

Reference values for echocardiographic parameters in healthy Weimaraner dogs

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Abstract

Echocardiography is an essential diagnostic tool for evaluating cardiac disease, but reference values for echocardiographic variables may differ among dog breeds. Establishing breed-specific reference values is particularly important for Weimaraners because the breed is considered predisposed to dilated cardiomyopathy. The aim of this study was to establish breed-specific reference intervals for echocardiographic variables in clinically healthy Weimaraners. A total of 339 clinically healthy Weimaraners met the inclusion criteria. Each dog underwent cardiac auscultation, electrocardiography, and a standard echocardiographic examination. Measurements included cardiac chamber dimensions, ventricular wall thicknesses, indices of left ventricular size and systolic function, heart rate, and blood flow velocities across the aorta and pulmonary artery. Reference intervals were established for these variables. Significant sex-related differences were found in several measurements of left ventricular dimensions and wall thicknesses, left ventricular volumes, and left atrial and aortic dimensions. These reference intervals are important for the accurate echocardiographic evaluation of Weimaraners and may facilitate the early detection and accurate diagnosis of cardiac disease. To the authors' knowledge, this is the first study to provide comprehensive breed-specific echocardiographic reference intervals for clinically healthy Weimaraners.

Cardiomyopathy, Doppler, ventricular volume, screening, intervals

Echocardiography is accepted as the most valuable diagnostic tool in the evaluation of cardiac anatomy and function, as well as in investigating cardiac diseases in small animal cardiology (Crippa et al. 1992).

The reference ranges of echocardiographic parameters have already been established for various dog breeds. Variation between breeds has recently been emphasized as an important factor affecting echocardiographic reference ranges (Gooding et al. 1986; Morrison et al. 1992; Page et al. 1993). This variation is especially important in the assessment of early systolic dysfunction because the definition of hypokinesis hinges on measurements such as fractional shortening (FS) being below a certain value, which has been demonstrated to vary widely between breeds (Torre et al. 2000). Dilated cardiomyopathy (DCM) is the second most common form of acquired cardiac disease in dogs after degenerative mitral valve disease with the greatest prevalence in large and giant dog breeds (Dutton and López-Alvarez 2018). The most frequently affected dogs are Doberman Pinschers (Tidholm et al. 2001), Great Danes (Meurs et al. 2001), Irish Wolfhounds (Distl et al. 2007), Boxers (Meurs et al. 2013), Weimaraners (Eason et al. 2015) and other breeds. The disease can start with arrhythmias or with systolic dysfunction of the myocardium (Wess 2022).

A modified staging system for canine DCM is clinically useful (Wess 2022). Stage A is characterized by no evidence of clinical signs of heart disease with a morphologically and

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electrically normal heart. At this stage, dogs with a breed predisposition to develop DCM should be examined. Stage B is described by evidence of morphologic or electrical lesions but without evidence of congestive heart failure (CHF). Stage B1 is an arrhythmogenic stage without cardiac enlargement that includes ventricular premature complexes. Stage B2 is typical for dogs with systolic dysfunction, i.e. left chamber enlargement, and at this stage, the dogs may or may not have arrhythmias. Stage C includes dogs with current or previous clinical signs of CHF. Stage D refers to dogs with end-stage DCM, in which clinical signs of CHF are refractory to standard treatment (Wess 2022).

The Weimaraner has been reported among breeds affected by DCM (Simpson et al. 2015; Filipejová et al. 2024). According to our knowledge, reference range values of echocardiographic parameters have not yet been established for this breed. The establishment of reference range values of echocardiographic parameters in this breed is vital for accurate examination and diagnostics. Knowing these values, we may be able to detect the cardiac disease at its early stage and thus start proper treatment to prolong the patient's lifespan.

Materials and Methods

This prospective study included exclusively Weimaraner dogs and was conducted at the Small Animal Clinic of the University of Veterinary Sciences Brno (VETUNI Brno) and the Veterinary Clinic Slaný.

