ECHOCARDIOGRAPHIC REFERENCE VALUES IN WHIPPETS

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The aim of the study was to establish reference echocardiographic values for whippets, to compare these values with previously published reference values for the general dog population, and to determine whether there is an influence of gender and breeding lines on echocardiographic measurements. Echocardiographic parameters from 105 apparently healthy whippets without cardiac symptoms were used to establish reference values for the breed and to compare these values with two previously reported reference ranges. The coefficients of the allometric equation $Y = aM^b$, useful to reconstruct normal M-mode and two-dimensional average values for whippets of varying weights, were calculated, as well as the lower and upper limits of the 95% prediction interval. First, we found that whippets have a significantly larger left ventricular diameter, increased left ventricular wall, and interventricular septum thickness than expected, in diastole as well as in systole. Fractional shortening was significantly lower than the reference value. Second, comparing males and females, taking body weight differences into account, females had a significantly larger left ventricular diameter in diastole and systole. Minor differences were found between racing and show pedigree dogs. In conclusion, the results of this study confirm that breed-specific reference values are needed in echocardiography. In whippets, the values found in this study can be used as references in order to avoid overinterpretation of cardiac dilation, hypertrophy, and/or decreased contractility in these dogs. *Veterinary Radiology & Ultrasound, Vol. 48, No. 3, 2007, pp 230–238.*

Key words: dog, heart, M-mode, reference value, whippet.

Introduction

REFERENCE ECHOCARDIOGRAPHIC values for healthy dogs have been published.[1–8] However, due to the large variation in canine size and somatotypic conformation, reference ranges are very broad, limiting their clinical usefulness. Therefore, some breed-specific reference values have been defined.[9–15] For example, sight hounds have a higher heart weight to body weight (BW) ratio compared with other breeds due to left ventricular dilation and myocardial thickening.[16–20] Whippets have also been reported to have a larger vertebral heart size on thoracic radiographs.[21,22] Although whippets comprise a small fraction of canine patients, they may be examined for inadequate race performance. The aim of this study was to establish reference echocardiographic values for whippets, to compare these values with published reference values for the general dog population, and to determine whether there is an influence of gender, breeding lines, and training on echocardiographic measurements.

Materials and Methods

Dogs

Privately owned whippets, $n = 125$, were recruited through contacts with breeders and owners. All dogs underwent physical and cardiologic examinations. Clinicopathologic assessment was also carried out and included conventional hematology and quantification of serum urea, creatinine, total protein, aspartic aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase, and glucose. Dogs <10 months of age or with cardiac abnormalities (moderate to severe mitral regurgitation) or dogs with incomplete data for M-mode or two-dimensional (2D) echocardiography were excluded. Lower age limit was set at 10 months as this is the age at which whippets are fully grown, according to the breeders and owners who regularly measure shoulder height to subscribe in the appropriate racing class. One-hundred and five whippets (51 males and 54 females), aged between 10 and 169 months (59.7 ± 39.3 months; mean $\pm$ standard deviation), weighing between 9.3 and 17.2 kg (13.2 ± 2.1 kg) were studied. Dogs were recruited from racing pedigree lines ($n = 89$), from show pedigree lines ($n = 10$), or were crosses between racing and show pedigree lines ($n = 6$). From the racing pedigree dogs, six dogs were not in training, 62 dogs were trained for sight hound races during 30.9 ± 22.8 months

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(range 2–78 months), and 21 completed training for 31.9 ± 21.1 months (range 7–80 months). The number of nontrained dogs was too small for comparison between trained and nontrained racing pedigree dogs, hence this influence was not evaluated.

Echocardiographic Measurements

The unsedated whippets were consecutively positioned in right and left recumbency (the former for right parasternal M-mode and 2D measurements and the Doppler study of the pulmonic valve; the latter for the Doppler study of the aortic, mitral, and tricuspid valve). All echocardiographic studies were performed by the first author using a Vingmed CFM 800 unit* with a 5 MHz mechanical sector transducer with color and spectral Doppler capabilities. All echocardiographic measurements were made in accordance with the guidelines of the American Society of Echocardiography using the leading-edge to leading-edge method of measurement. For all M-mode and 2D measurements, a lead II electrocardiogram was recorded simultaneously, and three representative cycles were measured and averaged, together with the respective heart rate.

