Echocardiographic evaluation of changes in left ventricular size and valvular regurgitation associated with physical training during and after maturity in Standardbred trotters

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Objective—To assess whether physical training induces cardiac hypertrophy and valvular regurgitation in maturing Standardbred trotters and to establish a prediction model for the size of the left ventricle.

Design—Longitudinal observational study.

Animals—53 Standardbred trotters.

Procedures—Each horse underwent 2-D, M-mode, and color flow Doppler echocardiography at 5.5 years of age; previously, each horse had been examined at 2, 2.5, 3, and 3.5 (time of maturity) years of age. Horses were or were not in training or racing for variable periods during the entire assessment period; data for a given horse were assigned to 1 of 2 groups on the basis of the horse's status at the fifth examination (racing [n = 40] or not racing [13]). At each examination, left ventricular (LV) internal diameter in diastole (LVIDd), LV mass, and mean and relative LV wall thicknesses were measured. Prevalence and severity of tricuspid, pulmonary, mitral, and aortic valve regurgitation were determined.

Results—During the assessment period, LVIDd, LV mass, and mean LV wall thickness increased; body weight was significantly associated with those variables. Prediction of LV mass was possible when sex and weight were included in the model. Prevalence of valvular regurgitation increased for all valves. An increased risk of development of tricuspid and pulmonary valve regurgitation for horses in racing was observed.

Conclusions and Clinical Relevance—The LV mass and prevalence of valvular regurgitation increased (indicative of development of exercise-induced cardiac hypertrophy and valvular regurgitation) in young horses, even during the latter part of the assessment period, when maturity was attained. (*J Am Vet Med Assoc* 2012;240:205–212)

Cardiac hypertrophy due to long-term intense physical exercise in humans and other animals was first demonstrated more than a century ago as cited by Rost.[1] Presently, increased cardiac muscular mass is recognized as a physiologic phenomenon (termed athlete's heart) in human and equine athletes.[2–7]

As well as cardiac hypertrophy, human and equine athletes develop minor valvular regurgitation as a result of intensive athletic training, and these valvular regurgitations are also considered part of athlete's heart.[8–12] Although the size of the heart appears to strongly influence racing performance, with a positive correlation between racing performance and a large heart,[8,10,11,13] no studies have identified any influence of valvular regurgitation on racing performance in horses or humans, to our knowledge.

In young horses, it is difficult to determine whether the cardiac hypertrophy that develops is due to physical training or is caused by normal physiologic growth; to make that determination, evaluation of untrained horses and an age-matched control group would be required. We are aware of only 1 study,[14] which involved 2-year-old Standardbred trotters undergoing light training, that has included such a control group. A longitudinal study including young horses evaluated during and after attainment of maturity would enhance our understanding of mechanisms responsible for hypertrophy of the heart in horses. Previously, our group has described echocardiographic changes in 103 horses as they aged from 2 to 3.5 years in a 2-year longitudinal study[7,8]; each horse was examined (focusing on LV size and valvular regurgitation) on 4 occasions at 6-month intervals. Those studies[7,8] were terminated when the horses were considered to have just reached maturity at 3.5 years of

Abbreviations

CI	Confidence interval
IVSd	Interventricular septum thickness in diastole
LV	Left ventricular
LVFWd	Left ventricular free wall thickness in diastole
LVIDd	Left ventricular internal diameter in diastole
LV mass	Left ventricular muscle mass
MWT	Mean left ventricular wall thickness
OR	Odds ratio
RWT	Relative left ventricular wall thickness
SE_p	SE of parameter estimate

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age, but reexamination at an older age after maturity is warranted to establish the effect of training.

Therefore, the purpose of the study reported here was to further examine a group of Standardbred trotters that underwent training from 2 to 5.5 years of age and to test the hypothesis that physical training induces cardiac hypertrophy and valvular regurgitation in Standardbred trotters. Furthermore, we intended to establish a model by which it would be possible to predict cardiac size in Standardbred trotters that are 2 to 5.5 years old.

Materials and Methods

Horses—Of a group of 103 Standardbred trotters examined in a previous study,[7,8] 53 horses (28 mares, 18 geldings, and 7 stallions) underwent a follow-up examination 2 years later. These horses were therefore examined 5 times, at 2, 2.5, 3, 3.5, and 5.5 years of age. In the present study, all analyses were performed on the basis of the 53 horses participating in the final follow-up examination. The first examination was performed in 2001, and the fifth (final) examination was performed in 2004. All horses were born in 1999, and the mean ± SD age at the last examination was 5.5 ± 0.1 years. The owner or trainer gave informed consent for participation of their horse in the study, but because the clinical procedures performed on the animals were all noninvasive, no permission was required from the Danish Animal Experimentation Inspectorate. The horses were trained by various trainers and associated with several training yards.

