at least 3 clips with 1 cardiac cycle were acquired for STE postprocessing. Electrocardiography-gated with a positive QRS complex with normal QRS amplitude and duration, good image quality and high frame rate (least acceptable frame rate: 80 fps<sup>14</sup>) were deemed fundamental, and thus frame rate, sector width and probe frequency were adjusted to optimize image acquisition. To standardize short-axis acquisitions, the basal plane was identified as containing mitral leaflets (right parasternal short-axis view at the level of mitral valve [MV]), whereas the midlevel was identified as containing the papillary muscles (right parasternal short-axis view at the level of the papillary muscles [PM]). Particular attention was given to make the LV cross-section as circular as possible and to limit transversal overlapping (“out-of-plane motion”) as much as possible. Left apical-4 chamber view (4Ch) also was acquired to optimize LV length and endocardial borders and to avoid including the LV outflow tract.<sup>14</sup> Circumferential S and SR were calculated by MV short-axis view,<sup>14</sup> radial S and SR by PM short-axis view<sup>14</sup> and longitudinal S and SR by 4Ch long-axis view.<sup>14</sup>

Commercial<sup>b</sup> software was used for off-line analysis. A mean of 10 minutes was required for post-processing 3 cine-loops. The cine-loop was evaluated by slow motion and a still frame was selected as a starting point. Generally, end-diastole was the preferred timing because of the best visualization of endocardial borders and, where necessary, epicardial borders. The starting points for endocardial tracing were manually placed (2 at midplane both in MV and PM and 3 in the apical 4Ch view at both mitral valve hinge points and cardiac apex), then the software provided tracking guidance by the presence of drawn lines originating from the LV cavity where the endocardial border was manually identified and selected (for 12 points in short-axis views and 13 in long-axis views). After selecting these points, the software automatically divided the myocardium into 6 segments, as shown by a continuous traced line, which follows the endocardial border and is manually adjusted to fit. Velocity vector imaging (VVI) arrows then are displayed above the endocardial border to help evaluate tracking quality during the cardiac cycle (Fig 1). When necessary, a single manual attempt to adjust endocardial points was considered acceptable. If VVI arrows showed unacceptable tracking quality, the cine-loop was discarded.

After this procedure, strain and strain rate curves were obtained by the software (Fig 2). No adjustment to the original tracking was done after obtaining the curves. Peak systolic strain (S) and strain rate (SR) values are provided by the software, and then are exported to a Microsoft Excel<sup>c</sup> data sheet and prepared for statistical analysis.



**Fig 1.** Tracking sequence. The starting points for endocardial tracing (A & B) are manually placed (2 at midplane), then the software provided tracking guidance by the presence of drawn lines originating from the LV cavity where the endocardial border had to be manually identified and selected (C & D, a total of 12 points in short-axis views). After selecting these points, the software automatically divides the myocardium into segments (E), as shown by a continuous line traced, which should follow the endocardial border and is manually adjusted to fit. Velocity vector imaging arrows are then displayed above the endocardial border and help evaluating tracking quality during the cardiac cycle: the direction of the arrows indicates the direction of the movement of the left ventricular myocardium and the length of the arrow indicates the velocity of such movement (F).

All echocardiographic values were measured repeatedly by 1 investigator (IS) 3 times on 3 different days from the same clip and images and the results are averaged. For advanced echocardiographic values, global S and SR are provided, which are the averaged 6 regional segments identified by the software.<sup>14</sup> Final S and SR values were obtained by an average of 3 consecutive measurements made on 3 different days. A between-day and within-day coefficient of variation (CV) was randomly assessed in 30% of the patients.

### Statistical Analysis

The statistical analysis was performed using a dedicated statistical software (SPSS v 1.7)<sup>d</sup> and in all cases  $P < .05$  was set to indicate statistical significance. Basic descriptive statistical analyses were performed using Microsoft Excel.<sup>c</sup> The Shapiro–Wilk and D’Agostino–Pearson tests were used to verify normal distribution of variables. If the distribution was normal, a *t*-test was used to compare the means of 2 continuous variables; the Mann–Whitney *U*-test or Wilcoxon signed-rank test were used with non-normally distributed variables. Data with normal distribution were expressed as mean  $\pm$  standard deviation (SD). Non-normally distributed data were expressed as median and first and third interquartile (IQ1-3).

