Comparison of echocardiographic measurements in elite and nonelite Arabian endurance horses

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Objective—To determine whether echocardiographic variables differed between successful (elite) and less successful (nonelite) Arabian endurance horses.

Animals—34 Arabian horses that competed in endurance racing.

Procedures—Horses were assigned to either an elite or nonelite group on the basis of results of a previous competition, and a standardized echocardiographic examination was performed on each horse within 1 to 4 weeks after that competition. Multivariable logistic regression with backward stepwise elimination was used to create a prediction model for the determination of horse status (elite or nonelite) as a function of the measured echocardiographic variables.

Results—The elite and nonelite groups consisted of 23 and 11 horses, respectively. One horse in the nonelite group had a frequent ventricular dysrhythmia that could have negatively affected its performance and rider's safety, whereas none of the horses in the elite group had remarkable cardiac abnormalities. The left ventricular internal diameter during systole and diastole and left ventricular mass and stroke volume were significantly greater for horses in the elite group, compared with those for horses in the nonelite group. The final logistic regression model correctly predicted the horse status for all of the horses in the elite group and 8 of 11 horses in the nonelite group.

Conclusions and Clinical Relevance—Results indicated that heart size was significantly associated with performance for Arabian endurance horses in a manner similar to findings for Thoroughbred and Standardbred racehorses in active competition. (*Am J Vet Res* 2014;75:893–898)

Heart size has long been suspected to be associated with performance in horses,[1–3] and certain echocardiographic variables have been associated with race performance of young Thoroughbreds.[4,5] Although $\dot{V}O_2max$ might be the single best predictor of athletic ability for horses,[6] it is costly to determine and can only be measured at specialized laboratories. In humans, LVM is associated with $\dot{V}O_2max$, and the $\dot{V}O_2max$ for elite human athletes that have undergone aerobic training is significantly higher than that for nonathletic humans who have not undergone aerobic training.[7–9] Results of studies[6,10] that involved aerobically trained Thoroughbreds indicate that heart size is correlated with $\dot{V}O_2max$.

Several methods for assessment of heart size in horses have been described. In 1957, Steel[11] described a heart score, which involved the use of the QRS interval on a standard 3-bipolar lead ECG recording; however, this technique was determined to be unreliable for the measurement of heart size.[12,13] Results of 1 study[12] suggest that echocardiography is a more appropriate method than is ECG for determination of heart size and performance in horses. Although echocardiography has been used successfully to assess heart size in Thoroughbreds,[10,14] it remains uncertain how useful evaluation of echocardiographic variables is for prediction of subsequent athletic performance. Investigators of a study[4] that involved 5,431 yearling and 2,003 two-year-old Thoroughbred racehorses reported that heart size as determined by echocardiography was positively associated with future race earnings. Likewise, inves-

Abbreviations

AERC	American Endurance Ride Conference
IVSd	Interventricular septal thickness at end diastole
LVFWd	Left ventricular free wall thickness at end diastole
LVIDd	Left ventricular internal dimension at end diastole
LVIDs	Left ventricular internal dimension at end systole
LVM	Left ventricular mass
LVSV	Left ventricular stroke volume
$\dot{V}O_2max$	Maximum oxygen consumption

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tigators of another study[5] that involved evaluation of British Thoroughbreds that were competing in either flat or jump racing reported a positive association between left ventricular size and function as determined by echocardiography and athletic performance; interestingly, this relationship appeared to be strongest for horses that competed in National Hunt racing, which involves long-distance races with jumps. Specifically, there was a positive linear relationship between a horse's echocardiographically measured heart size and its British Horseracing Board Official rating or Timeform rating,[3,5] which suggests that aerobic capacity may be more important for long-distance races than it is for sprint races. Clearly endurance racing, in which horses frequently race for 160 km (100 miles), differs from National Hunt racing, in which horses generally race up to 4 miles; most notably, horses competing in a National Hunt race typically run at a faster rate than do horses competing in an endurance race. Because the relationship between heart size and performance was stronger for horses involved in National Hunt racing than it was for horses involved in sprint racing, we were interested to see whether that pattern held for horses involved in endurance racing. Both National Hunt racing and endurance racing require a higher aerobic capacity than does sprint racing.