The following parameters were obtained from 2D views: aortic root diameter (Ao) and left atrial diameter (LA) from right parasternal short-axis view and LA from right parasternal long-axis four-chamber view. From right parasternal short-axis M-mode view at the chordae level, interventricular septal thickness (IVS), left ventricular internal diameter (LVD), and left ventricular wall thickness (LVW) in diastole (d) and systole (s) as well as E-point to septum separation (EPSS) were obtained. Aortic preejection period (PEP) and left ventricular ejection time (LVET) were obtained from the right parasternal long-axis five-chamber view. Peak velocities for pulmonary and aortic flow (VPulm and VAo, respectively) were measured from spectral Doppler echocardiography, as well as from mitral and tricuspid E- and A-peak velocities (MitrE, MitrA, TricE, and TricA, respectively). VPulm was obtained from the right parasternal short-axis view of the right ventricular outflow tract at the aortic valve level with the sample gate positioned in the pulmonary artery just distal to the pulmonic valve; VAo was obtained from the left parasternal apical five-chamber view with the sample gate positioned in the ascending aorta just distal to the aortic valve and sinus of Valsalva. Mitral inflow velocities were obtained from the left parasternal apical four-chamber view with the sample gate positioned at the tips of the mitral valve leaflets when they are wide open; tricuspid inflow velocities were obtained from left parasternal view between the apical four-chamber and transverse view to optimize the view on tricuspid valve opening, with the sample gate positioned at the tips of the tricuspid valve leaflets when they are wide open. No angle corrections were needed as parallel alignment of the Doppler gate was possible in all dogs. Regurgitations through each of these four valves were subjectively quantified from color Doppler profiles. Aortic and pulmonic valve regurgitations were evaluated from the above-described views for spectral Doppler measurements. Mitral and tricuspid valve regurgitations were evaluated from the above-described views for spectral Doppler measurements as well as from the right parasternal long-axis four-chamber view. The largest regurgitant jet was withheld. Mitral valve regurgitations for example were quantified as trivial regurgitations (jets not extending more than 1 cm past the mitral valve annulus), mild regurgitations (jets occupying $<20\%$ of the atrium), moderate regurgitations (jets occupying 20–50% of the atrium), and severe regurgitations (jets occupying more than 50% of the atrium).[23] Cardiac output (CO) was measured from the aortic flow profiles with Doppler envelope tracing, with CO (l/min) $= 6\pi(\text{Ao}/2)^2 V_{\text{mean}}$ with Ao in cm from the right parasternal short-axis view and V_{mean} in m/s.

The following parameters were calculated: LA/Ao, PEP/LVET, fractional shortening FS% $= [(\text{LVDd}–\text{LVDs})/\text{LVDd}]100$, left ventricular ejection fraction LVEF% $= [(\text{LVDd}^3–\text{LVDs}^3)/\text{LVDd}^3]100$. End systolic volume index (ESVI) was calculated according to the corrected Teichholz formula: ESVI (ml/m^2) $= (7\text{LVDs}^3)/[(2.4 + \text{LVDs})\text{BSA}]$, with LVDs in cm and BSA in m^2.[24] Velocity of circumferential fiber shortening (VcF) was calculated as VcF (cm/s) $= (\text{LVDd}–\text{LVDs})/(\text{LVDd} \times \text{LVET})$ with LVDd and LVDs in cm and LVET in s. Stroke volume (SV) was calculated as SV (ml/beat) $= (\text{CO}/\text{HR})1000$. Body surface area (BSA) was calculated as BSA (m^2) $= (10.1\text{BW}^{2/3})/10^4$, with BW expressed in g.[25]

The whippet echocardiographic measurements were compared with the expected values for the general population previously reported.[1,3]

Data Analysis

First, a paired Student's t-test was used to evaluate whether the observed M-mode measurements (IVS, LVD, LVW, and EPSS), parameters of function (FS, PEP, LVET, PEP/LVET, VcF), and heart rate (HR) differed significantly from the reference values.[1,3]

Linear regression analyses were performed after logarithmic transformation of the data. The coefficients of the allometric equation $Y = aM^b$ as well as the lower and upper limits of the 95% prediction interval were calculated for each of the BW-dependent M-mode and 2D measurements as described previously.[3] In this equation, "Y" represents a measure of heart size, "M" is BW, and "a" and "b" are parameters. Finally, Bland–Altman plots were made for the observed and expected LVWd.

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Second, the percentage of dogs that fell out of the reference ranges was determined. This percentage was further subdivided in dogs that fell below and above the reference range.

Finally, males were compared with females and racing pedigree dogs were compared with show pedigree dogs using analysis of variance, both in a univariate model and in a multivariate model with weight, age, and regurgitation as covariates. The difference in the occurrence of mitral valve regurgitations between racing and show pedigree lines was compared by the χ^2-test. All analyses were carried out at the 5% significance level.

Results

Comparison of Observed Echocardiographic Measurements to Previously Reported Reference Values

Mean BW, HR, M-mode, and 2D measurements of all dogs are presented in Table 1. Functional parameters are presented in Table 2, and Doppler-derived parameters are presented in Table 3.

The coefficients of the allometric equation $Y = aM^b$ were calculated for each of the BW-dependent M-mode and 2D measurements (see Table 4). These coefficients can be used to reconstruct normal M-mode and 2D average values for whippets of varying weights. For example, the LVDd for a 10 kg whippet can be calculated as $LVDd = 16.212 \times 10^{0.323} = 34.1$ mm. These M-mode and 2D average values together with their 95% prediction interval are shown in Table 5. The slope of the regression line "*b*" is similar to what was previously reported,[3] although the dogs in our study only represent a narrow range in body weight.

