

Echocardiographic values and prevalence of cardiac abnormalities in clinically healthy adult Borzoi dogs

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OBJECTIVE

To develop breed-specific echocardiographic values for normal Borzoi and to report the prevalence of structural cardiac abnormalities.

ANIMALS

146 clinically healthy, adult Borzoi dogs.

METHODS

Cardiac auscultation and standard echocardiograms were performed. Longitudinal follow-up was described in a subset of dogs (n = 25).

RESULTS

Most Borzoi were structurally normal (119/146, 81.5%), with breed-specific echocardiographic values generated independently for each sex, as females weighed significantly less than males (30.4 ± 3.8 kg vs 38.3 ± 4.1 kg, respectively; $P < .001$), and a significant impact of sex was found on most measurements. Physiologic heart murmurs were identified in 64/119 (53.8%) normal dogs. Thirty-six (30.2%) structurally normal dogs had trace or mild mitral regurgitation, and 43 (36.1%) had trace or mild tricuspid regurgitation. Structural cardiac disease was identified in 21 dogs (14.4%), including 9 dogs (6.2%) with dilated cardiomyopathy (DCM), 9 dogs (6.2%) with stage B1 myxomatous mitral valve disease (MMVD), and 3 (2.1%) dogs with congenital abnormalities. Seven dogs (4.8%) had equivocal abnormalities. During follow-up, new dogs were diagnosed with occult DCM (n = 3), equivocal DCM (1), and stage B1 MMVD (2). Two dogs originally diagnosed with DCM (1 occult and 1 equivocal) normalized after diet change.

CLINICAL RELEVANCE

Borzoi dogs commonly have physiologic heart murmurs and mild atrioventricular valve regurgitation. Both DCM and MMVD were identified at similar frequencies in healthy Borzoi, although dogs with MMVD all had normal heart sizes. Echocardiographic screening for DCM in Borzoi should be considered, with breed-specific echocardiographic values now available for improved diagnostic confidence.

Keywords: sighthound, dilated cardiomyopathy, left ventricle, heart murmur, breed-specific

Borzoi are large, athletic sighthounds, bred for coursing wild game. There is a substantial sex-based discrepancy in body weight, with breed-standard males being 15 to 20 pounds (6.8 to 9.1 kg) heavier than females. Prior work¹ has indicated that Borzoi may be predisposed to ventricular arrhythmias, dilated cardiomyopathy (DCM), and sudden death; however, prospective data defining the

prevalence of cardiac abnormalities in the breed are lacking. While it has been well demonstrated that sighthound breeds are likely to have different echocardiographic reference intervals compared to nonsighthound breeds,²⁻¹⁰ to date, no reference intervals have been developed for Borzoi dogs. In a small number (n = 9) of Borzoi evaluated as part of a much larger study,² left ventricular internal diameter at end systole (LVIDs) was found to be above non-breed-specific prediction intervals in 11.1% of dogs. Determination of breed-specific LVIDs reference intervals would be particularly important for appropriate DCM screening in Borzoi, given the

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importance of this echocardiographic measurement as criteria for diagnosis of DCM.

The first objective of the present study, therefore, was to develop breed-specific echocardiographic values for the Borzoi breed in clinically healthy, adult dogs. The second objective was to report the prevalence of structural cardiac abnormalities in the same population.

Methods

Clinically healthy, adult Borzoi dogs were prospectively recruited to participate either on-site at Texas A&M University's Small Animal Veterinary Medical Teaching Hospital or off-site at the 2022 National Borzoi Specialty Show cardiac screening event. The study was approved by the Institutional Animal Care and Use Committee at Texas A&M University (protocol 2020-0032 CA), and all owners provided informed signed consent. Demographic data and information regarding diet and medical history were provided by each dog's owner.

Cardiovascular auscultation was performed by 1 of 2 board-certified veterinary cardiologists (SW, ABS). The presence or absence of a heart murmur or gallop sound was recorded as a binary yes/no, along with the point of maximal intensity and grade of any noted heart murmurs.

Standard echocardiograms including 2-D, M-mode, and Doppler imaging were performed with dogs restrained in right and left lateral recumbency by board-certified veterinary cardiologists (SW, ABS). Left ventricular (LV) size and function assessments were made in standard, right parasternal, short axis views at the level of the chordae tendinae in both 2-D and M-mode views and included LV free wall thickness at end diastole and end systole, interventricular septal thickness at end diastole, and end systole and left ventricular internal diameter at end diastole (LVIDd) and end systole (LVIDs). Fractional shortening (FS) was calculated from 2-D and M-mode views as $FS = [LVIDd - LVIDs] / LVIDd \times 100\%$. The E-point to septal separation was measured on right parasternal short axis M-mode views at the level of the mitral valve.¹¹ The left atrial-to-aortic root ratio was obtained from right parasternal short axis views at the level of the heart base at end systole.¹² The LV length was measured from a right parasternal long axis 4-chamber view,¹¹ as was right ventricular end-diastolic diameter.¹³ Left atrial diameter and aortic valve diameter at the level of the aortic valve cusps were obtained from right parasternal long axis 4-chamber and outflow tract views at end systole and early systole, respectively.¹⁴ Volumetric assessment of the LV was obtained in either the right parasternal long axis 4-chamber view or the left apical 4-chamber view depending on which view allowed for optimal alignment and visualization of the entire endocardial border throughout the cardiac cycle at the discretion of the cardiologist. Left ventricular end-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF) were obtained by the Simpson method of disks. Left atrial

volume was measured using a biplane area-length method from left apical 4- and 2-chamber views.¹⁵ Volumetric measurements (LV EDV and LV ESV and left atrial volumes) were indexed to body weight in kilograms. Tricuspid annular plane systolic excursion was obtained from M-mode views directed by 2-D left parasternal views optimized for alignment parallel with the right ventricular free wall and transecting the right ventricular apex.¹⁶