A total of 370 Weimaraners were examined. Of these, 339 dogs had no abnormal findings on physical or cardiological examination. No heart murmurs or arrhythmias were detected by auscultation or standard electrocardiography, and no evidence of cardiac disease was identified by routine two-dimensional and M-mode echocardiography. These 339 clinically healthy Weimaraners, comprising 198 females and 141 males, met the inclusion criteria and were enrolled in the study.

All dogs underwent physical and cardiological examinations without sedation. All examinations were performed with the owners' written informed consent.

Standard six-lead electrocardiography was performed using a SEIVA EKG Praktik Veterinary electrocardiograph (SEIVA, Prague, Czech Republic) or an Eickemeyer PC-ECG system (Eickemeyer, Tuttlingen, Germany). Echocardiographic examinations were performed using an ALOKA 7 ultrasound system equipped with a 2.5–5 MHz phased-array transducer (Aloka Co., Ltd., Tokyo, Japan) or a GE Vivid E95 ultrasound system equipped with a 1.5–4.6 MHz phased-array transducer (GE Vingmed Ultrasound, Horten, Norway). Of the 339 dogs included in the study, 107 were examined using the ALOKA 7 ultrasound system and the remaining 232 using the GE Vivid E95 ultrasound system.

Two-dimensional and M-mode echocardiographic measurements were obtained using standard right parasternal and left apical views. The right parasternal long-axis four-chamber view, the right parasternal long-axis view optimized for the left ventricular outflow tract, and standard right parasternal short-axis views were obtained.

Left ventricular dimensions were measured using M-mode from the right parasternal short-axis view at the level of the chordae tendineae. The following variables were measured: interventricular septal thickness at end-diastole (IVSd), interventricular septal thickness at end-systole (IVSs), left ventricular internal diameter at end-diastole (LVIDd), left ventricular internal diameter at end-systole (LVIDs), left ventricular posterior wall thickness at end-diastole (LVPWd), and left ventricular posterior wall thickness at end-systole (LVPWs). FS was calculated automatically by the ultrasound system from the M-mode measurements.

The left atrial diameter (LA), aortic root diameter (Ao), and left atrial-to-aortic root ratio (LA/Ao) were determined from the right parasternal short-axis view at the level of the aortic root.

E-point-to-septal separation (EPSS) was measured from the right parasternal short-axis view at the level of the tip of the septal mitral valve leaflet. EPSS was defined as the distance between the maximal early diastolic excursion (E-point) of the septal mitral valve leaflet and the interventricular septum.

Left ventricular volumes were measured by Simpson's method of discs (SMOD) from the right parasternal long-axis four-chamber view and the left apical four-chamber view. The left ventricular endocardial border was traced at end-diastole and end-systole, and left ventricular length was measured from the mitral annulus to the endocardial border of the left ventricular apex. End-diastolic volume, end-systolic volume, and ejection fraction (EF) were calculated automatically by the ultrasound system. End-diastolic and end-systolic volumes were indexed to body surface area and expressed as the end-diastolic volume index (EDVI) and end-systolic volume index (ESVI), respectively, in ml/m².

Peak pulmonary artery flow velocity was measured from the right parasternal short-axis view, whereas peak aortic flow velocity was measured from the left apical five-chamber view. Both velocities were recorded using pulsed-wave Doppler, with the sample volume positioned immediately distal to the corresponding semilunar valve.

Statistical analysis

Statistical analyses were performed using STATISTICA 12 (StatSoft, Inc., Tulsa, OK, USA). Data were assessed for normality using the Shapiro-Wilk test. Normally distributed variables were compared between males and females using the unpaired Student's *t*-test, whereas non-normally distributed variables were compared using the Mann-Whitney U test.

Reference intervals were calculated as the mean $\pm$ 2 standard deviations when the data used to establish the interval were normally distributed. For non-normally distributed data, the lower and upper reference limits were defined as the 2.5th and 97.5th percentiles, respectively. When a significant difference between males and females was detected, sex-specific reference intervals were calculated. A *P* value < 0.05 was considered statistically significant.