TABLE 1. Body Weight, Body Surface Area, Heart Rate, M-Mode and Two Dimensional (2D) Measurements in 105 Whippets

	Mean	SD	Mean ± 2SD	Range
Body weight (kg)	13.2	2.1	9.0–17.4	9.3–17.2
Body surface area (m^2)	0.56	0.06	0.44–0.68	0.45–0.68
Heart rate (bpm)	93.9	22.7	48.5–139.3	54.0–158.0
M-mode (mm)				
IVSd	9.4	1.2	7.0–11.8	7.1–12.9
LVDd	37.3	3.8	29.7–44.8	25.7–47.5
LVWd	8.8	1.1	6.6–10.9	6.4–11.5
IVSs	12.0	1.5	9.0–15.1	9.0–15.5
LVDs	26.9	3.6	19.8–34.1	17.0–36.1
LVWs	12.4	1.5	9.3–15.4	8.6–17.2
EPSS	4.2	1.4	1.4–7.1	0.4–9.2
2D				
Ao(sa) (mm)	19.0	1.7	15.7–22.3	14.8–24.0
LA(sa) (mm)	26.5	3.2	20.2–32.8	18.4–33.7
LA/Ao	1.4	0.1	1.1–1.7	1.1–1.7
LA(la) (mm)	32.0	2.8	26.5–37.6	23.5–38.7

M-mode measurements: IVSd, interventricular septal thickness in diastole; LVDd, left ventricular internal diameter in diastole; LVWd, left ventricular wall thickness in diastole; IVSs, interventricular septal thickness in systole; LVDs, left ventricular internal diameter in systole; LVWs, left ventricular wall thickness in systole; EPSS, E-point to septum separation.2D measurements: Ao(sa), aortic root diameter from short-axis view; LA(sa), left atrial diameter from short-axis view; LA(la), left atrial diameter from long-axis view.

TABLE 2. Functional Parameters in 105 Whippets

	Mean	SD	Mean ± 2SD	Range
FS (%)	27.7	5.2	17.4–38.1	18.1–39.2
LVEF (%)	61.3	8.1	45.1–77.5	44.7–77.3
ESVI (ml/m^2)	48.9	13.9	21.1–76.6	18.5–83.6
PEP (ms)	51.9	9.7	32.5–71.3	35.0–85.0
LVET (ms)	167.2	22.1	123.0–211.4	125.0–255.0
PEP/LVET	0.314	0.059	0.196–0.432	0.159–0.457
VcF (circ/s)	1.69	0.39	0.91–2.47	0.98–3.05

FS, fractional shortening; LVEF, left ventricular ejection fraction; ESVI, end systolic volume index; PEP, aortic preejection period; LVET, left ventricular ejection time; VcF, velocity of circumferential fiber shortening.

Out of 105 dogs, no dog had aortic regurgitation and 36 (34.3%) had pulmonic regurgitation, which was mild in one and trivial in 35. Forty-five dogs (42.9%) had mitral regurgitation, which was mild in 12 and trivial in 33. Finally, 29 dogs (27.6%) had tricuspid regurgitation, which was mild in four and trivial in 25. Thirteen of 105 dogs had slight mitral valve thickening (only the central part of the septal leaflet) without any degree of prolapse. Seven of these 13 dogs (53.8%) had trivial regurgitation, whereas six (46.2%) had mild regurgitation. This means that six dogs with mild mitral regurgitation had no remarkable changes to their mitral valve. Only three of the 12 dogs with mild mitral regurgitation had a systolic murmur with point of maximal intensity at the level of the mitral valve, one with a grade two/six murmur and two with a grade three/six murmur. The 12 dogs with mild mitral regurgitation were all previously trained and/or racing dogs from racing pedigree lines, except for one dog out of crossed racing and show pedigree lines, between 5 and 14 years old (64, 78, 86, 86, 87, 88, 99, 107, 123, 124, 140, and 169 months old). The mitral valve thickening in these dogs occurred in the dogs of 64, 86, 107, 123, 140, and 169 months of age.

Compared with published regression equations, adjustment based on BSA,[1] the whippet values for IVS in diastole and LVD and LVW in diastole and systole were significantly higher ($P < 0.0001$), as was EPSS ($P = 0.0003$). On

TABLE 3. Doppler Derived Parameters in Whippets

	N	Mean	SD	Mean ± 2SD	Range
Aortic velocity (m/s)	105	1.39	0.25	0.90–1.89	0.78–2.13
Pulmonic velocity (m/s)	105	1.14	0.22	0.69–1.59	0.61–1.81
Mitral E (m/s)	105	0.77	0.13	0.51–1.02	0.48–1.08
Mitral A (m/s)	105	0.50	0.09	0.33–0.68	0.30–0.80
Tricuspid E (m/s)	105	0.75	0.15	0.45–1.05	0.45–1.52
Tricuspid A (m/s)	105	0.49	0.11	0.26–0.71	0.25–1.01
Cardiac output (l/min)	90	4.8	1.3	2.2–7.3	1.9–7.7
Stroke volume (ml/beat)	90	49.2	11.0	27.2–71.3	24.2–74.7

TABLE 4. Coefficients of the Allometric Equation $Y = aM^b$ for Each of the Body Weight-Dependent M-mode or Two-Dimensional (2D) Measurements

	a	*b*
IVSd	3.770	0.352
LVDd	16.212	0.323
LVWd	3.490	0.355
IVSs	5.383	0.311
LVDs	9.819	0.390
LVWs	5.239	0.332
Ao (sa)	9.278	0.277
LA (sa)	11.017	0.339
LA (la)	14.241	0.314