Peak transpulmonic flow velocities were measured using pulsed wave spectral Doppler from right parasternal short axis views at the level of the heart base or left cranial short axis views. Peak transaortic flow velocity was measured using continuous wave Doppler from left apical 5-chamber views, as was isovolumic relaxation time. Transmitral flow velocities were measured using pulsed wave Doppler at the tips of the open mitral valve leaflets on left apical 4-chamber views, with peak velocities of early and late diastolic transmitral flow and deceleration time of the early transmitral flow recorded. Tissue Doppler imaging of the lateral mitral annulus was used for measurement of peak early diastolic velocity (E'), peak late diastolic velocity (A'), and peak systolic velocity (S'). Color Doppler was used to screen all cardiac valves for evidence of regurgitation, which was graded, if identified, as trace, mild, moderate, or severe.¹⁷

Dogs with structural echocardiographic abnormalities were excluded from statistical analysis and calculation of reference intervals but were reported descriptively. A diagnosis of myxomatous mitral valve disease (MMVD) was made based on echocardiographic evidence of mitral valve thickening and/or prolapse in combination with mitral regurgitation. In the absence of breed-specific Borzoi data at the study outset, a diagnosis of DCM was made throughout the study enrollment period in dogs that exhibited a normalized LV diameter at end systole exceeding the upper 97.5 percentile prediction interval of 1.26, with or without the normalized LV diameter at end diastole exceeding the equivalent cut-off of 1.85¹⁸ in combination with 1 or more of the following: FS < 20%,¹⁹ EF by the Simpson method of disks of < 40%,¹⁹ or ESV indexed to body weight greater than a previously proposed sighthound-specific cut-off of 2.11 ml/kg.³

An equivocal echocardiographic diagnosis was made on a case-by-case basis by the attending cardiologist if they deemed 1 or more echocardiographic findings to be nonstandard; however, the findings did not meet clear criteria for a definitive abnormal diagnosis.

Longitudinal follow-up echocardiographic examinations were available in a convenience subset of dogs with owners who were able to return for repeat evaluation, with descriptive findings reported.

Statistical analysis

Statistical analyses were performed using SAS version 9.4 (SAS Institute). Effect of sex on each echocardiographic variable was assessed using 2 sample *t* tests. A *P* value of < 0.05 was considered significant. Normal echocardiographic values were computed using the Reference Value Advisor v. 2.1,²⁰ with the

nonparametric method utilized for all measurements. A linear regression model was used to explore whether an allometric relationship existed between body weight and individual echocardiographic measurements. For echocardiographic variables influenced by body weight, allometric scaling was performed as previously described.^{18,21,22} In the allometric equation ($y = ax^b$), y is the response variable (echocardiographic measurement), a is the proportionality constant, x is body weight, and b is the scaling exponent.

Predicted values and 95% prediction intervals were derived from the allometric relationship between echocardiographic variables and body weight.

Results

The entire study sample consisted of 146 Borzoi, with 86 females (5 spayed) and 60 males (5 neutered). The mean age was 3.9 ± 2.5 years, and the mean body weight was 33.6 ± 5.5 kg. The structurally

Table 1—Effect of sex on echocardiographic measurements in Borzoi dogs.

Measurement	Female	Male	P value
Body weight (kg)	30.4 (3.8)	38.3 (4.1)	< .001
Doppler			
AV V_{max} (m/s)	1.45 (0.31)	1.48 (0.26)	.580
PV V_{max} (m/s)	1.09 (0.23)	1.10 (0.24)	.822
IVRT (ms)	78.43 (12.21)	81.76 (11.52)	.140
Peak E (m/s)	0.69 (0.13)	0.69 (0.14)	.836
E-deceleration time (ms)	136.08 (32.17)	142.49 (30.64)	.282
Peak A (m/s)	0.53 (0.15)	0.50 (0.11)	.173
E' (m/s)	0.14 (0.03)	0.15 (0.04)	.052
A' (m/s)	0.10 (0.03)	0.11 (0.03)	.740
S' (m/s)	0.17 (0.03)	0.19 (0.04)	.018
M-mode			
IVSd (cm)	0.99 (0.12)	1.09 (0.13)	< .001
LVIDd (cm)	4.32 (0.30)	4.52 (0.30)	.001
LVPWd (cm)	1.03 (0.14)	1.13 (0.14)	< .001
IVSs (cm)	1.37 (0.18)	1.44 (0.20)	.047
LVIDs (cm)	3.15 (0.28)	3.30 (0.28)	.006
LVPWs (cm)	1.47 (0.19)	1.54 (0.21)	.049
Fractional shortening (%)	27.23 (3.49)	27.15 (3.59)	.904
EPSS (cm)	0.54 (0.17)	0.53 (0.11)	.572
TAPSE (cm)	1.41 (0.22)	1.57 (0.27)	.001
2-D			
IVSd (cm)	1.04 (0.14)	1.12 (0.12)	.002
LVIDd (cm)	4.34 (0.30)	4.56 (0.32)	< .001
LVPWd (cm)	1.09 (0.13)	1.17 (0.12)	.001
IVSs (cm)	1.34 (0.19)	1.46 (0.17)	.001
LVIDs (cm)	3.22 (0.30)	3.36 (0.30)	.018
LVPWs (cm)	1.44 (0.18)	1.56 (0.16)	.000
Fractional shortening (%)	25.79 (3.65)	26.32 (3.45)	.433
LV major (cm)	7.79 (0.48)	8.36 (0.55)	< .001
RVIDd (cm)	1.63 (0.29)	1.77 (0.27)	.013
AV cusp (long axis) (cm)	2.13 (0.20)	2.28 (0.23)	< .001
LA major (cm)	4.12 (0.36)	4.39 (0.40)	< .001
Ao diameter (short axis) (cm)	2.40 (0.19)	2.59 (0.23)	< .001
LA diameter (short axis) (cm)	3.02 (0.30)	3.26 (0.30)	< .001
LA:Ao (short axis)	1.26 (0.11)	1.26 (0.09)	.904
LV EDV (ml)	69.05 (16.06)	85.40 (19.07)	< .001
Indexed LV EDV (ml/kg)	2.39 (0.58)	2.25 (0.51)	.600
LV ESV (ml)	28.53 (9.04)	34.40 (12.25)	.003
Indexed LV ESV (ml/kg)	0.95 (0.32)	0.91 (0.33)	.485
Ejection fraction SMOD (%)	59.22 (6.47)	60.46 (8.93)	.383
LA area 2 chamber (cm ²)	11.17 (1.87)	12.66 (2.03)	< .001
LA area 4 chamber (cm ²)	11.56 (1.79)	13.45 (2.22)	< .001
LA length 4 chamber (cm)	3.58 (0.38)	3.93 (0.42)	< .001
LA volume (ml)	30.81 (6.60)	36.87 (9.42)	< .001
Indexed LA volume (ml/kg)	1.02 (0.22)	0.96 (0.22)	.175