Of the 103 horses that underwent the fourth examination in 2003, 23 had been slaughtered, 10 were retired from racing and used for riding purposes, 10 had become broodmares, 8 were sold and had been moved abroad, 49 were in race training, and 3 were temporarily out of training at the time of the fifth examination. The distribution of the 53 horses that underwent a fifth examination was 40 horses in racing and 13 horses not racing (8 broodmares, 2 used for riding purposes, and 3 horses temporarily out of training). The 13 horses that were not racing at the time of the fifth examination were all in training at the time of the fourth examination. For the 53 horses that underwent a fifth examination, 37 were racing at the time of the fourth examination. Fifty-two of the 53 horses had been racing between the fourth and fifth examinations. For purposes of the present study, data for the horses at each time point were divided into 2 groups according to the horses' status at the fifth examination (racing or not racing).

Registration of training status—Before each examination of each horse, the trainer completed a questionnaire regarding training status of the horse and whether the horse was participating in racing at the time of examination. Training was categorized as high or low grade. High-grade training included horses that fulfilled the following criteria: > 3 months training during the previous 6-month period with > 3 days of training/wk; horses either were in full training or had been untrained for ≤ 1 month at the time of the examination. Low-grade training included horses that fulfilled the following criteria: < 3 months training during the previous 6-month period with < 3 days of training/wk or untrained for > 1 month prior to the time of the examination as described previously.[7]

Clinical, ECG, and echocardiographic examinations—The examinations were performed with horses at rest at their training establishment or at racetracks. The same investigator (RB) performed all examinations. No tranquilizers were administered to conduct the examinations.

Body weight of each horse was indirectly determined via measurement of the thoracic girth circumference by use of a weight tape. Cardiac auscultation and ECG were performed as previously described.[7] Two-dimensional, M-mode, and color Doppler echocardiography were performed by use of a 1.5-MHz phased-arrayed sector transducer with harmonic imaging[a] at an imaging depth of 26 to 30 cm. A base-apex ECG tracing was superimposed for timing. An M-mode echocardiogram was obtained from a short-axis view of the left ventricle,[14] and 5 nonconsecutive cardiac cycles (5 frames) separated by at least 5 to 10 heartbeats were obtained and digitally stored for later analyses. Left ventricular internal diameter in systole, LVIDd, interventricular septum thickness in systole, IVSd, LV free wall thickness in systole, and LVFWd were measured from the stored images. Mean wall thickness, RWT, and LV mass were calculated by use of the following formulas[15]:

$$MWT = (LVFWd + IVSd)/2$$
$$RWT = (LVFWd + IVSd)/LVIDd$$
$$\text{LV mass} = 1.04 \times ([LVIDd + LVFWd + IVSd]^3 - LVIDd^3) - 13.6$$

These variables have been evaluated in horses echocardiographically and after necropsy, and the correlation between calculated echocardiographic values and heart weight was 0.8.[16]

Assessment of the repeatability of M-mode measurements—The intraobserver variation among M-mode measurements was determined before the fifth examination of the horses. Images obtained at the fourth examination in 2002 from 10 randomly chosen horses were selected, and the same investigator (RB) remeasured IVSd, LVIDd, and LVFWd in 2004. Five nonconsecutive cardiac cycles identical to the cycles measured in 2002 were chosen and examined in a blinded fashion with no information about the previous results obtained in 2002.

Following M-mode echocardiography, all 4 cardiac valves in each horse were examined by use of 2-D echocardiography and subsequently color flow Doppler echocardiography to detect and quantify tricuspid, pulmonary, mitral, and aortic valve regurgitation as previously described. If a regurgitant jet was present, 3 nonconsecutive images separated by at least 5 to 10 heartbeats were recorded and stored digitally for later analyses. For mitral and tricuspid valve regurgitation, 4 semiquantitative groups were defined on the basis of the area of the regurgitation jet in comparison with the approximated size of the atrium[17] and assigned a severity score, as follows: 1, very small jet (0% to 10% of the area of the atrium); 2, small jet (> 10% to 30%); 3, medium jet (> 30% to 50%); or 4, large jet (> 50%). For aortic and pulmonary valve regurgitation, the maximal

diameter (cm) of the regurgitant blood flow just below the aortic and pulmonary valves was measured.[18]

Statistical analysis—Descriptive analysis of echocardiographic results (LVIDd, LV mass, MWT, and RWT) and estimated body weight was performed by use of calculated mean and SD. The descriptive analysis of regurgitation of the tricuspid, mitral, pulmonary, and aortic valves was performed by means of frequency distributions, calculation of mean and SD for pulmonary and aortic valve regurgitation (continuous variables), and calculation of median and range for tricuspid and mitral valve regurgitation (categorical variables).