M-mode measurements: IVSd, interventricular septal thickness in diastole; LVDd, left ventricular internal diameter in diastole; LVWd, left ventricular wall thickness in diastole; IVSs, interventricular septal thickness in systole; LVDs, left ventricular internal diameter in systole; LVWs, left ventricular wall thickness in systole; EPSS, E-point to septum separation. 2D measurements: Ao(sa), aortic root diameter from short-axis view; LA(sa), left atrial diameter from short-axis view; LA(la), left atrial diameter from long-axis view.

the other hand, IVSs, FS, PEP, LVET, and VcF were significantly lower than the reference values ($P<0.0001$). No significant difference was noted for PEP/LVET and HR compared with published values,[1] although there is a tendency for whippets to have a lower HR than expected. For most parameters, a marked percentage of whippet values fell out of the reference range (see Table 6).[1]

Compared with the allometric equations,[3] the whippet values for IVS, LVD, and LVW in diastole and systole were significantly higher than those expected ($P<0.0001$), and none of these values fell below the reference range.[3] The percentage of values that fell above the reference range predicted by the allometric equations, however, is for most parameters smaller than the percentage obtained from the regression equations based on BSA (see Fig. 1).[1,3]

The Bland–Altman plots clearly show that the discrepancy between the observed and expected LVWd increases with increasing body surface area[1] or with increasing weight[3] (see Fig. 2).

Finally, comparing the whippet ESVI to the maximum value of 30 ml/m^2,[26] 96 dogs (91.4%) had a higher value, and only nine dogs (8.6%) had a value below this maximum value.

Comparison Between Male and Female Dogs

In the univariate model, in the female dogs, a significantly lower value was observed for IVS and LVW in diastole and systole, Ao, LA(sa), LA(la), PEP/LVET, VPulm, TricE, CO, and SV ($P<0.05$). However, there was also a statistically significant difference in BW, males weighing on

TABLE 5. Reconstruction of Normal M-mode and Two Dimensional (2D) Average Values and 95% Prediction Intervals for Whippets of Varying Weights

BW	IVSd	LVDd	LVWd	IVSs	LVDs	LVWs	AO	LA (sa)	LA (la)
7.0	7.5	30.4	7.0	9.8	21.0	10.0	15.9	21.3	26.2
	5.9–9.5	25.2–36.5	5.6–8.7	7.7–12.5	16.3–27.0	7.9–12.6	13.6–18.6	17.0–26.7	22.6–30.5
8.0	7.8	31.7	7.3	10.3	22.1	10.4	16.5	22.3	27.4
	6.2–9.9	26.4–38.1	5.8–9.1	8.1–13.0	17.2–28.4	8.3–13.2	14.2–19.3	17.9–27.9	23.6–31.8
9.0	8.2	32.9	7.6	10.6	23.1	10.9	17.1	23.2	28.4
	6.5–10.3	27.5–39.5	6.1–9.5	8.4–13.5	18.0–29.7	8.6–13.7	14.7–19.9	18.6–28.9	24.5–33.0
10.0	8.5	34.1	7.9	11.0	24.1	11.2	17.6	24.1	29.4
	6.7–10.7	28.5–40.8	6.3–9.9	8.7–13.9	18.8–30.9	8.9–14.1	15.1–20.4	19.3–29.9	25.3–34.0
11.0	8.8	35.1	8.2	11.3	25.0	11.6	18.0	24.8	30.3
	7.0–11.0	29.4–42.0	6.6–10.2	9.0–14.3	19.6–32.0	9.2–14.6	15.5–21.0	20.0–30.8	26.1–35.0
12.0	9.0	36.1	8.4	11.6	25.9	11.9	18.5	25.6	31.1
	7.2–11.4	30.3–43.2	6.8–10.5	9.2–14.7	20.3–33.0	9.5–15.0	15.9–21.5	20.6–31.8	26.9–36.0
13.0	9.3	37.1	8.7	11.9	26.7	12.3	18.9	26.3	31.9
	7.4–11.7	31.0–44.3	7.0–10.8	9.5–15.0	20.9–34.1	9.8–15.4	16.3–21.9	21.2–32.6	27.6–36.9
14.0	9.5	38.0	8.9	12.2	27.5	12.6	19.3	27.0	32.6
	7.6–12.0	31.8–45.4	7.2–11.1	9.7–15.4	21.5–35.1	10.0–15.8	16.6–22.4	21.7–33.5	28.2–37.8
15.0	9.8	38.8	9.1	12.5	28.2	12.9	19.7	27.6	33.3
	7.8–12.3	32.5–46.4	7.3–11.4	9.9–15.7	22.1–36.1	10.2–16.1	16.9–22.8	22.2–34.3	28.8–38.6
16.0	10.0	39.6	9.3	12.7	28.9	13.1	20.0	28.2	34.0
	7.9–12.6	33.2–47.4	7.5–11.6	10.1–16.1	22.6–37.0	10.5–16.5	17.2–23.3	22.7–35.1	29.4–39.4
17.0	10.2	40.4	9.6	13.0	29.6	13.4	20.4	28.8	34.7
	8.1–12.9	33.8–48.4	7.7–11.9	10.3–16.4	23.1–38.0	10.6–16.9	17.5–23.7	23.1–35.9	29.9–40.2
18.0	10.4	41.2	9.7	13.2	30.3	13.7	20.7	29.4	35.3
	8.2–13.2	34.3–49.4	7.8–12.2	10.4–16.7	23.6–38.9	10.8–17.2	17.8–24.1	23.5–36.7	30.4–41.0
19.0	10.6	41.9	9.9	13.4	31.0	13.9	21.0	29.9	35.9
	8.4–13.5	34.9–50.4	7.9–12.5	10.6–17.1	24.0–39.9	11.0–17.6	18.0–24.5	23.9–37.4	30.9–41.8

