Echocardiographic Measurements in the Irish Wolfhound: Reference Values for the Breed

Out of 400 Irish wolfhounds cardiologically examined, echocardiographic measurements of 262 normal dogs were analyzed to obtain reference values for the breed. Based on regression analysis, several echocardiographic parameters showed significant linear correlation with body weight and with age, but coefficients of determination were low. Therefore, due to a high individual variability of echocardiographic measurements in adult Irish wolfhounds, the predictive value of body weight for echocardiographic measurements was clinically not relevant. Sex had no influence on echocardiographic values. For the estimation of myocardial function, end-systolic volume index (ESVI) (mean, 29.0 ml/m^2±standard deviation [SD], 5.9 ml/m^2) was determined for the group of 262 normal dogs. **J Am Anim Hosp Assoc 1999;35:271–7.**

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Introduction

Echocardiography is an essential diagnostic tool in the evaluation of cardiac disease. Measurements of cardiac structures are important for the proper interpretation of the echocardiogram. Some publications have demonstrated the influence of age, heart rate, and cardiac cycle length on echocardiographic measurements in the dog and cat.[1–3] Most normal echocardiographic values for the dog that have been published have indicated linear correlations with body weight or body surface areas.[3–8] Published reference intervals were based on regression analysis and 95% prediction intervals using data obtained from dogs of many different breeds that were grouped together. Sometimes relatively small numbers of dogs were used. One study demonstrated that breed, in addition to body weight, was an important factor in the determination of normal echocardiographic measurements in the dog.[9] A significant variability of measurements within the breeds studied were demonstrated also. Few studies have reported normal echocardiographic values for specific breeds of dogs.[1,9–12] The purpose of this study was to obtain reference values for M-mode and two-dimensional (2D) echocardiographic measurements in the adult Irish wolfhound. Special attention was paid to age, sex, and body weight.

Materials and Methods

In this study, 400 Irish wolfhounds were screened to obtain 262 dogs without any abnormal findings on cardiovascular examination. The criteria to accept the 262 dogs as normal were: no abnormal findings on physical examination including history; electrocardiographic (EKG) measurements within reference ranges,[13,14] without any rhythm, vector, or conduction abnormalities; and no evidence of congenital or acquired heart disease on routine echocardiographic examination (2D and M-mode echocardiography, pulsed and continuous wave Doppler) and color-flow Doppler.

The 262 normal dogs consisted of 92 intact and three neutered males and 146 intact and 21 neutered females. They were between 12 months

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and 8.5 years of age (mean, 3.4 yrs), with body weights ranging from 48 to 93 kg. To ascertain the influence of age on echocardiographic measurements, data obtained was compared between three age groups: 1 to 2.5 years (mean, 1.8 yrs); 2.6 to 4.5 years (mean, 3.6 yrs); and 4.6 to 8.5 years (mean, 5.4 yrs) of age. To depict the influence of body weight on echocardiographic measurements, three groups of body weights were established: 48 to 59 kg (mean, 56.7 kg); 60 to 69 kg (mean, 63.5 kg); and 70 to 93 kg (mean, 78.6 kg).

Echocardiographic examinations were performed with an ultrasound machine[a] having color-flow Doppler capabilities using a 5- or 3.5-MHz transducer. Most dogs were examined in a standing position, as they were much calmer this way and less assistants were needed to lift and hold the large dogs onto a table. Some dogs were placed in left or right lateral recumbency to facilitate the examination when the dogs were panting or not standing still. To determine if the position used would influence the measurements, the first 20 Irish wolfhounds were examined standing as well as in right and left lateral recumbency. Changes in heart position related to posture did not affect the results of the examinations. Two-dimensional and M-mode echocardiograms were recorded and analyzed in accordance with recommendations of the American Society of Echocardiography.[4,5]

Measurements were made using the electronic calipers of the echocardiograph machine. The leading edge of each respective endocardial or epicardial image was used. M-mode echocardiographic evaluation of the heart was guided by the simultaneous display of real-time 2D echocardiographic images. The right parasternal long-axis four-chamber view and the long-axis view optimized for aortic outflow were used to make standard measurements. In addition, left ventricular internal dimensions were measured in the right parasternal short-axis view. Care was taken to carry out all measurements perpendicular to the cardiac walls. Ventricular dimensions were always measured below the mitral valve at the chordal level. The following M-mode measurements were made: left ventricular internal dimension at end-systole (LVIDs) and end-diastole (LVIDd), left ventricular free wall thickness at end-systole (FWs) and end-diastole (FWd), interventricular septal thickness at end-systole (IVSs) and end-diastole (IVSd), fractional shortening (FS), and the E-point to septal separation (EPSS). When evaluating the aortic-left atrial (LA) view, the recommendation of the American Society of Echocardiography to image two valve cusps could not always be achieved. Aortic root dimension (AO) was measured at end-diastole from the outer edge of the anterior wall to the inner edge of the posterior wall. Left atrial systolic dimension, measured at maximal aortic root excursion, included the posterior aortic wall thickness.