Values reported as mean (SD). A = Peak late diastolic transmitral flow velocity. A' = Peak late diastolic relaxation velocity of the lateral mitral annulus with tissue Doppler. Ao = Aorta. AV = Aortic valve. E = Peak early diastolic transmitral flow velocity. E' = Peak early-diastolic relaxation velocity of the lateral mitral annulus with tissue Doppler. EDV = End-diastolic volume. ESV = End-systolic volume. EPSS = E-point to septal separation. IVSd = Interventricular septal diameter at end diastole. IVSs = Interventricular septal diameter at end systole. IVRT = Isovolumic relaxation time. LA = Left atrium. LV = Left ventricle. LVIDd = Left ventricular internal diameter at end diastole. LVIDs = Left ventricular internal diameter at end systole. LVPWd = Left ventricular posterior wall at end diastole. LVPWs = Left ventricular posterior wall at end systole. PV = Pulmonic valve. RVIDd = Right ventricular internal diameter at end diastole. S' = Peak systolic relaxation velocity of the lateral mitral annulus with tissue Doppler. SMOD = Simpson's method of discs. TAPSE = Tricuspid annular plane systolic excursion. V_{max} = Maximum velocity.

normal study sample consisted of 119 Borzoi. There were 72 females (5 spayed) and 47 males (2 neutered). Females weighed significantly less than males (30.4 ± 3.8 kg versus 38.3 ± 4.1 kg, respectively; $P < .001$). The mean age of the structurally normal sample was 3.5 ± 2.3 years.

Heart murmurs were identified in 86/146 dogs (58.9%). All identified heart murmurs were systolic, with 26 considered grade 1, 55 as grade 2, 4 as grade 3, and 1 as grade 5. No dogs had gallop sounds identified.

Most Borzoi were structurally normal (119/146, 81.5%), with 64 normal dogs (53.8% of the structurally normal population) having a heart murmur identified. Thirty-six structurally normal dogs had trace or mild mitral regurgitation (30.2% of normal dogs) and 43 had trace or mild tricuspid regurgitation

(36.1% of normal dogs). Structural cardiac disease was identified in 21 dogs (14.4%), including 9 dogs (6.2%) with DCM (**Supplementary Video S1**) and 9 dogs (6.2%) with stage B1 MMVD. The mean age of dogs with DCM was 5.7 ± 2.3 years and 8/9 dogs were male. Seven dogs with DCM were eating a diet that met World Small Animal Veterinary Association Global Nutrition Guidelines²³ and 2 were not. The mean age of dogs with MMVD was 7.6 ± 3.0 years, and 8/9 dogs were female. Only 2/9 dogs with DCM had concurrent LV diastolic dilation based on left-ventricular end-diastolic diameter normalized to body weight exceeding the upper 97.5 percentile prediction interval from published non-breed-specific reference intervals.¹⁸ Three dogs (2%) had congenital heart disease (2 with tricuspid valve dysplasia and

Table 2—The relationship between body weight and echocardiographic measurements in Borzoi dogs.