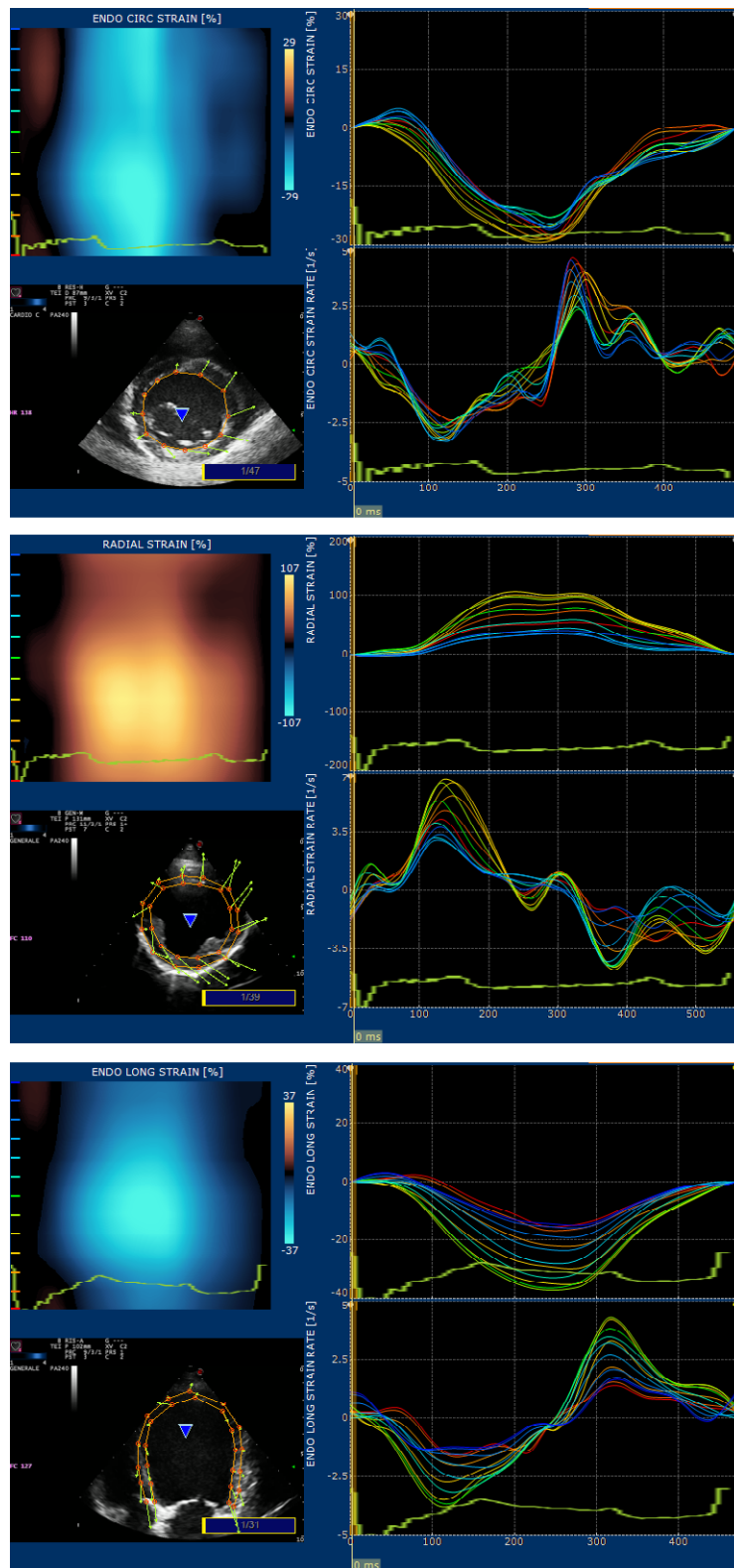
Correlation analysis was performed by Pearson’s correlation coefficients and expressed by a color-coded graph, including statistical significance and correlation coefficients.