A general linear mixed model was used to estimate the variance components attributable to variation among horses, variation between the 2 measurements (measurement 1 obtained in 2002 and remeasurement performed in 2004 [measurement 2]), and residual variation (ie, within-measurement variation). Horse and measurement number (measured in either 2002 or 2004) were included as random effects in the analyses. The proportion of between-measurements variation in relation to the total measurement variation was calculated as between-measurement variation divided by the sum of the between- and within-measurement variations (r).

Long-term effects of estimated body weight, sex, racing status (yes or no), and examination number (1 through 5) on LVIDd, LV mass, and MWT were evaluated by means of repeated-measures ANOVA with a general linear mixed model. Sex, racing status (yes or no), and examination number were included as fixed effects. Estimated body weight was included as a fixed covariate. The autocorrelation between repeated measurements obtained for the same horse was accounted for by use of an autoregressive covariance structure. Two-way interactions between fixed effects (including estimated body weight) were included. Pairwise comparisons of categories within the same variables were performed for significant variables. Assumptions for use of the general linear mixed model were evaluated by means of visual inspection of residual plots (evaluating equal variances) and the Shapiro-Wilk test for normal distribution.

The association between risk of tricuspid, pulmonary, mitral, and aortic valve regurgitation and examination number was evaluated by use of a Fisher

Table 1—Descriptive analysis of estimated body weight and echocardiographic variables (determined via 2-D, M-mode, and color Doppler echocardiography) for 53 Standardbred trotters in Denmark at each of 5 examinations performed when the horses were 2, 2.5, 3, 3.5, and 5.5 years old.

	Examination									
	First		Second		Third		Fourth		Fifth	
Variable	Racing (n = 40)	Not racing (n = 13)	Racing (n = 39)	Not racing (n = 12)	Racing (n = 38)	Not racing (n = 11)	Racing (n = 39)	Not racing (n = 13)	Racing (n = 40)	Not racing (n = 13)
Estimated body weight (kg)	443.3 ± 33.1	432.7 ± 37.7	472.1 ± 27.2	471.9 ± 39.6	474.5 ± 31.7	464.8 ± 24.6	480.9 ± 30.5	484.6 ± 40.0	488.3 ± 26.3	519.4 ± 61.3
LVIDd (cm)	11.04 ± 0.58	10.51 ± 0.51	11.64 ± 0.68	11.26 ± 0.61	11.98 ± 0.48	11.59 ± 0.62	12.39 ± 0.65	12.15 ± 0.76	12.93 ± 0.89	12.59 ± 0.54
LV mass (g)	2,416 ± 310	2,208 ± 225	2,871 ± 456	2,684 ± 343	3,125 ± 444	2,835 ± 325	3,362 ± 467	3,207 ± 418	3,872 ± 590	3,668 ± 654
MWT (cm)	2.19 ± 0.19	2.18 ± 0.09	2.33 ± 0.20	2.32 ± 0.15	2.40 ± 0.20	2.33 ± 0.13	2.43 ± 0.18	2.41 ± 0.12	2.56 ± 0.26	2.54 ± 0.30
RWT	0.40 ± 0.04	0.42 ± 0.03	0.40 ± 0.04	0.41 ± 0.04	0.40 ± 0.03	0.40 ± 0.03	0.39 ± 0.03	0.40 ± 0.03	0.40 ± 0.06	0.40 ± 0.05
Tricuspid valve regurgitation*										
Frequency (No. of horses [%])	3 (7.5)	1 (7.7)	15 (38.5)	1 (8.3)	23 (60.5)	3 (27.3)	30 (76.9)	7 (53.9)	35 (87.5)	8 (61.5)
Severity score	1 (1 and 1)	3 (—)	1 (1 and 1)	2 (—)	1 (1 and 2)	1 (1 and 1)	1 (1 and 2)	1 (1 and 2)	1 (1 and 2)	1 (1 and 2)
Pulmonary valve regurgitation†										
Frequency (No. of horses [%])	0 (0)	0 (0)	5 (12.8)	0 (0)	8 (21.1)	0 (0)	10 (25.6)	2 (15.4)	17 (42.5)	4 (30.8)
Maximum diameter (cm)	—	—	0.80 ± 0.17	—	0.88 ± 0.20	—	0.89 ± 0.23	0.72 ± 0.01	0.86 ± 0.14	0.75 ± 0.16
Mitral valve regurgitation*										
Frequency (No. of horses [%])	0 (0)	1 (7.7)	3 (7.7)	4 (33.3)	5 (13.2)	3 (27.3)	13 (33.3)	4 (30.8)	15 (37.5)	3 (23.1)
Severity score	—	1 (—)	1 (1 and 1)	1 (1 and 2)	1 (1 and 1)	1 (1 and 1)	1 (1 and 1)	1 (1–1)	1 (1 and 2)	1 (1 and 1)
Aortic valve regurgitation†										
Frequency (No. of horses [%])	1 (2.5)	1 (7.7)	9 (23.1)	1 (8.3)	12 (31.6)	4 (36.4)	16 (41.0)	6 (46.2)	24 (60.0)	4 (30.8)
Maximum diameter (cm)	0.96	0.84	0.87 ± 0.25	0.89	0.88 ± 0.22	0.88 ± 0.26	0.94 ± 0.21	1.01 ± 0.32	0.99 ± 0.22	0.79 ± 0.13