Measurement	Slope	SE of the slope	Slope P value	Intercept	SE of the intercept	R ²
Doppler						
AV V _{max}	0.145	0.116	.215	-0.063	0.177	0.013
PV V _{max}	0.013	0.118	.916	0.011	0.179	0.000
IVRT	0.082	0.089	.357	1.772	0.135	0.007
Peak E	-0.020	0.109	.857	-0.141	0.165	0.000
E-deceleration time	0.146	0.127	.254	1.910	0.193	0.011
Peak A	-0.022	0.144	.879	-0.267	0.219	0.000
E'	0.056	0.139	.687	-0.930	0.211	0.001
A'	-0.029	0.150	.845	-0.949	0.228	0.000
S'	0.263	0.130	.046	-1.164	0.198	0.035
M-mode						
IVSd	0.386	0.067	< .001	-0.577	0.102	0.223
LVIDd	0.193	0.037	< .001	0.349	0.056	0.192
LVPWd	0.475	0.069	< .001	-0.699	0.104	0.295
IVSs	0.234	0.074	.002	-0.213	0.112	0.081
LVIDs	0.164	0.050	.001	0.256	0.076	0.085
LVPWs	0.366	0.072	< .001	-0.386	0.110	0.183
Fractional shortening	0.074	0.072	.306	1.319	0.109	0.009
EPSS	-0.122	0.151	.424	-0.102	0.231	0.006
TAPSE	0.406	0.092	< .001	-0.456	0.140	0.143
2-D						
IVSd	0.262	0.071	< .001	-0.371	0.107	0.107
LVIDd	0.195	0.039	< .001	0.349	0.059	0.181
LVPWd	0.375	0.060	< .001	-0.525	0.091	0.256
IVSs	0.326	0.079	< .001	-0.360	0.120	0.130
LVIDs	0.167	0.053	.002	0.260	0.080	0.080
LVPWs	0.388	0.061	< .001	-0.421	0.092	0.263
Fractional shortening	0.078	0.077	.312	1.292	0.117	0.009
LV major	0.218	0.036	< .001	0.572	0.055	0.237
RVIDd	0.170	0.107	.116	-0.039	0.163	0.022
AV cusp (long axis)	0.240	0.054	< .001	-0.028	0.083	0.145
LA major	0.310	0.045	< .001	0.152	0.068	0.295
Ao diameter (short axis)	0.225	0.048	< .001	0.050	0.072	0.163
LA diameter (short axis)	0.246	0.056	< .001	0.117	0.085	0.144
LA:Ao	0.020	0.048	.676	0.069	0.073	0.002
LV EDV	0.529	0.144	< .001	1.060	0.220	0.103
Indexed LV EDV (ml/kg)	-0.471	0.144	.001	1.060	0.220	0.084
LV ESV	0.361	0.222	.107	0.910	0.338	0.022
Indexed LV ESV (ml/kg)	-0.639	0.222	.005	0.910	0.338	0.066
Ejection fraction SMOD	0.081	0.068	.236	1.650	0.103	0.012
LA area 2 chamber	0.500	0.091	< .001	0.304	0.139	0.207
LA area 4 chamber	0.581	0.082	< .001	0.201	0.125	0.303
LA length 4 chamber	0.373	0.056	< .001	0.000	0.086	0.277
LA volume	0.687	0.123	< .001	0.465	0.187	0.216
Indexed LA volume (ml/kg)	-0.292	0.127	.023	0.432	0.193	0.044

Slope represents the scaling exponent in the allometric equation $y = axb$.

See Table 1 for remainder of key.

1 with mild pulmonic stenosis). Seven dogs had equivocal diagnoses (4.8%), including 2 dogs with equivocal subaortic/aortic stenosis, 2 dogs with equivocal DCM (1 being the same dog who was also diagnosed with mild pulmonic stenosis), 1 dog with equivocal MMVD, and 2 dogs with equivocal mitral valve dysplasia versus MMVD.

Statistical analyses were performed on the sample of 119 structurally normal Borzoi. Sex had a significant effect on nearly all 2-D and M-mode assessments of heart size but not calculated assessments of heart function such as FS or EF, as expected (Table 1). Doppler measurements were not significantly different based on sex with the exception of S'.

The relationship between echocardiographic measurements and body weight was assessed (Table 2). While the relationship between many of the echocardiographic measurements and body weight was statistically significant, the corresponding R^2 values were low. Given the significant sex-based differences and the significant difference in body weight between males and females, normal echocardiographic values were generated independently for male (Table 3) and female (Table 4) Borzoi. For ease of use during DCM screening assessments, particularly for dogs at the upper or lower end of expected body weight for the breed, predicted values and 95% prediction intervals were derived for the following

Table 3—Echocardiographic values for normal male Borzoi.