Results

Of the 370 Weimaraners examined, 339 clinically healthy dogs met the inclusion criteria and were enrolled in the study. The study population comprised 198 females and 141 males. Age ranged from 17 to 131 months, with a mean of 58.5 ± 21.9 months. Body weight ranged from 23 to 46 kg, with a mean of 33.9 ± 4.4 kg. In females, body weight ranged from 23 to 40 kg, with a mean of 31.5 ± 3.5 kg. In males, body weight ranged from 27 to 46 kg, with a mean of 37.3 ± 3.2 kg.

No significant differences between females and males were detected in heart rate, FS, LA/Ao, EF, peak aortic flow velocity, peak pulmonary artery flow velocity, or EPSS (all *P* > 0.05). Therefore, common reference intervals were established for these variables: 68–154 beats/min for heart rate, 23–41% for FS, 1.07–1.60 for LA/Ao, 46–76% for EF, 0.80–1.86 m/s for peak aortic flow velocity, 0.60–1.50 m/s for peak pulmonary artery flow velocity, and 2.00–8.00 mm for EPSS. Significant differences between females and males were detected for IVSd, LVIDd, LVPWd, IVSs, LVIDs, LVPWs, Ao, LA, EDVI SMOD, and ESVI SMOD (all *P* < 0.001).

In females, the reference intervals were 8.00–14.00 mm for IVSd, 36.23–49.78 mm for LVIDd, 8.00–13.20 mm for LVPWd, 10.00–18.00 mm for IVSs, 24.40–35.96 mm for LVIDs, 11.00–18.50 mm for LVPWs, 19.00–31.00 mm for Ao, 27.00–40.60 mm for LA, 55.97–96.37 ml/m² for EDVI SMOD, and 21.81–52.38 ml/m² for ESVI SMOD.

In males, the reference intervals were 8.00–16.00 mm for IVSd, 38.00–52.00 mm for LVIDd, 8.00–16.00 mm for LVPWd, 10.00–20.00 mm for IVSs, 23.60–38.00 mm for LVIDs, 11.00–20.00 mm for LVPWs, 21.00–31.60 mm for Ao, 27.00–43.00 mm for LA, 59.94–101.93 ml/m² for EDVI SMOD, and 25.13–55.13 ml/m² for ESVI SMOD.

Complete descriptive statistics and reference intervals are presented in Tables 1–3. Statistically significant differences between females and males for EDVI SMOD and ESVI SMOD are presented in Figs 1 and 2.

Table 1. Descriptive statistics and reference intervals for echocardiographic variables in clinically healthy Weimaraners (both males and females).

Variable	n	Mean $\pm$ SD	Median (Q1–Q3)	Range	Reference interval
Heart rate (bpm)	339	106.28 $\pm$ 20.77	100.00 (98.00–120.00)	60.00–240.00	68.00–154.00
FS (%)	339	29.89 $\pm$ 4.94	29.00 (26.00–33.00)	22.00–55.00	23.00–41.00
LA/Ao	339	1.33 $\pm$ 0.15	1.31 (1.22–1.41)	1.00–1.60	1.07–1.60
EF (%)	339	59.91 $\pm$ 7.96	59.00 (54.00–65.00)	44.00–87.00	46.00–76.00
Ao PW (m/s)	339	1.32 $\pm$ 0.26	1.31 (1.10–1.48)	0.70–2.00	0.80–1.86
PV PW (m/s)	339	0.97 $\pm$ 0.23	0.91 (0.80–1.10)	0.40–1.70	0.60–1.50
EPSS (mm)	338	4.68 $\pm$ 1.56	4.75 (3.40–6.00)	1.10–8.00	2.00–8.00

Data are presented as mean $\pm$ standard deviation (SD), median with the first and third quartiles (Q1–Q3), observed range, and reference interval.

Ao PW, peak aortic flow velocity measured using pulsed-wave Doppler; EF, ejection fraction; EPSS, E-point-to-septal separation; FS, fractional shortening; LA/Ao, left atrial-to-aortic root ratio; PV PW, peak pulmonary artery flow velocity measured using pulsed-wave Doppler.

Table 2. Descriptive statistics and reference intervals for echocardiographic variables in clinically healthy female Weimaraners.