For the repeatability study, mean and SD values resulting from postprocessing of repeated examination of dogs with PDA and controls were used for the calculation of within-day and between-day CV (SD of the measurements/average of measurements). For all tests, statistical significance was set at  $P < .05$ .

### Results

Two dogs in the normal group were excluded because of increased respiratory frequency (panting) and low quality clip (1 each). In the PDA group, 6 dogs were excluded for incomplete data set for STE analysis ( $n = 5$ ) and 1 dog for low quality images (out-of-plane motion and respiratory artifacts).

The final population comprised 10 healthy control dogs and 34 dogs with PDA; female dogs were overrepresented ( $n = 34$ , 77%) as compared to male dogs ( $n = 10$ , 23%). In the PDA group, 82% of the patients were females and 60% of dogs in the healthy control group were female.



**Fig 2.** Examples of the graphs originating with STE. On top, circumferential S and SR, radial S and SR, longitudinal S and SR.

Age and weight were normally distributed in the healthy control group but not in the PDA group, so that data are presented as median and IQ1-3, and statistical analysis was

performed using the Mann–Whitney *U*-test. Median age was 12 months (IQ1-3, 6–24 months) and median weight was 12.2 kg (IQ1-3, 7–20 kg) in the overall population.



No statistical difference was found in body weight between dogs with PDA (median weight, 12.2 kg, IQ1-3, 7.5–17.5 kg) and healthy control dogs (median weight, 15 kg, IQ1-3, 6.9–21 kg).

The only statistical difference between the 2 groups was age ( $P = .02$ ), with PDA dogs being younger (median age, 8 months, IQ1-3 5–13 months) than control dogs (median age, 12 months, IQ1-3 12–24 months). No dog in the PDA group showed clinical signs attributable to a left-to-right PDA. Dogs affected by PDA had statistically significant increases in most of the conventional echocardiographic parameters:  $EDVI_M$  ( $187.8 \pm 80.6$  mL/m<sup>2</sup> PDA group versus  $87.7 \pm 25.7$  mL/m<sup>2</sup> control group,  $P < .001$ ),  $EDVI_B$  ( $117.1 \pm 57.5$  mL/m<sup>2</sup> PDA group versus  $56.1 \pm 23.9$  mL/m<sup>2</sup> control group,  $P < .001$ ),  $ESVI_M$  ( $74.7 \pm 37.5$  mL/m<sup>2</sup> PDA group versus  $30.9 \pm 11.2$  mL/m<sup>2</sup> control group,  $P < .001$ ),  $ESVI_B$  ( $50 \pm 28.2$  mL/m<sup>2</sup> PDA group versus  $21.6 \pm 11.5$  mL/m<sup>2</sup> control group,  $P < .001$ ),  $AlloD$  ( $2.20 \pm 0.38$  PDA group versus  $1.62 \pm 0.20$  control group,  $P < .001$ ), and  $AlloS$  ( $1.42 \pm 0.27$  PDA group versus  $1.03 \pm 0.16$  control group,  $P < .001$ ). The Qp/Qs ratio was greater in dogs with PDA as compared to healthy dogs ( $1.8 \pm 0.5$  PDA group versus  $1 \pm 0.2$  control group,  $P < .001$ ). The EF and FS did not differ significantly between the 2 groups (Table 1). The STE-derived parameters were negative for longitudinal and circumferential S and SR, whereas radial S and SR were positive. Dogs with PDA had increased absolute values as compared to normal dogs: longitudinal S was more negative in dogs with PDA ( $-20.20 \pm 5.54\%$  PDA group versus  $-16.74 \pm 3.07\%$  control group,  $P < .001$ ), as well as longitudinal SR ( $-2.34 \pm 0.72$  s<sup>-1</sup> PDA group versus  $-1.69 \pm 0.39$  s<sup>-1</sup>,  $P < .001$ ; Table 1).