Horses were or were not in training or racing for variable periods during the entire assessment period, and data were grouped for horses that were racing (n = 40) and horses that were not racing (13) at the time of the fifth examination. Body weight of each horse was indirectly determined via measurement of the chest girth circumference.

*For mitral and tricuspid valve regurgitation, 4 semiquantitative groups were defined on the basis of the area of the regurgitation jet in comparison to the approximated size of the atrium[17] and assigned a score, as follows: 1, very small jet (0% to 10% of the area of the atrium); 2, small jet (> 10% to 30%); 3, medium jet (> 30% to 50%); or 4, large jet (> 50%). †For aortic and pulmonary valve regurgitation, the maximal diameter of the regurgitant blood flow just below the pulmonary and aortic valves was measured.

Data are reported as mean ± SD for all variables except severity of tricuspid and mitral valve regurgitation, which are reported as median (minimum and maximum values); frequency of tricuspid, pulmonary, mitral, and aortic valve regurgitation is reported as number of horses affected (percentage).

— = Not applicable.

Table 2—Intraobserver variation of the M-mode measurements of IVSd, LVIDd, and LVFWd derived from echocardiographic images of 10 randomly selected 3.5-year-old Standardbred trotters obtained at the fourth study examination in 2002 (measurement 1) and remeasured in 2004 (measurement 2) by the same observer.

	Measurement (mean ± SE)		Variance estimate			
Variable	1	2	Among horses	Between measurements	Within measurements	r (%)
IVSd	2.63 ± 0.10	2.67 ± 0.12	0.114	0.00024	0.0049	4.7
LVIDd	11.98 ± 0.19	11.92 ± 0.19	0.351	0.00213	0.0032	27.8
LVFWd	2.15 ± 0.037	2.16 ± 0.040	0.0143	0.000067	0.00064	9.5

For each horse, 5 nonconsecutive cardiac cycles identical to the cycles measured in 2002 were chosen and examined in a blinded fashion in 2004 with no information about the previous results obtained in 2002. The variance components for the interhorse-measurement, between-measurement, and within-measurement variations and the proportion of the between-measurement variation of the total measurement variation (r) were calculated.

exact test. Differences in risk of tricuspid, pulmonary, mitral, and aortic valve regurgitation between horses classified as either racing or not racing were evaluated by use of a Fisher exact test and logistic regression. Initially, a Fisher exact test was used to test for an overall association between racing status (yes or no) and regurgitation (yes or no). The analysis was performed by use of the sum of regurgitations across the 5 examinations for each of the 4 valves. If the overall test yielded a significant finding, a logistic regression analysis was performed including racing status and examination number as explanatory variables. The generalized estimating equations method was used. In this approach, a working correlation matrix is used to approximate the true correlation matrix of the observations. The parameter estimate of the autocorrelation was based on the exchangeable correlation as the working correlation matrix. Odds ratios with 95% CIs were calculated for significant effects.

Prediction models for LV mass and LVIDd at the ages of the horses at the time of the fifth examination were derived on the basis of sex, body weight, LV mass, and LVIDd at a previous examination, respectively. Linear regression was used to derive the models. The variable sex was included in the analysis as a qualitative explanatory variable. The variables body weight, LV mass, and LVIDd were included as quantitative explanatory variables. The parameter estimate for sex was a constant value (for females vs males), and for body weight, LV mass, and LVIDd, the parameter estimates were obtained as slopes. The coefficient of determination was used to express the proportion of the variability in the data that were accounted for by the model. All analyses were performed with statistical software.[b] Values of $P < 0.05$ were considered significant.