Measurement	Mean ± SD	Lower male Borzoi RI	90% CI of lower RI	Upper male Borzoi RI	90% CI of upper RI
Doppler					
AV V _{max} (m/s)	1.48 ± 0.26	0.85	0.80–1.09	2.07	1.84–2.13
PV V _{max} (m/s)	1.10 ± 0.24	0.61	0.59–0.80	1.92	1.35–2.00
IVRT (ms)	81.76 ± 11.52	52.14	49.47–65.84	106.75	98.95–107.27
Peak E (m/s)	0.69 ± 0.14	0.43	0.43–0.49	1.11	0.87–1.16
E-deceleration time (ms)	142.49 ± 30.64	84.75	82.83–106.67	237.19	193.46–247.59
Peak A (m/s)	0.50 ± 0.11	0.32	0.32–0.36	0.72	0.68–0.73
E' (m/s)	0.15 ± 0.04	0.08	0.08–0.09	0.28	0.21–0.29
A' (m/s)	0.11 ± 0.03	0.04	0.04–0.07	0.18	0.16–0.18
S' (m/s)	0.19 ± 0.04	0.07	0.06–0.12	0.28	0.24–0.29
M-mode					
IVSd (cm)	1.09 ± 0.13	0.83	0.82–0.90	1.33	1.29–1.33
LVIDd (cm)	4.52 ± 0.30	3.87	3.83–4.08	5.12	5.05–5.12
LVPWd (cm)	1.13 ± 0.14	0.88	0.87–0.94	1.49	1.38–1.51
IVSs (cm)	1.44 ± 0.20	1.05	1.03–1.22	2.08	1.75–2.13
LVIDs (cm)	3.30 ± 0.28	2.65	2.64–2.89	3.83	3.70–3.83
LVPWs (cm)	1.54 ± 0.21	1.03	1.00–1.24	2.11	1.80–2.12
Fractional shortening (%)	27.15 ± 3.59	20.85	20.68–22.69	35.95	33.69–36.22
EPSS (cm)	0.53 ± 0.11	0.34	0.33–0.36	0.77	0.70–0.77
TAPSE (cm)	1.57 ± 0.27	0.98	0.96–1.12	2.24	2.05–2.26
2-D					
IVSd (cm)	1.12 ± 0.12	0.89	0.88–0.93	1.34	1.29–1.34
LVIDd (cm)	4.56 ± 0.32	3.85	3.80–4.15	5.37	5.09–5.39
LVPWd (cm)	1.17 ± 0.12	0.92	0.91–1.00	1.49	1.34–1.49
IVSs (cm)	1.46 ± 0.17	1.04	1.02–1.17	1.81	1.68–1.84
LVIDs (cm)	3.36 ± 0.30	2.67	2.66–2.80	4.00	3.87–4.02
LVPWs (cm)	1.56 ± 0.16	1.28	1.28–1.35	1.97	1.80–2.00
Fractional shortening (%)	26.32 ± 3.45	19.91	19.83–21.54	34.53	32.09–34.65
LV major (cm)	8.36 ± 0.55	7.09	7.03–7.48	9.48	9.11–9.51
RVIDd (cm)	1.77 ± 0.27	1.23	1.23–1.31	2.14	2.11–2.14
AV cusp (long axis) (cm)	2.28 ± 0.23	1.85	1.84–1.91	2.73	2.65–2.73
LA major (cm)	4.39 ± 0.40	3.62	3.59–3.80	5.21	5.07–5.22
Ao diameter (short axis) (cm)	2.59 ± 0.23	2.16	2.15–2.30	3.19	2.99–3.21
LA diameter (short axis) (cm)	3.26 ± 0.30	2.54	2.51–2.72	3.76	3.68–3.77
LA:Ao (short axis)	1.26 ± 0.09	1.10	1.09–1.12	1.44	1.42–1.44
LV EDV (ml)	85.40 ± 19.07	43.76	42.04–58.02	126.84	113.71–129.36
Indexed LV EDV (ml/kg)	2.25 ± 0.51	1.16	1.16–1.45	3.33	3.05–3.33
LV ESV (ml)	34.40 ± 12.25	11.63	11.52–13.47	59.82	51.16–61.24
Indexed LV ESV (ml/kg)	0.91 ± 0.33	0.30	0.30–0.33	1.55	1.39–1.58
Ejection fraction SMOD (%)	60.46 ± 8.93	47.95	47.75–49.99	83.95	79.33–84.43
LA area 2 chamber (cm ²)	12.66 ± 2.03	7.83	7.49–9.71	19.11	15.58–19.52
LA area 4 chamber (cm ²)	13.45 ± 2.22	9.97	9.97–10.29	19.16	17.17–19.54
LA length 4 chamber (cm)	3.93 ± 0.42	3.15	3.13–3.38	5.04	4.66–5.07
LA volume (ml)	36.87 ± 9.42	21.32	20.60–26.35	68.62	51.34–69.55
Indexed LA volume (ml/kg)	0.96 ± 0.22	0.58	0.58–0.71	1.79	1.16–1.83

Measurements are presented as mean ± SD, with preliminary reference intervals and 90% confidence intervals of the lower and upper preliminary reference intervals provided.

RI = Reference interval.

See Table 1 for remainder of key.

Table 4—Echocardiographic values for normal female Borzoi.