Two-dimensional measurements of the end-diastolic right ventricular dimensions (RVIDd) were made in the standard right parasternal long-axis four-chamber view below the tricuspid valve. In the same view, the widest end-systolic diameters of both atria (LA and right atrium [RA]) were measured parallel to a line through each atrioventricular valve anulus.

Measurements for each variable were determined by the average of three to five cardiac cycles that were not necessarily continuous. As there was no difference between left ventricular internal dimensions (LVIDs and LVIDd) in short-axis and long-axis views in individual dogs, measurements of both views were averaged together for each dog. Taking body weight into account, calculations of myocardial end-systolic volume index (ESVI) were determined. Based on the left ventricular end-systolic measurement (in cm) at M-mode, ESVI was calculated according to the cube formula of Teichholz:[15,16]

$$\text{ESVI (ml/m}^2\text{)} = \frac{7\,(\text{LVIDs})^3}{2.4 + \text{LVIDs}} \times \frac{1}{\text{BSA}}$$

(where BSA=body surface area).

Statistical Analysis

Data collected from all normal dogs was pooled, and regression analysis was performed using body weight in kg and age as the independent variables against 13 echocardiographic variables. The validity of regressions was examined by evaluating the adjusted coefficients of determination (r^2). First to be tested was whether the polynomical or logarithmical type of regression analysis resulted in higher r^2 values when compared with the simple linear regression model. This was not the case. Therefore, simple linear regression analysis was regarded as sufficient. The r^2 values were considered significant at a P value of less than 0.05 and were used to estimate the percentage of variation in echocardiographic variables explained by the regression model. If r^2 was low, it was concluded that the predictive value of the independent variable (body weight or age) was also low for prediction of echocardiographic measurements.

Differences in echocardiographic measurements between males and females and between the three age groups and the three body weight groups were tested with unpaired, two-tailed Student's *t*-test. A P value of less than 0.05 was considered significant.

Results

Influence of Age (Years) [Table 1]

Significant linear correlation with age (P less than 0.05) was observed in LVIDs and LVIDd, EPSS, FWs, and RVIDd; but coefficients of determination were very low (r^2=0.03 to 0.17). In this study, IVSs and IVSd as well as FWd and FS were not linearly related to age. A significant, continuous increase in LA dimensions (r^2=0.10, P less than 0.05) resulted in a greater LA:AO ratio with advancing age, as AO significantly diminished with age (r^2=0.04). To ascertain the influence of age on

Table 1

Age Correlations With Echocardiographic Measurements* in the Irish Wolfhound (n=262)

	Regression (y =)	P<0.05†	Coefficient of Determination (r^2)
LVIDs (mm)	0.42 x + 33.7	S	0.0391
LVIDd (mm)	0.757 x + 50.4	S	0.092
FS (%)	-0.016 x + 34.2	NS	0.00005
FWs (mm)	0.208 x + 14.3	S	0.0264
FWd (mm)	0.06 x + 9.7	NS	0.0037
IVSs (mm)	0.058 x + 13.5	NS	0.0015
IVSd (mm)	0.069 x + 0.06	NS	0.0038
LA (mm), M-mode	0.703 x + 30.3	S	0.0946
AO (mm), M-mode	-0.34 x + 34.7	S	0.0388
EPSS (mm)	0.427 x + 5.2	S	0.1672
RVIDd (mm), 2D	0.518 x + 27.4	S	0.0394
Weight (kg)	0.47 x + 63.4	NS	0.0076

* LVIDs=left ventricular end-systolic dimension; LVIDd=left ventricular end-diastolic dimension; FS=fractional shortening; FWs and FWd=left ventricular free wall thickness at end-systole and end-diastole; IVSs and IVSd=interventricular septal thickness at end-systole and end-diastole; LA=left atrial systolic dimension; AO=aortic root dimension at end-diastole; EPSS=E-point to septal separation; RVIDd=end-diastolic right ventricular internal dimension; 2D=two-dimensional echocardiographic measurement

† S=significant at P<0.05 level; NS=not significant based on pooled age data

echocardiographic measurements, data was examined between three age groups. Echocardiographic measurements with significant differences at the P less than 0.05 level when compared between two age groups are depicted in Table 2.