**Table 1.** Standard and advanced parameters in dogs with PDA and healthy controls.

	PDA	Control	<i>P</i> value
Heart Rate (BPM)	128 ± 35	117 ± 30	NS
Qp/Qs	1.8 ± 0.5	1.0 ± 0.2	<.001
EDVI M-mode (mL/m <sup>2</sup> )	187.8 ± 80.6	87.7 ± 25.7	<.001
ESVI M-mode (mL/m <sup>2</sup> )	74.7 ± 37.5	30.9 ± 11.2	<.001
EDVI B-mode (mL/m <sup>2</sup> )	117.1 ± 57.5	56.1 ± 23.9	<.001
ESVI B-mode (mL/m <sup>2</sup> )	50 ± 28.2	21.6 ± 11.5	<.001
AlloD	2.20 ± 0.38	1.62 ± 0.20	<.001
AlloS	1.42 ± 0.27	1.03 ± 0.16	<.001
FS M-mode (%)	32.7 ± 6.1	32.9 ± 7.2	NS
EF M-mode (%)	60.9 ± 8.9	61.6 ± 10.4	NS
EF B-mode (%)	58.1 ± 8.0	61.6 ± 12.3	NS
Circumferential S (%)	-26.35 ± 5.04	-22.39 ± 4.12	.002
Circumferential SR (second <sup>-1</sup> )	-3.21 ± 0.8	-2.57 ± 0.68	.002
Radial S	50.26 ± 17.7	35.15 ± 9.9	<.001
Radial SR (second <sup>-1</sup> )	4.37 ± 1.29	2.89 ± 0.47	<.001
Longitudinal S	-20.20 ± 5.54	-16.74 ± 3.07	<.001
Longitudinal SR (second <sup>-1</sup> )	-2.34 ± 0.72	-1.69 ± 0.39	<.001

*T*-test was used for comparison, and  $P < .05$  was set as statistically significant.

**Table 2.** Coefficient of variation for advanced echocardiographic techniques.

CV	Circ		Rad		Long		Global CV
	Circ S	SR	Rad S	SR	S	SR	
Between day	0.12	0.15	0.14	0.16	0.13	0.14	0.14
Within day	0.10	0.12	0.12	0.14	0.10	0.11	0.11

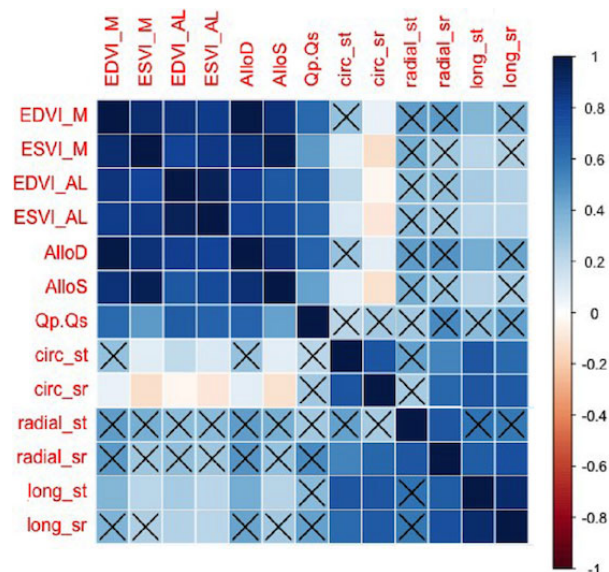
Circ, circumferential; Rad, radial; Long, longitudinal.

Circumferential S was more negative in dogs with PDA ( $-26.35 \pm 5.04\%$  PDA group versus  $-22.39 \pm 4.12\%$ ,  $P = .002$ ) as well as circumferential SR ( $-3.21 \pm 0.8$  s<sup>-1</sup> PDA group versus  $-2.57 \pm 0.68$  s<sup>-1</sup> control group,  $P = .002$ ). Dogs with PDA had more positive radial S ( $50.26 \pm 17.7\%$  PDA group versus  $35.15 \pm 9.9\%$  control group,  $P < .001$ ) and radial SR ( $4.37 \pm 1.29$  s<sup>-1</sup> PDA group versus  $2.89 \pm 0.47$  s<sup>-1</sup> control group,  $P < .001$ ).

No statistical difference in heart rate was observed between dogs with PDA and control dogs ( $128 \pm 35$  bpm PDA group versus  $117 \pm 30$  bpm control group,  $P > .05$ ).

Between-day CV was <15%, whereas within-day CV was <12%. Radial S and SR had the highest CV (Table 2).