Variable	n	Mean $\pm$ SD	Median (Q1–Q3)	Range	Reference interval
IVSd (mm)	198	10.76 $\pm$ 1.54	10.70 (10.00–12.00)	6.00–16.00	8.00–14.00
LVIDd (mm)	198	43.00 $\pm$ 3.39	43.00 (41.00–45.10)	35.00–54.00	36.23–49.78
LVPWd (mm)	198	10.29 $\pm$ 1.50	10.00 (9.00–11.00)	7.00–17.00	8.00–13.20
IVSs (mm)	198	13.89 $\pm$ 2.02	14.00 (12.70–15.00)	6.00–18.20	10.00–18.00
LVIDs (mm)	198	30.18 $\pm$ 2.89	30.00 (28.10–32.00)	21.00–36.10	24.40–35.96
LVPWs (mm)	198	14.43 $\pm$ 1.73	14.20 (13.20–15.20)	11.00–21.00	11.00–18.50
Ao (mm)	198	25.44 $\pm$ 2.83	25.90 (24.00–27.00)	18.00–38.00	19.00–31.00
LA (mm)	198	33.47 $\pm$ 3.32	33.80 (31.30–35.00)	26.00–46.00	27.00–40.60
EDVI (SMOD; ml/m ²)	198	76.17 $\pm$ 10.10	76.90 (68.00–83.00)	48.70–100.00	55.97–96.37
ESVI (SMOD; ml/m ²)	198	37.09 $\pm$ 7.64	37.00 (32.00–42.00)	18.90–55.00	21.81–52.38

Data are presented as mean $\pm$ standard deviation (SD), median with the first and third quartiles (Q1–Q3), observed range, and reference interval.

Ao, aortic diameter; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; IVSd and IVSs, interventricular septal thickness in diastole and systole, respectively; LA, left atrial diameter; LVIDd and LVIDs, left ventricular internal diameter in diastole and systole, respectively; LVPWd and LVPWs, left ventricular posterior wall thickness in diastole and systole, respectively; SMOD, Simpson's method of discs.

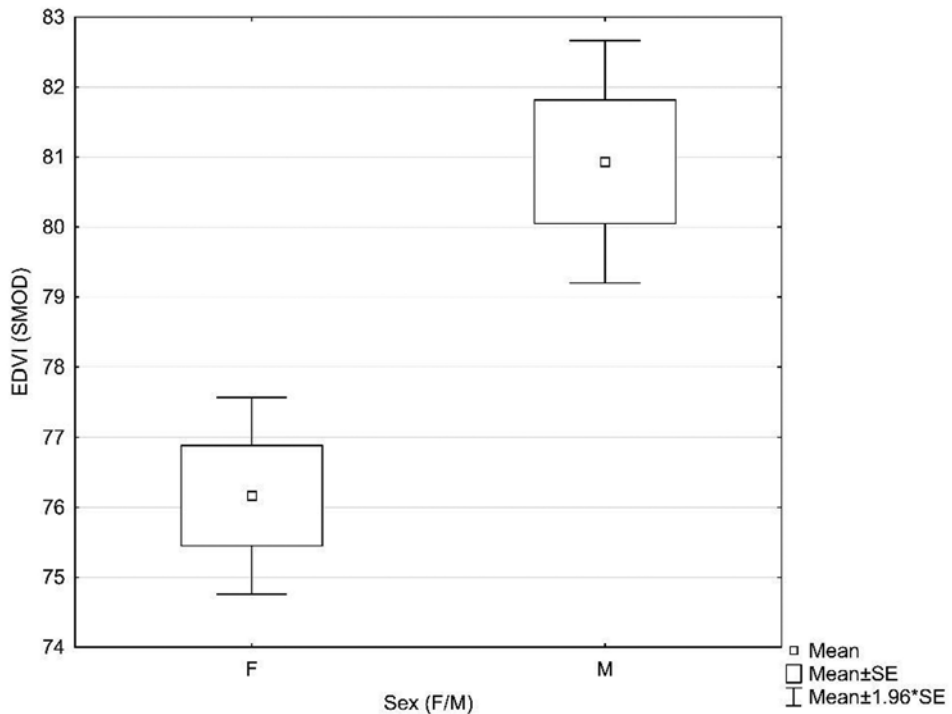


Fig. 1. Comparison of the end-diastolic volume index determined by Simpson's method of discs (EDVI SMOD) between female and male Weimaraners ($P < 0.001$).