BW, body weight in kg. M-mode measurements (in mm): IVSd, interventricular septal thickness in diastole; LVDd, left ventricular internal diameter in diastole; LVWd, left ventricular wall thickness in diastole; IVSs, interventricular septal thickness in systole; LVDs, left ventricular internal diameter in systole; LVWs, left ventricular wall thickness in systole.2D measurements (in mm): Ao(sa), aortic root diameter from short-axis view; LA(sa), left atrial diameter from short-axis view; LA(la), left atrial diameter from long-axis view.

TABLE 6. Percentage of Whippet Values Below and Above Published Reference Ranges

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	% Below	% Above	% Below	% Above
IVSd	0.0	53.3	0.0	10.5
LVDd	1.0	61.9	0.0	27.6
LVWd	0.0	97.1	0.0	1.9
IVSs	25.7	8.6	0.0	2.9
LVDs	0.0	89.5	0.0	35.2
LVWs	0.9	72.4	0.0	0.9
EPSS	0.0	1.9		
HR	0.0	2.9		
FS	84.8	0.0		
PEP	0.0	0.0		
LVET	33.3	9.6		
PEP/LVET	0.0	0.0		
VcF	21.9	1.0		

M-mode measurements: IVSd, interventricular septal thickness in diastole; LVDd, left ventricular internal diameter in diastole; LVWd, left ventricular wall thickness in diastole; IVSs, interventricular septal thickness in systole; LVDs, left ventricular internal diameter in systole; LVWs, left ventricular wall thickness in systole; EPSS, E-point to septum separation; HR, heart rate; FS, fractional shortening; PEP, aortic preejection period; LVET, left ventricular ejection time; VcF, velocity of circumferential fiber shortening.

average 14.5 ± 1.8 kg (range 9.6–17.2 kg) and females 11.9 ± 1.5 kg (range 9.3–14.7 kg). In the multivariate model with weight, age, and regurgitation as covariates, females had a significantly larger LVD in diastole and systole ($P = 0.0054$ and 0.0188, respectively), a significantly higher EPSS ($P = 0.0204$), LVET ($P = 0.0367$), ESVI ($P = 0.0227$), and VPulm ($P = 0.0258$) and a significantly lower VcF ($P = 0.0469$), with no significant difference any longer for CO and SV.

Comparison Between Racing and Show Pedigree Lines

Eighty-nine dogs (43 males and 46 females) came out of racing pedigree lines, and 10 dogs (four males and six females) came out of show pedigree lines. Six dogs came out of crosses between these two pedigree lines and were excluded from this analysis. The mean age and weight of the racing pedigree dogs was 59.9 ± 39.0 months and 13.2 ± 2.1 kg. The mean age and weight of the show pedigree dogs was 58.8 ± 44.3 months and 13.5 ± 2.3 kg. In racing pedigree dogs, 43 dogs (48.3%) had mitral regurgitation, which was mild in 11 and trivial in 32. In show pedigree dogs, in contrast, only one previously trained dog (10%) had mitral regurgitation, which was trivial. The occurrence of mitral regurgitations was significantly higher in racing pedigree dogs compared with show pedigree dogs ($P = 0.033$).

In the univariate model, only LA(sa) and MitrE were significantly different, LA(sa) being significantly larger in racing pedigree dogs ($P = 0.022$) and MitrE being signif-