Table 3—Effects of racing status* (racing or not racing), estimated body weight, sex, or examination on values of LVIDd, LV mass, and MWT derived from echocardiographic images of Standardbred trotters at each of 5 examinations performed when the horses were 2, 2.5, 3, 3.5, and 5.5 years old.

Outcome measure	Variable and category (where applicable)	Estimate	SE_p	Least squares means†	SE_{lsm}	*P* value
LVIDd (cm)	Intercept	10.97	0.67	—		—
	Racing status					
	Not racing	–0.44[b]	0.14	11.57	0.13	0.004
	Racing	0[a]	—	12.01	0.07	
	Estimated body weight	0.004	0.001	—		0.003
	Examination					
	First	–1.67[e]	0.15	10.94	0.11	< 0.001
	Second	–1.15[d]	0.13	11.45	0.10	
	Third	–0.84[c]	0.13	11.77	0.10	
	Fourth	–0.40[b]	0.12	12.21	0.10	
	Fifth	0[a]	—	12.60	0.11	
	Autocorrelation	0.48	0.065			
	Residual variation	0.44	0.053			
LV mass (g)	Intercept	2,166	407	—		
	Sex					
	Male	191[a]	76.0	3,178	6,260	0.013
	Female	0[b]	—	2,986		
	Estimated body weight	3.03	0.78	—		< 0.001
	Examination					
	First	–1,217[e]	93.0	2,485	66	< 0.001
	Second	–860[d]	79.6	2,842	61	
	Third	–637[c]	75.7	3,065	61	
	Fourth	–386[b]	70.0	3,316	61	
	Fifth	0[a]	—	3,702	66	
	Autocorrelation	0.64	0.050			
	Residual variance	192,868	24,885			
MWT (cm)	Intercept	1.97	0.20	—	—	
	Sex					
	Male	0.11	0.03	2.44	0.03	0.001
	Female	0	—	2.32	0.03	
	Estimated body weight	0.001		—	—	0.009
	Examination					
	First	–0.28[e]	0.05	2.24	0.03	< 0.001
	Second	–0.18[d]	0.04	2.33	0.03	
	Third	–0.12[b,c]	0.04	2.39	0.03	
	Fourth	–0.09[b]	0.04	2.42	0.03	
	Fifth	0[a]	—	2.51	0.03	
	Autocorrelation	0.48	0.065			
	Residual variance	0.039	0.005			

Results are reported as parameter estimates, SE_p, least squares means, SE of least squares means, and overall *P* value for each variable testing the hypothesis that at least 2 of the categories were significantly different (if $P < 0.05$ for the hypothesis that at least 2 of the categories were significantly different for that variable). The parameter estimate and SE_p of the autoregressive correlation between repeated measurements and the estimated residual variance are shown. A value of $P < 0.05$ was considered significant.

*Racing status was determined on the basis of whether a horse was or was not in racing at the time of the fifth examination. †No least squares means for slopes.

— = Not applicable. SE_{lsm} = Standard error of least squares means.

[a–e]For a given variable, different superscript letters indicate significant differences between the categories of the measured variable.

Results

Training category—At the time of the fifth examination, all horses participating in races (n = 40) were categorized as undergoing high-grade training; the 3 horses that were temporarily out of training were categorized as undergoing low-grade training because they had been out of training for 1 to 2 months. The remaining 10 horses had been untrained between 3 and 6 months at the time of the fifth examination and were categorized in the low-grade training group. Overall, the horses that were not racing had all been in regular race training until 1 to 6 months before the fifth examination, and most of them were still in light training, albeit with variable workloads, at the time of the fifth examination.

Echocardiographic data—Descriptive analyses of body weight, LVIDd, LV mass, MWT, RWT, and presence and severity of tricuspid, pulmonary, mitral, and aortic valve regurgitation were performed for horses classified as either racing or not racing at the fifth examination (**Table 1**).

Assessment of the repeatability of M-mode measurements—The descriptive analysis of the 2 repeated measurements of IVSd, LVIDd, and LVFWd obtained from fourth-examination images of 10 horses in 2002 and again in 2004 by the same investigator (RB) revealed that the differences between the repeated measurements were minimal (**Table 2**). With regard to these repeated echocardiographic measurements, between-measurement variation accounted for 4.7%, 27.8%, and 9.5% of the total measurement variation for IVSd, LVIDd, and LVFWd, respectively.