Table 3. Descriptive statistics and reference intervals for echocardiographic variables in clinically healthy male Weimaraners.

Variable	n	Mean $\pm$ SD	Median (Q1–Q3)	Range	Reference interval
IVSd (mm)	141	11.52 $\pm$ 1.81	11.40 (10.30–13.00)	6.00–18.00	8.00–16.00
LVIDd (mm)	141	45.12 $\pm$ 3.73	45.00 (42.50–47.80)	35.80–58.00	38.00–52.00
LVPWd (mm)	141	11.27 $\pm$ 1.88	11.00 (10.00–12.00)	8.00–19.00	8.00–16.00
IVSs (mm)	141	15.06 $\pm$ 2.47	15.00 (14.00–16.30)	7.00–22.00	10.00–20.00
LVIDs (mm)	141	31.53 $\pm$ 3.70	32.00 (29.00–34.00)	19.00–39.00	23.60–38.00
LVPWs (mm)	141	15.79 $\pm$ 2.23	15.60 (14.40–17.00)	10.00–24.00	11.00–20.00
Ao (mm)	141	26.65 $\pm$ 2.95	27.10 (25.00–29.00)	20.00–33.00	21.00–31.60
LA (mm)	141	35.63 $\pm$ 3.98	36.00 (33.00–38.00)	25.00–44.00	27.00–43.00
EDVI (SMOD; ml/m ²)	141	80.93 $\pm$ 10.50	82.00 (73.80–89.00)	55.70–105.30	59.94–101.93
ESVI (SMOD; ml/m ²)	141	40.13 $\pm$ 7.50	40.00 (35.10–45.00)	20.40–58.00	25.13–55.13

Data are presented as mean $\pm$ standard deviation (SD), median with the first and third quartiles (Q1–Q3), observed range, and reference interval.

Ao, aortic diameter; EDVI, end-diastolic volume index; ESVI, end-systolic volume index; IVSd and IVSs, interventricular septal thickness in diastole and systole, respectively; LA, left atrial diameter; LVIDd and LVIDs, left ventricular internal diameter in diastole and systole, respectively; LVPWd and LVPWs, left ventricular posterior wall thickness in diastole and systole, respectively; SMOD, Simpson's method of discs.