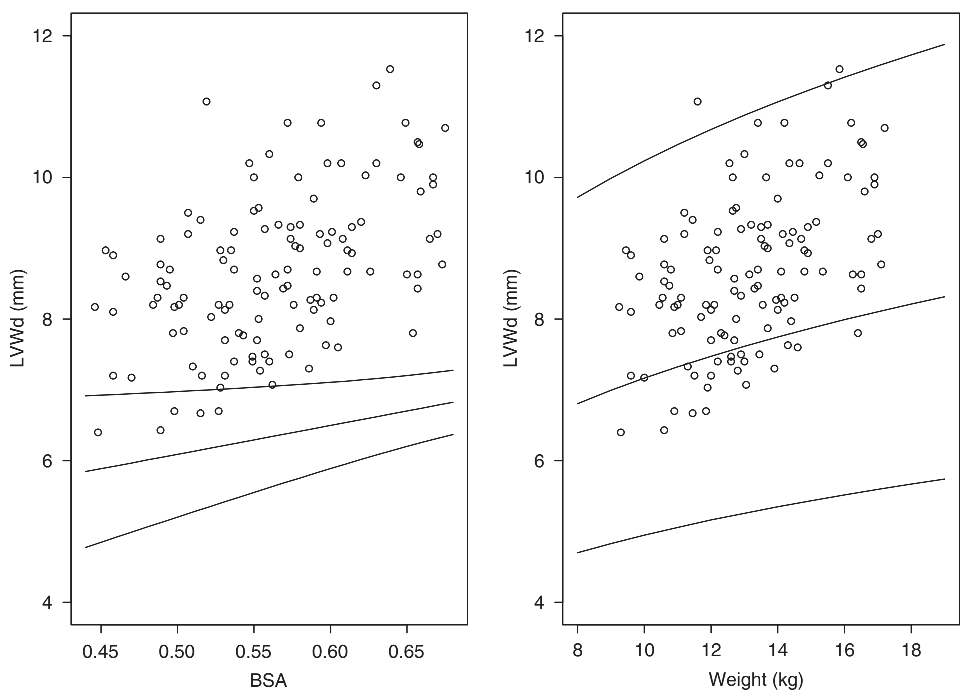

FIG. 1. Comparison of whippet left ventricular wall thickness in diastole (LVWd) observed values to previously published reference ranges. Data in the left panel are from reference #1 and in the right panel from reference #3. Individual values for the LVWd of the 105 whippets in this study (dots) are compared with the regression line and 95% confidence interval of LVWd according to reference #1 (left panel) and to the regression line and 95% prediction interval of LVWd according to reference #3 (right panel).

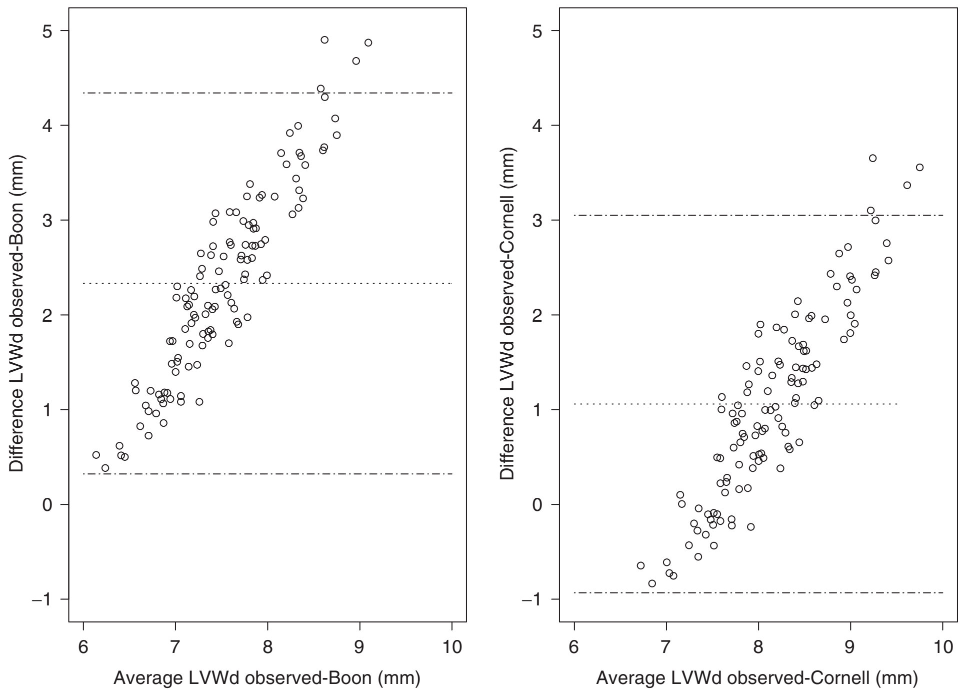

FIG. 2. Bland–Altman plots of whippet left ventricular wall thickness in diastole (LVWd) observed values compared with expected values from reference #1 (left panel) and reference #3 (right panel). Dotted lines represent the mean difference between the observed LVWd and the LVWd given by reference #1, Boon et al., (left panel)/reference #2, Cornell et al., (right panel). Dashed lines in the left panel represent the 95% confidence interval of the difference between the observed LVWd and the LVWd given by reference #1 (left panel). Dashed lines in the right panel represent the 95% prediction interval of the difference between the observed LVWd and the LVWd given by reference #3 (right panel).

icantly lower in racing pedigree dogs ($P = 0.0041$). There was also a tendency for Ao and LVET to be higher in racing pedigree dogs ($P = 0.068$ and 0.081, respectively). In the multivariate model with weight, age, and regurgitation as covariates, LVDd ($P = 0.0159$), Ao ($P = 0.0063$), LA(sa) ($P = 0.0067$), and LVET ($P = 0.0263$) were significantly higher in racing pedigree dogs, and MitrE was significantly lower in racing pedigree dogs ($P = 0.0036$). There was a tendency for LA(la), LA/Ao, and EPSS to be higher in racing pedigree dogs ($P = 0.0989$, 0.0575, and 0.0895, respectively).