Measurement	Mean ± SD	Lower female Borzoi RI	90% CI of lower RI	Upper female Borzoi RI	90% CI of upper RI
Doppler					
AV V _{max} (m/s)	1.45 ± 0.31	0.90	0.83–1.00	2.09	1.97–2.11
PV V _{max} (m/s)	1.09 ± 0.23	0.74	0.71–0.79	1.68	1.45–1.79
IVRT (ms)	78.43 ± 12.21	51.44	49.48–57.96	99.31	97.46–102.76
Peak E (m/s)	0.69 ± 0.13	0.48	0.47–0.50	1.03	0.90–1.07
E-deceleration time (ms)	136.08 ± 32.17	76.94	75.77–91.71	231.95	184.33–236.05
Peak A (m/s)	0.53 ± 0.15	0.29	0.26–0.34	0.91	0.79–1.07
E' (m/s)	0.14 ± 0.03	0.09	0.08–0.10	0.20	0.19–0.21
A' (m/s)	0.10 ± 0.03	0.06	0.06–0.07	0.18	0.15–0.21
S' (m/s)	0.17 ± 0.03	0.10	0.10–0.12	0.25	0.23–0.25
M-mode					
IVSd (cm)	0.99 ± 0.12	0.71	0.67–0.78	1.24	1.18–1.25
LVIDd (cm)	4.32 ± 0.30	3.70	3.60–3.84	5.06	4.78–5.08
LVPWd (cm)	1.03 ± 0.14	0.71	0.68–0.81	1.33	1.28–1.35
IVSs (cm)	1.37 ± 0.18	1.05	0.99–1.08	1.80	1.65–1.80
LVIDs (cm)	3.15 ± 0.28	2.46	2.27–2.68	3.75	3.52–3.77
LVPWs (cm)	1.47 ± 0.19	1.08	0.96–1.14	1.84	1.77–1.84
Fractional shortening (%)	27.23 ± 3.49	21.12	20.94–22.17	36.61	34.05–36.78
EPSS (cm)	0.54 ± 0.17	0.30	0.28–0.33	1.07	0.76–1.45
TAPSE (cm)	1.41 ± 0.22	0.96	0.89–1.06	1.87	1.76–1.93
2-D					
IVSd (cm)	1.04 ± 0.14	0.79	0.77–0.82	1.29	1.26–1.31
LVIDd (cm)	4.34 ± 0.30	3.56	3.42–3.91	4.96	4.79–5.02
LVPWd (cm)	1.09 ± 0.13	0.79	0.79–0.88	1.35	1.31–1.36
IVSs (cm)	1.34 ± 0.19	0.90	0.78–1.04	1.69	1.63–1.71
LVIDs (cm)	3.22 ± 0.30	2.53	2.21–2.69	3.75	3.61–3.80
LVPWs (cm)	1.44 ± 0.18	1.06	1.03–1.14	1.87	1.72–1.93
Fractional shortening (%)	25.79 ± 3.65	20.17	19.55–20.92	35.40	33.06–35.42
LV major (cm)	7.79 ± 0.48	6.57	6.47–6.99	8.68	8.46–8.78
RVIDd (cm)	1.63 ± 0.29	0.88	0.84–1.23	2.25	2.07–2.31
AV cusp (long axis) (cm)	2.13 ± 0.20	1.74	1.68–1.79	2.56	2.43–2.59
LA major (cm)	4.12 ± 0.36	3.44	3.26–3.60	4.85	4.73–4.92
Ao diameter (short axis) (cm)	2.40 ± 0.19	2.05	2.00–2.13	2.80	2.72–2.80
LA diameter (short axis) (cm)	3.02 ± 0.30	2.37	2.32–2.55	3.49	3.45–3.51
LA:Ao (short axis)	1.26 ± 0.11	1.06	1.01–1.11	1.51	1.44–1.52
EDV (ml)	69.05 ± 16.06	35.26	35.03–39.86	97.17	94.01–101.06
Indexed EDV (ml/kg)	2.39 ± 0.58	1.10	1.08–1.25	3.42	3.04–3.55
ESV (ml)	28.53 ± 9.04	10.72	8.17–47.61	47.61	41.72–52.61
Indexed ESV (ml/kg)	0.95 ± 0.32	0.36	0.27–0.47	1.60	1.44–1.61
Ejection fraction SMOD (%)	59.22 ± 6.47	50.02	47.94–51.57	76.80	70.23–77.32
LA area 2 chamber (cm ²)	11.17 ± 1.87	7.79	6.81–8.13	15.07	14.19–15.09
LA area 4 chamber (cm ²)	11.56 ± 1.79	8.20	7.92–9.13	16.29	14.93–17.07
LA length 4 chamber (cm)	3.58 ± 0.38	2.90	2.76–3.06	4.32	4.20–4.50
LA volume (ml)	30.81 ± 6.60	18.75	17.60–20.77	45.92	42.81–47.31
Indexed LA volume (ml/kg)	1.02 ± 0.22	0.56	0.51–0.69	1.52	1.41–1.59

Measurements are presented as mean ± SD, with preliminary reference intervals and 90% CI of the lower and upper preliminary reference intervals provided.

See Table 1 for remainder of key.

measurements across a body weight range of 24 to 48 kg: LVIDd, LVIDs, EDV, and ESV (**Table 5**).

Twenty-five dogs had longitudinal examinations within a recheck period ranging from 1 to 2.5 years. Three dogs developed occult DCM (1 who was originally diagnosed with equivocal DCM and 2 that were originally normal), 1 dog transitioned from normal to an equivocal DCM diagnosis, and 2 dogs developed stage B1 MMVD. Two dogs with DCM (1 occult and 1 equivocal) had normalized echocardiographic measurements when reevaluated 10 to 11 months after diet change from a diet that did not meet World Small Animal Veterinary Association Global Nutrition Guidelines to 1 that did. Longitudinal follow-up was also available in 4 other dogs diagnosed

with occult DCM. Each of these dogs was started on pimobendan and an angiotensin-converting enzyme inhibitor. One dog had progressive LV dilation and systolic dysfunction despite medications, while the other 3 had variable degrees of improvement in LV end-systolic dimensions and indices of systolic function after starting medication. All 4 had ventricular arrhythmias, with sotalol therapy initiated in 3 of 4 due to arrhythmia severity. Eight dogs that had trace or mild mitral and/or tricuspid regurgitation identified on their initial echocardiogram had a longitudinal examination, with no progression in their valvular regurgitation at the time of their second examination. Three dogs experienced sudden death during the follow-up period. All were clinically healthy

Table 5—Predicted values and 95% prediction intervals for linear and volumetric measurements of left ventricular size in Borzoi ranging in weight from 24 to 48 kg.