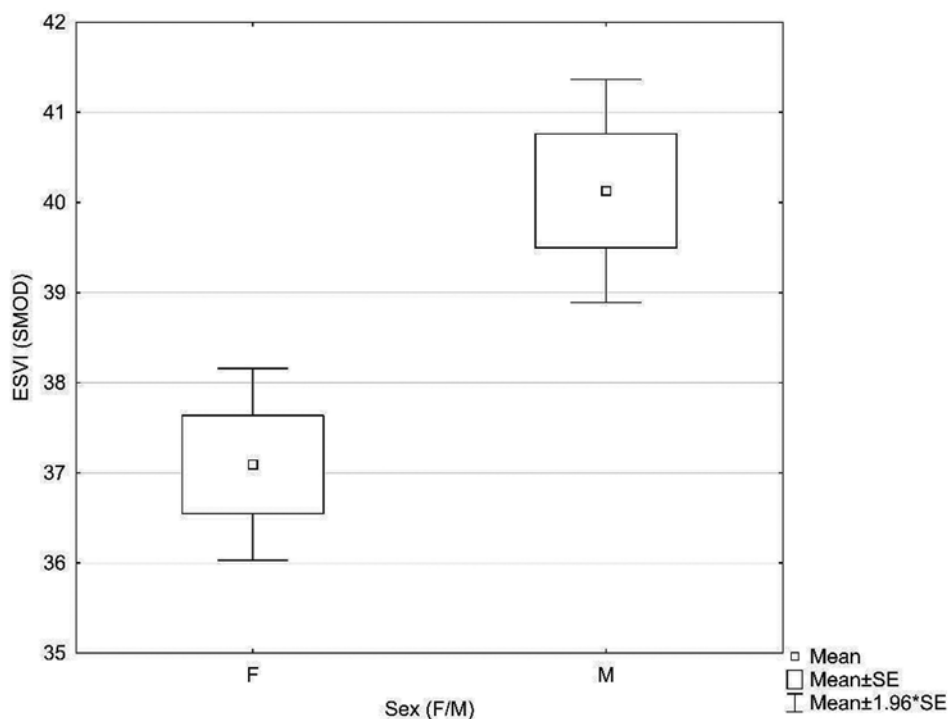


Fig. 2. Comparison of the end-systolic volume index determined by Simpson's method of discs (ESVI SMOD) between female and male Weimaraners ($P < 0.001$).

Discussion

Echocardiographic measurements and their reference intervals vary among dog breeds, emphasizing the importance of establishing breed-specific values. To the best of our knowledge, this is the first study to establish reference intervals for echocardiographic variables in a large population of clinically healthy Weimaraners. Breed-specific echocardiographic values have previously been reported for English Cocker Spaniels (Gooding et al. 1986), English Pointers (Sisson and Schaeffer 1991), Golden Retrievers and Afghan Hounds (Morrison et al. 1992), Beagles (Crippa et al. 1992), Greyhounds (Page et al. 1993), Spanish Mastiffs (Bayón et al. 1994), Irish Wolfhounds (Vollmar 1999), Bull Terriers (O'Leary et al. 2003), Whippets (Bavegems et al. 2007) and Boxers (Smets et al. 2014), but no information was available for Weimaraners. The present study aimed to determine the echocardiographic parameters reference ranges in Weimaraner dogs of both sexes and evaluated the effect of sex on the measured variables.

Significant differences between males and females were identified for several cardiac dimensions, including IVSd, IVSs, LVIDd, LVIDs, LVPWd, LVPWs, Ao, and LA, as well as for EDVI and ESVI determined by SMOD. In contrast, no significant sex-related differences were observed for FS, EF, or the LA/Ao ratio. Sex-related differences in left ventricular wall thickness have also been reported in Beagles and German Shepherds (Crippa et al. 1992; Kayar et al. 2006), whereas FS, EF, and LA/Ao were not significantly affected by sex in these breeds. Lower LVID values have been reported in female Great Danes than in males (Stephenson et al. 2012). Male Dachshunds have been shown to have larger systolic and diastolic left ventricular dimensions than females (Garncarz et al. 2018). A statistically significant but clinically negligible effect of sex on several echocardiographic variables has also been reported in adult Cavalier King Charles Spaniels (Misbach et al. 2014). These findings support the use of sex-specific reference intervals for cardiac dimensions when statistically and clinically appropriate.

In the present study, the reference interval for LVIDd was 38.00–52.00 mm in males and 36.23–49.78 mm in females. The corresponding reference interval for LVIDs was 23.60–38.00 mm in males and 24.40–35.96 mm in females. In Doberman Pinschers, previously proposed M-mode thresholds for occult DCM include an LVIDd > 48 mm in males and > 46 mm in females and an LVIDs > 36 mm in both sexes (Wess et al. 2010). These Doberman-specific thresholds fall within the reference intervals established for clinically healthy Weimaraners in the present study. Therefore, applying these thresholds directly to Weimaraners could result in the misclassification of healthy dogs as having left ventricular enlargement. This observation further demonstrates the clinical importance of breed- and sex-specific reference intervals.