Correlation analysis identified close correlation between conventional echocardiographic parameters (positive correlation 1-0.7 for all variables), a good correlation between advanced echocardiographic parameters (positive correlation > 0.7 except for radial S/SR) but no correlation was identified between standard and advanced echocardiographic variables (Fig 3).



**Fig 3.** Correlation analysis as outlined by a graph showing Pearson's correlation on a color-coded bar graph. Blue indicates positive correlation, red negative correlation. Crossed cells indicate statistically not significant correlations ( $P > .05$ ).

## Discussion

We identified a statistically significant difference between standard echocardiographic parameters (except for EF and FS) and all STE-derived parameters in dogs with PDA as compared to healthy dogs. Correlation analysis did not identify a correlation between advanced and standard echocardiographic parameters, indicating inability to extrapolate S and SR values based on conventional echocardiographic indices. Conventional echocardiographic variables are inter-related as a probable consequence of a similar technique (based on LV internal diameters). Of the advanced echocardiography variables, only circumferential and longitudinal S and SR were correlated, whereas radial S and SR did not correlate with any other variable except each other.

Echocardiographic findings of PDA are consistent with a global increase in LV dimensions (EDVI, ESVI, and AlloD/S). There are marked differences in these parameters between normal dogs and dogs with PDA. The increase in LV dimensions is a consequence of LV overload and is a result of the increase in preload secondary to L-R PDA shunting.<sup>6–8</sup> Our results are in accordance with previous studies in human and veterinary medicine.<sup>6,7,9,26–29,35</sup> Correlation analysis showed good agreement among different methods of evaluating LV dimensions, regardless of the different underlying geometrical assumption (Teichholz method, area-length method and allometric scaling). However, to provide the best information, we suggest using the same technique in serial measurements on the same patient.

The FS and EF did not differ between the 2 groups. These parameters are regarded by most authors as the conventional parameters to evaluate systolic function. They provide information obtained by a change in LV dimensions during systole and diastole. A decrease in FS or EF generally is thought to be associated with a decrease in contractility and thus may be referred to as systolic dysfunction, whereas an increase in FS or EF indicates a hyperdynamic LV but does not provide an accurate estimate of systolic function, as is the case for dogs with mitral valve disease.<sup>34</sup> Most cardiac diseases have stable loading conditions, so that EF and FS correctly represent cardiac function and are useful tools to investigate pathophysiology. However, under particular loading conditions, FS or EF can over- or under-estimate actual contractility, leading to a misunderstanding of the pathophysiology of the underlined disease.<sup>36</sup>

Patent ductus arteriosus is characterized by volume overload, which simultaneously will affect preload and afterload. Although the latter plays a greater role in hemodynamics after PDA closure, in the preoperative setting it is secondarily increased as a consequence of greater LV systolic distension and an increase in LV wall tension (induced by the presence of an increased amount of blood during the entire cardiac cycle), which is reflected by the increase in LV end-systolic dimensions reported in the veterinary literature and found also in our study (ESVI<sub>B/M</sub>, AlloS). Preload is increased after blood escapes through the shunt, and its effect on the LV can be represented by an increase in LV end-

diastolic dimensions reported in the veterinary literature and found in our study. The LV mechanics are influenced both by preload and afterload. An increase in preload will affect contractility by the Frank–Starling law, which states that an increased venous return will physiologically increase stroke volume by an increase in contractility. The FS and EF then may not be able to discriminate between healthy and diseased hearts, because of an underestimation of contractility that occurs in dogs with PDA. If this is the case, EF and FS may not be the most reliable tools to evaluate contractility in dogs with PDA.

The Qp/Qs ratio can be regarded as another marker of shunt severity and although it has some technical and reproducibility difficulties,<sup>33</sup> it can be taken into account when assessing PDA severity to classify the extent of blood flow shunting (mild, moderate, or severe).