Body weight (kg)	M-mode LVIDd (cm)	M-mode LVIDs (cm)	2-D LVIDd (cm)	2-D LVIDs (cm)	LV EDV (ml)	LV ESV (ml)
24	4.13 (3.62–4.70)	3.03 (2.54–3.62)	4.15 (3.62–4.75)	3.09 (2.56–3.73)	61.60 (36.83–103.00)	25.62 (11.60– 56.56)
26	4.19 (3.68–4.77)	3.07 (2.58–3.66)	4.21 (3.68–4.82)	3.13 (2.60–3.77)	64.25 (38.56–107.06)	26.37 (12.01–57.90)
28	4.25 (3.74–4.84)	3.11 (2.61–3.70)	4.27 (3.73–4.89)	3.17 (2.64–3.82)	66.82 (40.20–111.07)	27.08 (12.38–59.24)
30	4.31 (3.79–4.90)	3.14 (2.64–3.74)	4.33 (3.79–4.95)	3.21 (2.67–3.86)	69.30 (41.76–115.03)	27.77 (12.72–60.60)
32	4.36 (3.84–4.96)	3.18 (2.67–3.78)	4.38 (3.83–5.02)	3.24 (2.70–3.90)	71.71 (43.23–118.94)	28.42 (13.04–61.96)
34	4.41 (3.88–5.02)	3.21 (2.70–3.82)	4.44 (3.88–5.07)	3.28 (2.73–3.94)	74.05 (44.64–122.81)	29.05 (13.32–63.33)
36	4.46 (3.92–5.08)	3.24 (2.72–3.86)	4.49 (3.92–5.13)	3.31 (2.75–3.98)	76.32 (45.99–126.64)	29.65 (13.59–64.70)
38	4.51 (3.96–5.13)	3.27 (2.74–3.89)	4.53 (3.96–5.19)	3.34 (2.78–4.02)	78.53 (47.28–130.44)	30.24 (13.84–66.07)
40	4.56 (4.00–5.18)	3.29 (2.77–3.92)	4.58 (4.00–5.24)	3.37 (2.80–4.05)	80.69 (48.51–134.21)	30.80 (14.07–67.45)
42	4.60 (4.04–5.23)	3.32 (2.79–3.96)	4.62 (4.04–5.29)	3.40 (2.82–4.09)	82.80 (49.70–137.94)	31.35 (14.28–68.82)
44	4.64 (4.07–5.29)	3.35 (2.81–3.99)	4.676 (4.07–5.35)	3.42 (2.84–4.12)	84.86 (50.84–141.65)	31.88 (14.48–70.20)
46	4.68 (4.11–5.33)	3.37 (2.82–4.02)	4.71 (4.10–5.40)	3.45 (2.86–4.16)	86.88 (51.93–145.34)	32.40 (14.67–71.57)
48	4.72 (4.14–5.38)	3.39 (2.84–4.05)	4.75 (4.14–5.44)	3.47 (2.88–4.19)	88.85 (52.99–149.00)	32.90 (14.84–71.57)

See Table 1 for remainder of key.

before the sudden death, and 2 were observed a few minutes before the event and confirmed normal. One of these was a 5.5-year-old intact male who had a necropsy with no abnormal findings and had been structurally normal on the echocardiogram 1.2 years prior. The other was a 5.5-year-old intact female who had a ruptured right auricular hemangiosarcoma identified on necropsy. No tumor had been found when the dog had an echocardiogram as part of the study 2.2 years prior. The third dog, an 8.8-year-old intact male, died in his sleep, having been seen by the owner 2 hours prior when he laid down to nap. A necropsy was not performed. This dog had been equivocal for early MMVD versus mitral valve dysplasia on the study echocardiogram 2.5 years before his death.

Discussion

Normal echocardiographic reference ranges are known to vary in different breeds of dogs, particularly when comparing sighthound breeds to nonsighthound breeds. Before the present study, breed-specific echocardiographic values for the Borzoi breed had not been reported. While the total population of normal Borzoi dogs used for generation of normal echocardiographic values nearly met an “ideal” sample size of 120 subjects or more²⁰ (n = 119 in this study), given the significant difference in body weight between male and female Borzoi and the resulting differences in echocardiographic measurements between sexes, it was pertinent to provide separate values for each sex. This resulted in smaller individual sample sizes used to generate the sex-specific echocardiographic values, with 72 females and 47 males making up each sample. Given the inherent homogeneity in a sample that includes a single sex of a single dog breed, however, a smaller sample size can reasonably be used to generate normal values. All echocardiographic values presented here attained “green” status from the open-source application that was used,²⁰ signifying they met recommended standards set forth by the Clinical and Laboratory Standards Institute for development of reference intervals. As such, these

Borzoi-specific echocardiographic values can now be utilized to improve echocardiographic evaluation and cardiac screening in the breed.

From an acquired cardiac disease perspective, both MMVD and DCM were identified in clinically healthy Borzoi dogs at similar rates. Of note, all Borzoi with MMVD had the earliest stage of the disease (stage B1), with no MMVD dogs in which longitudinal examinations were performed progressing to more advanced MMVD stages. The predominance of stage B1 MMVD may relate to the relatively younger age of the present sample population, or it may be consistent with a low likelihood of advanced MMVD developing in the breed. A multicenter, retrospective study¹ of Borzoi presenting to veterinary cardiologists for evaluation was similar in identifying almost exclusively stage B1 MMVD. Interestingly, there was also an increased number of females diagnosed with MMVD compared to males in the prior retrospective study¹ (75% female) as well as in the study presented here (89% female).

Borzoi with DCM were initially diagnosed based on non-breed-specific cut-offs at the time of study enrollment. After Borzoi-specific echocardiographic values were able to be generated, all dogs with an initial DCM diagnosis were compared against breed-specific data to confirm that diagnostic criteria for DCM were still met and in all 9 dogs they were. Interestingly, Borzoi-specific values for ESV indexed to body weight were lower (0.36 to 1.60 ml/kg for females and 0.30 to 1.55 ml/kg for males) than reference intervals proposed for sighthound breeds in general (0.82 to 2.11 ml/kg).³ The reason for this difference compared to other sighthound breeds is unknown; however, it underscores the importance of relying upon breed-specific echocardiographic data for Borzoi rather than general sighthound breed data.