Left ventricular volume indices derived by SMOD are particularly important for the detection of preclinical DCM and have been shown to be more sensitive than conventional M-mode measurements for detecting early echocardiographic changes in Doberman Pinschers (Wess et al. 2010). In that breed, EDVI > 95 ml/m² and ESVI > 55 ml/m² have been proposed as diagnostic thresholds for occult DCM. In the present population of healthy Weimaraners, the EDVI reference interval was 59.94–101.93 ml/m² in males and 55.97–96.37 ml/m² in females. The ESVI reference interval was 25.13–55.13 ml/m² in males and 21.81–52.38 ml/m² in females. Thus, the upper EDVI reference limits in both sexes exceeded the Doberman-specific threshold of 95 ml/m², whereas the upper ESVI reference limit in males only marginally exceeded the corresponding threshold of 55 ml/m². These findings suggest that SMOD thresholds established for Doberman Pinschers may not be directly applicable to Weimaraners and emphasize the importance of breed-specific interpretation of left ventricular volume indices.

E-point-to-septal separation provides an indirect assessment of left ventricular size and systolic function (Vollmar 1999). A study evaluated the diagnostic performance of EPSS for detecting occult DCM in Doberman Pinschers and showed that an EPSS > 6.5 mm had 100% sensitivity and 99% specificity (Holler and Wess 2014). The normal value for EPSS for other dog breeds is less than 10 mm but it can vary among breeds. In healthy Labrador Retrievers, a reference interval of 4.5–7.5 mm has been reported (Gugjoo et al. 2014). The EPSS reference interval in the present study was 2.0–8.0 mm. Consequently, its upper portion extends beyond the Doberman-specific diagnostic threshold of 6.5 mm. This overlap indicates that EPSS should not be interpreted using a universal cutoff and should instead be assessed together with breed-specific reference intervals, other echocardiographic measurements, clinical findings, and electrocardiographic results.

The reference interval for peak aortic flow velocity in the Weimaraners examined in the present study was 0.80–1.86 m/s, whereas the reference interval for peak pulmonary artery flow velocity was 0.60–1.50 m/s. These findings are consistent with previously reported Doppler-derived aortic and pulmonary flow velocities in clinically healthy dogs (Brown et al. 1991). Aortic flow velocities below approximately 2.0 m/s are generally considered compatible with the absence of clinically relevant left ventricular outflow obstruction, although values close to or above this threshold should be interpreted in conjunction with valve morphology, spectral Doppler characteristics, and the complete echocardiographic examination. In healthy Dogue de Bordeaux dogs, peak aortic velocities were below 2.07 m/s, whereas values between 2.0 and 2.5 m/s were considered equivocal for subaortic stenosis (Locatelli et al. 2011).

The reference interval for fractional shortening in the present study was 23%–41%. This interval is broadly consistent with previously reported values in healthy dogs (Lombard 1984). Nevertheless, FS is influenced by loading conditions, sympathetic tone, breed, and athletic conditioning. Lower FS values have been reported in healthy Whippets than in the general canine population (Bavegems et al. 2007), and more recent findings in conditioned and unconditioned Whippets further demonstrate the importance of population-specific echocardiographic reference intervals in athletic breeds (Stepien et al. 2023). Therefore, FS should be interpreted together with left ventricular dimensions, volume indices, and the overall clinical and echocardiographic findings.

Several limitations of this study should be considered. The classification of dogs as clinically healthy was based on physical examination, standard electrocardiography, and routine echocardiography performed at a single time point. In a subset of dogs, the clinical evaluation also included a complete blood workup and thoracic radiography; however, these examinations were not performed in all dogs. Ambulatory electrocardiographic monitoring and long-term follow-up were not performed in all dogs. Therefore, very early or predominantly arrhythmic forms of occult DCM could not be completely excluded. Furthermore, examinations were performed at two centres using two ultrasound systems, which may have introduced measurement variability. Nevertheless, the large number of clinically healthy dogs included in the study provides a robust basis for establishing breed-specific reference intervals.

In conclusion, this study provides echocardiographic reference intervals for clinically healthy Weimaraners and demonstrates significant sex-related differences in several cardiac dimensions and SMOD-derived volume indices. The overlap between reference intervals in healthy Weimaraners and diagnostic thresholds previously established for Doberman Pinschers indicates that such thresholds should not be transferred directly between breeds. The reference intervals established in this study may facilitate more accurate interpretation of echocardiographic examinations in Weimaraners and support the early detection of cardiac disease, particularly DCM.

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