Influence of Sex

To test the influence of sex, only dogs (44 males and 67 females) with similar body weights (60 to 69 kg) were compared. There were no significant differences of any cardiac dimensions between male and female dogs.

Influence of Body Weight [Table 3]

There is a wide range of body size and body weight within the breed. In adult females, the body weight registered between 48 and 90 kg, with an average of 61.2±standard deviation (SD) 6.8 kg. The body weight in adult males ranged from 58 to 93 kg, with most dogs weighing between 65 and 75 kg (mean, 70±SD 7.2 kg).

Body weight was positively correlated (P less than 0.05) to LVIDs and LVIDd, to RVIDd and AO, and to systolic dimensions of both atria, but coefficients of determination were low (r^2, 0.02 to 0.32). Fractional shortening and heart rate were significantly negatively correlated to body weight (P less than 0.05; r^2, 0.02 and 0.08). Systolic and diastolic septal and free wall thickness showed no linear correlation with body weight.

To depict the influence of body weight upon echocardiographic values within the breed, three groups of body weights were established. Measurements with significant differences between groups are shown as mean values with SD in Table 4. Common reference values for all adult Irish wolfhounds are given in Table 5.

Calculations of End-Systolic Volume Index (ESVI)

In 262 normal Irish wolfhounds weighing 48 to 93 kg, ESVI values between 15.3 and 40.6 ml/m^2 were calculated (mean, 29.0±SD 5.9 ml/m^2), resulting in a normal range for ESVI (x±2 SD) between 17.2 and 40.8 ml/m^2.

Significant positive linear correlation was observed between ESVI measurements and EPSS, but the coefficient of determination was low ($y=0.4907x + 4.058$; $r^2=0.0949$). Fractional shortening was significantly negatively correlated to ESVI ($y=0.4907x + 49.459$; $r^2=0.3842$).

Discussion

Several studies have reported normal M-mode echocardiographic measurements related to body weight in dogs up to 40 or 50 kg.[3–11] In most studies using data from dogs of different breeds as well as mongrels, regression equations depicted the potential of predicting cardiac dimensions in correlation to body weight.[5–9] In one study, echocardiographic examinations in 15 adult Great Danes were carried out to obtain reference values for the breed. The authors found smaller systolic and diastolic left ventricular internal dimensions related to body weight than they had expected from regression equations of previous studies from other breeds of dogs.[12]

Table 2

Irish Wolfhound Echocardiographic Measurements (mm) With Regard to Age

Group Age (yrs)	1 1.0–2.5 (mean, 1.8) n=88		2 2.6–4.5 (mean, 3.6) n=91		3 4.6–8.5 (mean, 5.4) n=83	
	Mean±SD*	Group 1 vs. 2†	Mean±SD	Group 2 vs. 3†	Mean±SD	Group 1 vs. 3†
LVIDs‡	34.4±3.5	S	35.7±3.3	S	36.2±2.4	S
LVIDd	52.2±3.5	S	53.4±3.1	S	54.5±3.1	S
FWs	14.5±1.9	NS	14.9±2.0	S	15.5±2.1	S
LA (M-mode)	31.5±3.1	NS	32.3±4.9	S	34.8±2.4	S
EPSS	6.2±1.2	S	6.7±1.6	S	7.7±1.4	S
LA (2D)	46.5±3.2	NS	47.3±4.4	NS	48.7±4.0	S
RVIDd (2D)	28.7±3.8	NS	28.8±3.5	S	30.1±3.3	S

* Mean±SD=mean±standard deviation

† S=significant at P<0.05; difference between two age groups tested with unpaired, two-tailed Student's *t*-test; NS=not significant

‡ LVIDs=left ventricular internal dimension at end-systole; LVIDd=left ventricular internal dimension at end-diastole; FWs=left ventricular free wall thickness at end-systole; LA=left atrial end-systolic dimension; EPSS=E-point to septal separation; 2D=two-dimensional echocardiographic measurement; RVIDd=end-diastolic right ventricular internal dimension