Left ventricular internal diameter in diastole, LV mass, and MWT increased significantly ($P < 0.001$) during the study period (**Table 3**). For LV mass and MWT, there were significantly ($P = 0.013$ and 0.001, respectively) larger increases in males than in females. Estimated body weight was significantly associated with LVIDd ($P = 0.003$), LV mass ($P < 0.001$), and MWT ($P = 0.009$), meaning that large horses had larger hearts than those of small horses. There was a significant ($P = 0.004$) association of LVIDd with racing, and higher values of LVIDd were detected in horses that were racing. For LVIDd, LV mass, and MWT, the autocorrelation between 2 consecutive repeated measures was moderate (0.48, 0.64, and 0.48, respectively).

Prevalence of valvular regurgitation increased ($P < 0.001$) for all valves during the study period, but no significant increase in severity was observed. An association between presence of valvular regurgitation and racing was identified for both tricuspid and pulmonary valve regurgitation. Further analyses revealed a significantly higher risk of tricuspid and pulmonary valve regurgitation for horses in racing (OR = 3.8 and 2.6, respectively), compared with horses not in racing. Also, there was an increasing risk of tricuspid and pulmonary valve regurgitation during the study period; the OR for tricuspid valve regurgitation at the fifth examination was 65.57, compared with first examination as the reference, and the OR for pulmonary valve regurgitation at the fifth examination was 6.32, compared with the second examination as the reference (**Table 4**). For the presence of tricuspid and pulmonary valve regurgitation, the autocorrelation between 2 consecutive repeated measures was moderate to small (0.37 and 0.22, respectively).

Table 4—Effects of racing status* (racing or not racing), estimated body weight, sex, or examination on presence of tricuspid and pulmonary valve regurgitation detected on echocardiographic images of Standardbred trotters at each of 5 examinations performed when the horses were 2, 2.5, 3, 3.5, and 5.5 years old.

Valvular regurgitation	Variable and category (where applicable)	Estimate	SE_p	OR (95% CI)	*P* value
Tricuspid	Intercept	1.88	0.42		
	Racing status				
	Racing	0[a]	—	1 (—)	0.021
	Not racing	–1.32[b]	0.51	3.76 (1.39–10.18)	
	Examination				
	First	–4.18[d]	0.64	1 (—)	< 0.001
	Second	–2.43[d]	0.46	5.79 (0.69–2.82)	
	Third	–1.49[c]	0.39	14.81 (4.97–44.14)	
	Fourth	–0.62[b]	0.34	35.13 (10.79–114.38)	
	Fifth	0[a]	—	65.57 (18.70–229.9)	
	Autocorrelation	0.37			
Pulmonary	Intercept	–0.21	0.31		
	Racing status				
	Racing	0	—	2.58 (1.01–6.06)	0.041
	Not racing	–0.95	0.44	1 (—)	
	Examination				
	Second	–1.84[c]	0.47	1 (—)	< 0.001
	Third	–1.35[b,c]	0.47	1.72 (0.03–3.17)	
	Fourth	–0.79[a,b]	0.43	2.87 (1.01–8.13)	
	Fifth	0[a]	—	6.32 (2.50–16.01)	
	Autocorrelation	0.22			

Results are reported as the parameter estimate, SE_p, OR with corresponding 95% CIs, and overall *P* value. The parameter estimate of the autocorrelation is shown.

— = Not applicable.

[a–d]The superscript letters indicate a significant difference between the categories of the measured variables.

See Table 3 for remainder of key.

Table 5—Prediction models for LV muscle mass and LVIDd in 5.5-year-old Standardbred trotters (ie, at the fifth study examination) based on data obtained during previous echocardiographic examinations performed when the horses were 2, 2.5, 3, or 3.5 years old (ie, at the first, second, third, or fourth study examination).

Echocardiographic variable	Examination	Parameter estimate (SE_p)				
		Intercept (μ)	Sex* (g)	Body weight (β_1)	LV mass or LVIDd (β_2)	R^2
LV mass	First	2,612.1 (1,041.8)	−148.7 (74.76)	0.571 (2.224)	0.522 (0.256)	0.18
	Second	2,154.6 (1,013.5)	−65.55 (65.19)	−1.462 (2.480)	0.870 (0.180)	0.43
	Third	−29.13 (960.1)	−35.53 (60.94)	2.643 (2.042)	0.873 (0.150)	0.54
	Fourth	−467.4 (1,017.2)	−106.5 (65.49)	3.779 (2.252)	0.814 (0.149)	0.60
LVIDd	First	−1.105 (1.121)	0.132 (0.062)	0.0037 (0.0018)	0.935 (0.074)	0.77
	Second	−0.352 (1.394)	0.079 (0.094)	0.0038 (0.0026)	0.876 (0.094)	0.71
	Third	−0.230 (1.306)	0.120 (0.071)	0.0067 (0.0026)	0.752 (0.083)	0.74
	Fourth	−0.291 (0.761)	0.043 (0.045)	0.0037 (0.0016)	0.879 (0.056)	0.88