Discussion

Several reference ranges for echocardiographic measurements in dogs are adjusted for BW, BSA, or other size measurements.[1–4,6,7] Often, these reference ranges are based on various breeds of dogs as well as on mongrels, over a large weight range. However, breed, in addition to weight, is an important factor in the determination of normal M-mode variables, but only few articles describe reference ranges for a specific breed of dog.[9–13,15] Two reference ranges were used for comparison with the whippet values obtained in this study, the regression equations based on BSA[1] and allometric equations.[3]

Comparison of Observed Echocardiographic Measurements to Previously Reported Reference Values

Reference regression equations are based on 20 dogs (eight males and 12 females), weighing between 9.8 and 28.6 kg (mean 19.3 kg); the breeds included were one terrier cross, one English setter, one English springer, three doberman crosses, three dingo crosses, one beagle, four German shepherd crosses, three golden retrievers, one dalmatian, and two of unknown mixes.[1] Reference allometric equations are based on retrospectively collected data from 494 dogs, weighing between 2.2 and 95.0 kg, comprising 33 dachshunds, 57 Cavalier King Charles spaniels, 20 Italian greyhounds, 12 English cocker spaniels, 20 whippets, 20 greyhounds, 75 boxers, 144 Irish wolfhounds, and 113 dogs of mixed or unknown breeds. These dogs were examined by nine investigators.[3]

Compared with reference values for dogs of the same weight range, the whippets in our study had a larger LVD, a thicker LVW and IVS, and a higher EPSS.[1,3] These findings are in agreement with previous studies describing a larger heart weight to BW ratio in other sight hounds such as greyhounds. However, some authors only found a consistently thicker LVW in systole and diastole,[13] while others also found increased LVD and IVS.[9,14] Heart rate did not differ significantly from the published reference value,[1] so this cannot explain the larger LVD.[5,27] The values obtained for the whippets in this study correlate very well with other values in whippets, although dogs in the other study were sedated.[9]

There was a remarkable difference in the percentage of whippet values that fell out (below or above) of the reference ranges (see Table 6, Figs. 1 and 2).[1,3] The reference range predicted by the allometric equations[3] is much broader and the expected value for a given BW is higher due to several factors. First, that paper describes the 95% prediction interval for individual observations, which is broader than the 95% confidence interval for the mean value of an M-mode variable for all dogs of a particular weight. Second, an obvious source of variability in the prior study is the diverse source of data, which were collected by many different observers using different equipments in different environments. Finally, the sample group in the prior study contained 204 sight hounds (20 greyhounds, 20 whippets, 20 Italian greyhounds, and 144 Irish wolfhounds) out of 494 dogs (41%), in contrast to the regression equation study where no sight hounds were included.[1] This could have influenced the values toward higher means. Nevertheless, it seems that the whippet values in our study are even higher, which can be due to the fact that our population is a 100% sight hound population. It was however not determined how well the allometric equations would predict M-mode dimensions in animals that differ substantially from the sample group, and as observed for our data, it cannot be extrapolated to all breeds of dogs.[3]

There has been debate whether the higher heart weight to BW ratio in sight hounds or other working dogs is an influence of training, a genetic influence, or both. In humans, a distinction is made between the effects on the heart of isometric (resistance) vs. isotonic (endurance) training, the former inducing a concentric hypertrophy with a thicker LVW and IVS without LV dilation, and the latter inducing an eccentric hypertrophy with LV dilation and a proportional increase in LVW and IVS thickness.[28–34] Many athletic endeavors, as well as the whippet training, are a combination of isometric and isotonic work, and thus may produce a combination of both morphologic patterns.[28–34] Several articles describe various influences of training on the canine heart. The most consistent finding throughout different studies is a higher heart weight to BW ratio in trained dogs as compared with nontrained control dogs of the same breed or BW range. This could in part be due to a 50% thicker LVW in these trained greyhounds.[35,36] Others reported a 30% higher LV weight to BW ratio in trained compared with control mongrel dogs,[37] which is similar to another study reporting that the exercise program resulted in an elevation in LV weight and LVW thickness, and a significantly lower HR at rest and at submaximal work loads in trained mongrel dogs.[35]

In contrast to the previous references, several articles report no significant difference in LVW thickness, LV mass, or heart weight to BW ratio between trained, detrained, and control greyhounds, although all variables were significantly higher in all groups compared with mongrel dogs of comparable BW.[16–19] This suggests that LV hypertrophy in racing greyhounds reflects a genetic trait rather than a response to training. Moreover, the exercise component may be too small and the individual variability too great to show difference by comparing small groups of different animals.[16–19] In addition, no significant difference in LV mass was found between the exercise and sedentary group of beagles.[38]

It should be emphasized that two articles reviewing previous results of research on exercise-induced cardiac hypertrophy reveal that a number of problems associated with the measurement techniques and methodology cast some doubt on the validity of the conclusions that both animal and human research has provided a strong argument in favor of a physiological cardiac hypertrophy as an outcome of chronic exercise.[39,40]