Table 3

Body Weight Correlations With Echocardiographic Measurements in the Irish Wolfhound (n=262)

	Regression (y =)	P<0.05*	Coefficient of Determination (r^2)
LVIDs (mm)†	0.164 x + 24.3	S	0.1755
LVIDd (mm)	0.205 x + 39.4	S	0.1996
FS (%)	-0.07 x + 38.9	S	0.0179
FWs (mm)	0.025 x + 13.4	NS	0.0128
FWd (mm)	0.023 x + 8.5	NS	0.0121
IVSs (mm)	0.013 x + 12.7	NS	0.0022
IVSd (mm)	0.02 x + 8.0	NS	0.0104
LA (mm), M-mode	0.166 x + 21.7	S	0.1474
AO (mm), M-mode	0.048 x + 30.6	S	0.0238
EPSS (mm)	-0.011 x + 7.2	NS	0.0041
LA (mm), 2D	0.172 x + 35.7	S	0.1655
RA (mm), 2D	0.040 x + 21.4	S	0.3244
RVIDd (mm), 2D	0.086 x + 23.4	S	0.0344
Age (yrs)	0.002 x + 2.3	NS	0.0076
Heart rate (beats/min)	-0.77 x + 170.97	S	0.0784

* S=significant at P<0.05 level; NS=not significant based on pooled body weight data

† LVIDs=left ventricular end-systolic dimension; LVIDd=left ventricular end-diastolic dimension; FS=fractional shortening; FWs and FWd=left ventricular free wall thickness at end-systole and end-diastole; IVSs and IVSd=interventricular septal thickness at end-systole and end-diastole; LA and RA=left and right atrial end-systolic dimension; AO=aortic root diameter at end-diastole; EPSS=E-point to septal separation; 2D=two-dimensional echocardiographic measurement; RVIDd=end-diastolic right ventricular internal dimension

Table 4

Irish Wolfhound Echocardiographic Measurements (mm) With Regard to Body Weight (kg)

Group	1		2		3	
Body Weight (kg)	48–59 (mean, 56.7) n=80		60–69 (mean, 63.5) n=118		70–93 (mean, 78.6) n=64	
	Mean±SD*	Group 1 vs. 2†	Mean±SD	Group 2 vs. 3†	Mean±SD	Group 1 vs. 3†
LVIDs‡	32.2±3.1	S	35.5±2.9	S	37.0±2.5	S
LVIDd	49.7±2.5	S	53.4± 2.8	S	55.2±2.3	S
LA (M-mode)	30.0±3.4	S	33.3± 3.8	S	34.4±2.9	S
AO (M-mode)	32.6±2.5	S	34.3± 2.5	NS	34.5±3.0	S
LA (2D)	45.7±4.2	NS	46.3±3.3	S	49.9 ±2.4	S
RA (2D)	38.0±3.2	S	40.1±5.7	S	44.8±5.0	S
RVIDd (2D)	27.4±4.4	S	29.5±3.9	NS	30.5± 3.9	S
Heart rate	130±22	NS	129± 29	S	118±21	S
Age (yrs)	3.2±1.6	NS	3.4±1.6	NS	3.6±1.7	NS

* Mean±SD=mean±standard deviation

† S=significant at $P<0.05$; difference between two body weight groups tested with unpaired, two-tailed Student's *t*-test; NS=not significant

‡ LVIDs=left ventricular internal dimension at end-systole; LVIDd=left ventricular internal dimension at end-diastole; LA=left atrial end-systolic dimension; AO=aortic root diameter at end-diastole; RA=right atrial end-systolic dimension; 2D=two-dimensional echocardiographic measurement; RVIDd=end-diastolic right ventricular internal dimension

In a study by Morrison *et al.*,[10] 80 normal dogs of four morphologically distinct breeds (i.e., Pembroke Welsh corgi, miniature poodles, Afghan hounds, and golden retriever) were studied by echocardiography to determine the importance of breed and weight in establishing echocardiographic reference ranges. Regression lines referring to body weight revealed different slopes and different intercepts for the different breeds, indicating that dogs of the same weight but different breed had different predicted echocardiographic measurements. Within the breeds, some echocardiographic measurements were not linearly related to weight (e.g., FWd in miniature poodles and Afghan hounds, LVIDd in Pembroke Welsh corgis and Afghan hounds). The authors demonstrated that if different breeds of dogs were combined to estimate an overall regression line referring to body weight, for some breeds the line was incorrect and misleading. According to the opinion of Morrison *et al.*,[10] closer attention should also be paid to the sample size used to establish reference ranges, because the number of dogs directly affects the width of the reference range.