Parameter estimates, SE_p, and coefficient of determination (R^2) are reported. The prediction models for the fifth examination were based on the actual measures for each horse of the weight (*weight*), LV mass ($LVmass_i$; *i* being the examination number; $i = 1, \ldots, 4$), and gender (female or male) and the parameter estimates of the -intercept (μ), the parameter estimates for each horse for sex (g), body weight (β_1), and LV mass or LVIDd (β_2) at a previous examination (first through fourth examinations [$i = 1, \ldots, 4$]) as follows: $LVmass_5 = \mu + g + \beta_1 weight + \beta_2 LVmass_i$ and $LVIDd_5 = \mu + g + \beta_1 weight + \beta_2 LVIDd_i$.

*Parameter estimate for female versus male horses.

Prediction models were estimated for LV mass and LVIDd for horses up to 5.5 years of age (**Table 5**). The models were based on the results from the repeated-measures analyses. When the model was used, information about sex and body weight was required together with the current echocardiographic result of either LVIDd or LV mass of the horse. For the study horses, coefficient of determination (R^2) increased from 0.18 to 0.60 for LV mass from the first examination at 2 years of age to the fourth examination at 3.5 years of age. For LVIDd, the coefficient of determination increased from 0.77 to 0.88, indicating that 77% to 88% of the total variation of LVIDd at 5.5 years of age can be explained by sex, body weight, and LVIDd at the time of examination.

Discussion

In the study of this report, repeated echocardiographic examination data obtained from Standardbred trotters during a period of 3.5 years were analyzed and revealed that cardiac hypertrophy develops increasingly from 2 to 5.5 years of age in those horses. This change was partly a result of normal physical growth of immature young horses, but also a result of training-induced hypertrophy because cardiac enlargement continued after the horses were considered mature (ie, the fourth to fifth examination). This finding supports the hypothesis of the athlete's heart, in which training induces cardiac hypertrophy. Results of human studies[2,4] have indicated that endurance-trained athletes develop a proportional increase in MWT and LVIDd. Thus, endurance-trained athletes will generally have eccentric LV hypertrophy characterized by an unchanged relationship between MWT and LVIDd with an unchanged RWT. In contrast to this situation, athletes involved in mainly strength training, such as sprinters and weightlifters, develop predominantly increased MWT with an unchanged LVIDd.[2,4] Thus, strength-trained athletes are presumed to have concentric LV hypertrophy, which is characterized by an increased ratio of MWT and LVIDd leading to increased RWT.[2,4] Given that MWT and LVIDd increased significantly yet the RWT remained unchanged in the horses in the present study, it appears that mainly endurance-type training of the horses had an influence on cardiac development. At the fifth examination in the present study, only LVIDd was larger in the racing horses, compared with findings in the horses that were not racing. We expected that LV mass would be significantly larger in the horses that were racing, but we did not find any difference between the 2 groups. An explanation for this could be that the horses that were not racing had all been in regular race training until 1 to 6 months before the fifth examination and most of them were still in light training at the time of the fifth examination, which may have sustained the cardiac hypertrophy to some extent. Also, the number of horses in the nonracing group was limited, and the horses had variable workloads, which might explain the lack of difference between the 2 groups. Finally, the effect of detraining might influence the results. In a previous study,[19] echocardiographic measures in Standardbred trotters did not change during the first month after cessation of training, but significant decreases were observed thereafter.

The data obtained in the present study also support results of other investigations[6,7,20,21] in equine and human athletes, indicating that sex exerts independent effects on LV mass and MWT, with males having larger hearts than those of females. A similar sex-related difference has also been documented for skeletal muscles.[22,23] The significant correlations between body weight and LV mass, LVIDd, and MWT, with larger horses having larger hearts, were consistent with previous findings.[6,7]