Another possible influence of training on the heart is LV dilation. One study on greyhounds reported significantly larger echocardiographic parameters for trained compared with nontrained greyhounds,[41] while another reported an LVD dilation of approximately 30% in hearts of trained greyhounds compared with normal dogs of similar BW.[35,36] Another study supports this finding, reporting a significant increase in ventricular volume between the exercise and sedentary group of beagles.[38] In these beagles, no significant difference in resting HR between the exercised and the sedentary beagles was found.[38] In contrast, lowering of the HR at rest and during standard work load was reported by several authors.[35,42,43] This lowering of the HR might explain the larger LVD for trained dogs in several studies, as it has been previously described that cycle length had a significant influence on LVD in clinically normal dogs, in a way that, as cycle length increases (and thus HR decreases), LVD increases.[5,27]

The fractional shortening, PEP, LVET, and VcF were significantly lower in our whippets compared with reference values.[1] In our study, mean FS was 27.7% (range 18.1–39.2%), with 39 out of 105 dogs (37%) having an FS $<25\%$. In another study, 95% of all dogs had an FS $>25\%$; in the dogs with FS $<25\%$, greyhounds were disproportionately represented, and almost half of the greyhounds had an FS $<25\%$.[3] The finding that the whippet FS was lower than expected for dogs of comparable size[1,3] is therefore not surprising. In addition, the echocardiographic measurement of FS is subject to a number of possible error sources.[13] Moreover, although FS is often used as an estimation of left ventricular global systolic function, it does not allow to detect changes in contractility when preload and/or afterload (or wall stress) are not controlled for.[28,32] In another echocardiographic study in whippets, a mean FS value of 32% was found.[9] However, these dogs were sedated using acepromazine and morphine. This intervention might have influenced preload, afterload and also contractility, making comparison difficult. In greyhounds, FS values ranged from 25% to 36% depending on the study[9,13,14,41], also reflecting the dependence of FS on many variables. Nevertheless, the clinician should be aware of the occurrence of low FS values in whippets at rest in order to avoid misdiagnosis of myocardial failure.

ESVI is also higher than expected in our whippets. ESVI was calculated according to the corrected Teichholz formula ESVI $(ml/m^2) = (7LVDs^3)/[(2.4 + LVDs)BSA]$, with LVDs in cm and BSA in m^2.[24] As whippets have higher LVDs than expected for their BW (which is in part due to a lower FS than expected), and this parameter is used in a second-degree relation, it is clear that the result of the equation is greater than expected.

Comparison Between Male and Female Dogs

Male dogs had significantly higher IVS, LVW, Ao, LA(sa), LA(la), CO, and SV than female dogs. However, these are BW-related parameters, and after multivariate analysis with weight, age, and regurgitation as covariates, females had a significantly larger LVD in diastole and systole, and a significantly higher EPSS and ESVI. These findings are in accordance with an earlier study in training greyhounds, where female training greyhounds had a significantly greater IVSs, LVD, and LVW in diastole and systole, Ao, FS, and EPSS following normalization to BW.[41] A possible explanation for this is the larger mean heart weight to BW ratio for females compared with males.[16,20] In contrast, in horses, males had a significantly larger weight-adjusted LV mass and LVDd compared with females.[44,45] Furthermore, no sex difference was found after allometric scaling in humans.[46]

Comparison Between Racing and Show Pedigree Lines

Dogs of racing pedigree lines had a significantly larger LA(sa) than dogs of show pedigree lines, and there was also a tendency for Ao to be higher in racing pedigree dogs. Racing pedigree dogs also had a significantly higher prevalence of mitral valve regurgitations. However, LA(sa) remained significantly higher in racing pedigree dogs after multivariate analysis with weight, age, and regurgitation as covariates.

Several articles in humans report the influence of training and ageing on mitral and tricuspid valve regurgitation. Grossly, valves become thicker and more opaque with advancing age. These changes are both genetically determined and age related. Longstanding mechanical stress also may play a role in producing regurgitation. The left-sided valves, aortic and mitral, are exposed to high pressures and may therefore undergo degenerative changes earlier than the right-sided valves.[47–49] Moreover, one article reports that the prevalence of both mitral and tricuspid regurgitation in thoroughbred horses are subjected to athletic training. Before training, the prevalence of mitral regurgitation murmurs was 7.3% and the prevalence of tricuspid regurgitation murmurs was 12.7%. After 9 months of training, the prevalence proportions increased to 21.8% and 25.5%, respectively.[50] Studies by pulsed Doppler echocardiography in humans have also shown that atrioventricular valvular regurgitation is detected more commonly in endurance-trained athletes compared with sedentary controls, and that it did not imply structural valvular abnormalities.[34,51,52] These reports are in agreement with our findings that mitral regurgitations are more common in trained dogs from racing pedigree lines.

Conclusion

We confirm that whippets have a larger LVD, a thicker IVS and LVW, and a lower FS than expected for dogs of comparable body weight. The clinician should be aware of these specific differences in whippets to avoid misdiagnosis of cardiac dilation, hypertrophy, and/or myocardial failure in these dogs. The values reported in this study can be used as reference values specific for whippets.

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