In the present study, body weight and age correlated linearly with left and right ventricular and LA dimensions. In addition, EPSS and FWs correlated significantly with age, while RA and AO showed significant linear correlation with body weight. However, the coefficients of determination were low for all parameters. Therefore, according to the author's opinion, the regression equations with body weight as the independent variable offer no significant advantage over standard descriptive statistics (mean±SD) in predicting echocardiographic measurements in the adult Irish wolfhound. There is marked individual variation in cardiac dimensions and wall thickness within the breed, which is much stronger than the influence of body weight and age.

According to Knight,[16] ESVI provides a convenient method for recognizing myocardial dysfunction in the presence of marked preload abnormalities. In humans, an index less than 30 is considered normal. Comparing data from mature, healthy beagles (n=12) and Great Danes (n=10) to normal values reported for humans, Knight considers that "particularly in large dogs, the normal upper limits perhaps should be greater than 30 ml/m^2." In 21 Doberman pinchers, Sottiaux and Amberger[10] report ESVI values of 26.4±SD 9.5 ml/m^2, while in the present study of 262 normal Irish wolfhounds, ESVI values of 29.0±SD 5.9 ml/m^2 were determined.

Conclusion

Since Irish wolfhounds are frequently affected with dilated cardiomyopathy, it is important to have reference echocardiographic values for the breed which provide information for an early diagnosis of the disease. According to the results of this study, within the Irish

Table 5

Echocardiographic Measurements in the Irish Wolfhound
(n=262 dogs; 95 males and 167 females)

	Mean	SD*	Range	Mean±2SD
LVIDs (mm)[†]	35.4	2.8	25.4–41.5	29.8–41
LVIDd (mm)	53.2	4.0	42.7–65.5	45.2–61.2
FS (%)	34.0	4.5	25–48	25–43
FWs (mm)	14.9	2.2	9.7–21.3	10.6–19.2
FWd (mm)	9.8	1.6	6.6–13.8	6.6–13.0
IVSs (mm)	13.7	2.4	8.1–19.0	8.9–18.5
IVSd (mm)	9.3	1.8	5.2–13.5	5.7–12.9
LA (mm), M-mode	32.9	3.4	25.4–40.9	26.1–39.7
AO (mm), M-mode	33.1	2.8	23.1–39.7	27.7–38.7
EPSS (mm)	6.8	1.6	4.0–11.4	3.6–10.0
LA (mm), 2D	47.3	4.3	36.5–56.8	38.7–55.9
RA (mm), 2D	40.4	7.5	30.9–54.6	25.4–55.4
RVIDd (mm), 2D	29.1	3.9	17.9–37.6	21.4–36.8
ESVI (ml/m^2)	29.0	5.9	15.3–40.6	17.2–40.8
Heart rate (beats/min)	121	23.5	74–166	74–168
Age (yrs)	3.4	1.6	1–8.5	
Body weight (kg)	65.0	8.75	48–93	

* SD=standard deviation

† LVIDs=left ventricular end-systolic dimension; LVIDd=left ventricular end-diastolic dimension; FS=fractional shortening; FWs and FWd=left ventricular free wall thickness at end-systole and end-diastole; IVSs and IVSd=interventricular septal thickness at end-systole and end-diastole; LA=left atrial end-systolic dimension; AO=aortic root diameter at end-diastole; EPSS=E-point to septal separation; RA=right atrial end-systolic dimension; 2D=two-dimensional echocardiographic measurement; RVIDd=end-diastolic right ventricular internal dimension; ESVI=end-systolic volume index

wolfhound breed, the influence of body weight on echocardiographic measurements is much smaller than expected from other studies using data from several different breeds of dogs and mongrels. In a breed showing immense variations of body weight in adult dogs, like the Irish wolfhound, calculation of ESVI is a helpful tool in considering left ventricular function.

[a] SIM 7000 Challenge; Esaote Company, Italy

Acknowledgments

The author wishes to acknowledge Philip Fox, DVM, The Animal Medical Center, New York, New York, for help in preparing this manuscript. Special thanks to Dr. Cordula Poulsen-Nautrup, Institute for Veterinary Anatomy, Ludwigs Maximilians Universität, Munich, Germany, for assistance in the statistical evaluation.

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