Although valvular regurgitation increased in prevalence during the study period (up to 87% for the horses that were racing), no increase in severity of regurgitation was observed. A high prevalence of multivalvular regurgitation was identified in a cross-sectional study[10] of Thoroughbreds and has similarly been found in human athletes.[11,13] In the present study, tricuspid and pulmo-

nary valve regurgitation increased significantly during the study period, with greater prevalence in racing horses than in nonracing horses. The explanation for this is not clear, but potential changes in right ventricular size may influence the development of the right-sided heart valve regurgitation. In the horses in the present study, the size and development of the right ventricle was not measured, but a previous study[24] revealed an increase in right ventricular size in racehorses; it is likely that the right ventricle undergoes adaptations similar to those occurring in the left side of the heart. Changes in pulmonary pressure may also be responsible for the development of right-sided heart valve regurgitation. In human athletes, pulmonary arterial systolic pressure (measured indirectly via tricuspid valve regurgitation peak velocity) is higher at rest and during exercise. Therefore, it has been speculated that tricuspid and pulmonary valve regurgitation develop as a result of increased pulmonary arterial systolic pressure.[25] During strenuous exercise, pulmonary arterial systolic pressure more than doubles in horses[26,27]; this may explain the increased development of tricuspid and pulmonary valve regurgitation observed in the present study.

The large differences in cardiac variables depending on the age of the horses (Table 1) are representative of the difficulty faced by clinicians in determining whether a heart is of normal size. Even though pathological cardiac hypertrophy is extremely rare in young racehorses, the size of the heart may be important when predicting race potential in younger horses because a possible correlation between heart size and racing performance is known.[5–7] Therefore, as part of our study, we developed a model with which it is possible to predict cardiac size at 2 to 5.5 years of age in Standardbred trotters. The results of the overall statistical analyses indicated that age, sex, and body weight were significantly associated with cardiac size and needed to be included in the model. The model showed that the coefficient of determination was higher for LVIDd, compared with that for LV mass, meaning that prediction of subsequent size of LVIDd can be performed more precisely and is therefore a more reliable measure than LV mass, especially in earlier years. Because the hearts of Thoroughbreds are larger than those of Standardbred trotters, especially in regard to LVIDd,[6] it must be emphasized that this model was established on the basis of data obtained in Standardbred trotters and has only been validated in this group of study horses.

Overall, the present longitudinal study of Standardbred trotters as they aged from 2 to 5.5 years revealed that cardiac size increased significantly during that period. A horse's heart not only increased in size as a result of normal physical development, but also continued to increase as a result of training-induced changes after the horse was considered physiologically mature, which is consistent with the definition of athlete's heart. Multivalvular regurgitation developed in these horses, which is also related to athlete's heart. Importantly, the data obtained in the present study enabled development of a model that provides means for estimation and prediction of heart size in young Standardbred trotters.

a. Vingmed Vivid 3, GE Healthcare Technologies, Brøndby, Denmark.
b. SAS, version 9.1, SAS Institute Inc, Cary, NC.

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From this month's *AJVR*

Respiratory mechanics and results of cytologic examination of bronchoalveolar lavage fluid in healthy adult alpacas

Ana P. Pacheco et al

Objective—To evaluate respiratory mechanical function and bronchoalveolar lavage (BAL) cytologic results in healthy alpacas.

Animals—16 client-owned adult alpacas.

Procedures—Measurements of pulmonary function were performed, including functional residual capacity (FRC) via helium dilution, respiratory system resistance via forced oscillatory technique (FOT), and assessment of breathing pattern by use of respiratory inductive plethysmography (RIP) in standing and sternally recumbent alpacas. Bronchoalveolar lavage was performed orotracheally during short-term anesthesia.

Results—Mean ± SD measurements of respiratory function were obtained in standing alpacas for FRC (3.19 ± 0.53 L), tidal volume (0.8 ± 0.13 L), and respiratory system resistance at 1 Hz (2.70 ± 0.88 cm H_2O/L/s), 2 Hz (2.98 ± 0.70 cm H_2O/L/s), 3 Hz (3.14 ± 0.77 cm H_2O/L/s), 5 Hz (3.45 ± 0.91 cm H_2O/L/s), and 7 Hz (3.84 ± 0.93 cm H_2O/L/s). Mean phase angle, as a measurement of thoracoabdominal asynchrony, was 19.59 ± 10.06°, and mean difference between nasal and plethysmographic flow measurements was 0.18 ± 0.07 L/s. Tidal volume, peak inspiratory flow, and peak expiratory flow were significantly higher in sternally recumbent alpacas than in standing alpacas. Cytologic examination of BAL fluid revealed 58.52 ± 12.36% alveolar macrophages, 30.53 ± 13.78% lymphocytes, 10.95 ± 9.29% neutrophils, 0% mast cells, and several ciliated epithelial cells.

Conclusions and Clinical Relevance—Pulmonary function testing was tolerated well in nonsedated untrained alpacas. Bronchoalveolar lavage in alpacas yielded samples with adequate cellularity that had a greater abundance of neutrophils than has been reported in horses. (*Am J Vet Res* 2012;73:146–152)

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