Also of interest, only 2/9 Borzoi diagnosed with DCM met the criteria for diastolic dilation of the left ventricle based on non-breed-specific cut-offs. When breed-specific criteria were applied, the same 2 Borzoi continued to demonstrate left ventricular diastolic dilation, with 2 additional Borzoi being very slightly above (0.2 to 0.3 mm) the upper reference interval for M-mode measurements of left ventricular

diameter at end diastole but within normal limits for equivalent 2-D measurements. On the whole, this suggests that many Borzoi with DCM might better be defined as hypokinetic nondilated cardiomyopathy (HNDC), as proposed by the European Society of Cardiology.²⁴ This distinction was made to better distinguish individuals with systolic dysfunction that do not have concurrent diastolic dilation of the left ventricle from those that do, as diastolic left ventricular dilation is required in humans to warrant a DCM diagnosis.²⁴ While HNDC may simply represent an earlier stage of DCM, increasing evidence in humans suggests a difference in the likelihood of specific genetic mutations associated with HNDC compared to DCM, as well as differences with regard to the likelihood of left ventricular reverse remodeling with treatment and overall prognosis.^{25,26} Interestingly, 3 of 4 Borzoi with occult DCM that had longitudinal follow-up after pimobendan was initiated demonstrated improvement in left ventricular end-systolic dimensions. This was similar to reverse remodeling reported in some Doberman Pinschers with occult DCM after receiving pimobendan, with Dobermans who reverse remodeled having a significant hazard reduction for reaching primary study endpoints.²⁷ In veterinary medicine, a distinction between HNDC and DCM is not currently made. As clinical and genetic DCM research progresses; however, it may prove clinically useful to begin to consider these 2 populations separately in veterinary medicine as well.

Previously published retrospective data showed that trace or mild atrioventricular (AV) valve regurgitations were relatively common in normal Borzoi dogs, potentially falling within the spectrum of normal for the breed.¹ The present prospective data support that idea, with 30.2% of normal Borzoi having trace or mild mitral regurgitation and 36.1% of normal Borzoi having trace or mild tricuspid regurgitation. Similarly, a recent study²² in normal Leonberger dogs reported 45% of the population had trace or mild mitral regurgitation. It is possible that breed-specific differences play a role in the prevalence of minor AV valve regurgitations in otherwise normal hearts. Another important factor to consider is the continual, on-going advancement in ultrasound technology, which may allow for detection of color Doppler abnormalities that would have previously gone unrecognized. In people with structurally normal hearts, over 80% of individuals across all age groups are reported to have tricuspid regurgitation, while 34% of people aged 10 to 19 years, 56% of people aged 20 to 29 years, and 60% to 70% of people aged 30 years or more have documented mitral regurgitation.²⁸ Similar data for dogs are lacking, with the exception of a study²⁹ from 1994 in 20 healthy research Beagles between 7 and 18 months of age, in which 15% were found to have mitral regurgitation and none had tricuspid regurgitation. A similar study⁹ in a broader population of dogs with current ultrasound technology is needed to better define the amount of AV valve regurgitation that should be considered within the realm of normal in the absence of anatomic abnormalities of

the associated valve(s). Currently, it is common for dogs with trace or mild AV valve regurgitations to be excluded from “normal” populations. For example, 17% of evaluated North American Salukis were excluded from contributing to reference intervals in their breed due to trace to mild mitral regurgitation, with another 11% excluded for mild tricuspid regurgitation.⁹ This approach may warrant reconsideration in select breeds. Furthermore, in the setting of cardiac screening in breeding animals, broader recognition of trace to mild AV valve regurgitations being within the realm of normal in the absence of obvious anatomic valvular abnormalities is needed, particularly in breeds like the Borzoi to avoid overdiagnosis of AV valve dysplasia.

The prevalence of heart murmurs in otherwise normal Borzoi was also high, with 53.8% of structurally normal Borzoi in the present study having a documented murmur. In the absence of structural disease, these murmurs were considered physiologic or benign “flow” murmurs. This is consistent with studies^{30–32} in other sighthound breeds, where physiologic heart murmurs are also commonly reported. From a cardiac screening perspective, the high frequency of heart murmurs in normal Borzoi indicates that screening of breeding Borzoi by auscultation alone is likely to be unrewarding, with an echocardiogram required to confirm the nature of the murmur in many cases.

This study has several limitations, including the development of normal breed-specific echocardiographic values from a single center, with only 2 cardiologists performing echocardiographic measurements. Inclusion of data across multiple centers and a larger number of observers may have provided a more robust set of reference intervals; however, this was not feasible at the time of the study. Ideally, the data generated from this study should be externally validated prior to accepting these echocardiographic values as breed standard reference intervals. Additionally, approximately half of the population was recruited from breeders in relatively close geographic proximity to the author’s institution, while the other half was representative of Borzoi from breeders across the United States. An influence of locally overrepresented genetics on the reference intervals cannot entirely be excluded but is considered unlikely to be meaningful given the homogeneity and relatively small gene pool of this unusual breed. Finally, the distinction between mild forms of AV valve dysplasia, early degenerative change, and normal variation remains incredibly difficult when assessing an individual dog at a single time point. There is inevitable potential for overlapping diagnoses of these 3 possibilities when dogs are evaluated by different observers. Although a longer period of longitudinal assessment may have improved confidence in identifying the etiologic origin of minor AV valve regurgitations, definitive distinction remains difficult to impossible without gross anatomic and histopathologic assessment. A lack of advanced MMVD cases along with an absence of progression in the dogs with trace to mild AV valve regurgitation

that had a longitudinal evaluation suggests that these minor leaks, regardless of etiology, may be clinically inconsequential for the breed.

In conclusion, breed-specific echocardiographic reference intervals have been proposed for Borzoi dogs. Trace to mild AV valve regurgitations and physiologic murmurs were commonly appreciated in the breed. Both MMVD and DCM were recognized in this population of healthy Borzoi at similar rates, although all Borzoi with MMVD had the earliest stage of the disease with no heart enlargement (stage B1). Screening for DCM may be clinically relevant in the breed.

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Supplementary Materials

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