Advanced echocardiographic techniques represent an important field of investigation and facilitate understanding cardiac mechanics and pathophysiology.<sup>11–13,17,18,36</sup> Speckle-tracking echocardiography might be a more suitable tool to analyze LV systolic function in this setting, because of its ability to diagnose early myocardial impairment<sup>13</sup> and the fact that S and SR directly measure contractility.<sup>11–13,17,18,36</sup> An important finding identified by our study is that S and SR values are increased in dogs with PDA (more negative results for longitudinal and circumferential S and SR values, more positive results for radial S and SR) as compared to normal dogs.

Lower than normal S and SR absolute values (less negative for longitudinal and circumferential S/SR and less positive radial S/SR) are regarded as markers of impaired cardiac function in a wide variety of diseases in human cardiology (coronary artery disease, dilated cardiomyopathy, cardiac resynchronization treatment).<sup>13</sup>

Although PDA in infants has a different etiology, being more commonly identified in premature infants,<sup>35</sup> and intervencor software variability is a source of variation in results that must be taken into account when evaluating STE values,<sup>14</sup> pediatric patients > 6 months of age undergoing percutaneous closure had similarly increased preoperative longitudinal S and SR values (higher absolute values).<sup>37</sup>

Based on our findings, PDA may induce an increased contractility response of the LV to counteract increasing preload and maintain effective pump function for long periods of time. Dogs with PDA probably are able to cope better with volume loading as compared to dogs with other disease conditions (eg, mitral regurgitation secondary to degenerative mitral valve disease) because of an early adaptive response. Increased myocyte proliferation in the form of an eccentric hypertrophy may decrease wall stress by subdividing the load between an increased number of myocytes, which will determine a change in the geometry of LV, and a greater spherical shape (Laplace's law). The myocardium continues to develop during fetal life and for a short time after birth, and myocyte numbers increase by cell division until 6 months postnatally.<sup>38</sup> The fact that PDA is a congeni-

tal heart defect could be a protective factor, as the immature heart reaches maturity already adapting itself to the presence of an increased volume load from birth.

Our population comprises young asymptomatic dogs, and they might be considered at lower risk for developing myocardial failure during the first years of life. Whether older dogs might experience decreased contractility as a consequence of the hemodynamic changes of a PDA is yet to be proven and additional studies might help clarify the long-term effects of patent L-R PDA on LV function. Deformation imaging has been proven specific and accurate in detecting abnormalities before the onset of clinical signs or the detection of abnormal standard echocardiographic parameters,<sup>12,13</sup> so that it might be considered the gold standard in the assessment of early myocardial impairment in dogs with PDA.

Correlation analysis did not show any relationship between standard and STE-derived indices of cardiac function, probably as a result of a difference in the technique (direct- and indirect assessment of cardiac function). Based on our results, standard and advanced echocardiographic parameters may be considered as complementary tools in the echocardiographic evaluation of dogs with PDA.

Limitations of the study are related to a small sample size (34 dogs), absence of a comparison with cardiac magnetic resonance imaging (which is the general comparative technique for advanced echocardiographic measurements) or invasive parameters of cardiac function. Being a clinical study, no controlled setting for physiological determinants on cardiac contractility was available (fixed or a standardization of preload or after load) so that a complete load independency for the parameters analyzed cannot be ruled out. Although age was not associated with a change in systolic STE-derived parameters, dogs with PDA were younger than control dogs.

In conclusion, dogs with PDA showed a marked increase in conventional echocardiographic parameters (EDVI<sub>M/B</sub>, ESVI<sub>M/B</sub>, Allo D/S, Qp/Qs) and an absolute increase in advanced echocardiographic parameters (Long/Circ/Rad S and SR), whereas EF and FS were not different between the 2 groups. Patent ductus arteriosus may be associated with an increased contractility as identified by STE. Correlation analysis indicated good correlation between standard parameters, good correlation between advanced echocardiographic parameters, but no correlation between the 2 categories, namely standard and advanced echocardiographic techniques.

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## Footnotes

<sup>a</sup> Esaote © MyLab 50 and Class C, Firenze (I)

<sup>b</sup> XStrain© software, Firenze (I)

<sup>c</sup> Microsoft Excel©, Microsoft Corporation, Redmond, Washington (USA)

<sup>d</sup> SPSS statistic©; IBM Corporation, Armonk, New York (USA)

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*Off-label Antimicrobial Declaration:* Authors declare no off-label use of antimicrobials.

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