Since Steinhaus et al[15] reported that dogs that routinely exercised (ie, swam and ran) had larger hearts than did control dogs that did not exercise regularly, it has been well-established that cardiac hypertrophy is a normal adaption to exercise in both humans and animals.[3,16–24] However, some investigators suggest that exercise-induced cardiac hypertrophy is equivocal at best and is confounded by other exercise-induced factors such as training-induced bradycardia (the occurrence of which is uncertain in horses[2]) and plasma volume expansion.[17] Perrault and Turcotte[17] also cite reports in which heart size was not affected by exercise or was dependent on gender. In a recent study,[20] the LVIDd of Standardbred trotters during training was significantly greater than that of similar horses that were not in training; however, confounders such as heart rate and plasma volume were not assessed. In that study,[20] echocardiography was performed on each horse at 2, 2.5, 3, 3.5, and 5.5 years of age, and the increase in heart size was not simply an effect of physiologic growth and maturity. Other studies[5,25] in which exercise-induced cardiac hypertrophy was described in horses involved immature racehorses, and investigators suggest that age might have a confounding effect on heart size. In humans, hereditary or familial factors likely influence heart size.[16] In horses, heart enlargement caused by hereditary factors and normal physiologic maturation versus that caused by exercise is unclear.

The purpose of the study reported here was to determine whether echocardiographic indices of cardiac dimensions and function were significantly associated with performance of Arabian horses involved in endurance racing. Because of the aerobic nature of the sport, we hypothesized that the echocardiographic variables would differ significantly between horses that performed well (ie, elite horses) and horses that did not perform well (ie, nonelite horses).

Materials and Methods

Animals—Results of AERC-sanctioned 160-km rides during the 2010 season were obtained from the organization's website. Only actively performing purebred Arabians between 7 and 17 years of age that participated in at least 1 of 4 specified 160-km races were considered for study enrollment; these criteria were used to reduce inherent variability in the study population. The owners of the eligible horses were contacted by telephone to recruit horses for the study. Client consent was obtained for all horses enrolled in the study. All study procedures were reviewed and approved by the Institutional Animal Care and Use Committee of the University of Pennsylvania.

For each horse enrolled in the study, performance history was obtained from the AERC website. Horses were classified into 2 groups (elite or nonelite) on the basis of their performance in the 4 specified 160-km races. Horses were classified in the elite group if they won or finished within 30 minutes or 10% of the winning time in 1 of the specified races. Horses were classified in the nonelite group if they did not meet the criteria for the elite group and had never won or finished within 2 hours of the winning time for a 160-km endurance race. Each horse's entire endurance record was reviewed to ensure that its performance history was consistent with its performance in the 160-km race used for study recruitment. All horses had been competing in endurance racing for at least 2 years prior to study enrollment and were trained athletes; horses that were just beginning a training program were excluded from the study.

Examination procedure—Each horse was evaluated in its home environment within 1 to 4 weeks after completion of the race used to determine its group classification. A brief physical examination was performed, and the horse's height at the highest point of the shoulders (withers) was measured. Ambulatory ECG equipment[a] was used to obtain a 60-minute ECG recording; electrodes were applied in a base-apex lead configuration and data were downloaded onto a laptop computer for future analysis. Following removal of the ECG monitoring equipment, a standardized 2-D, M-mode and Doppler (pulsed wave, continuous wave, and color) echocardiographic examination was performed as described[23,26] with a portable ultrasound machine and a 1.5- to 2.5-MHz probe.[b] From each view, frozen images or video loops from 3 nonconsecutive cardiac cycles were obtained for future analysis. All images and cardiac measurements were obtained with the probe positioned on the right thorax with the exception of 2-D diameters of the pulmonary artery and aorta, which were imaged and measured from both the left and right thorax at the end of diastole, and the 2-D dimension of the left atrium, which was measured in a long-axis view obtained from the left thorax during systole. The same investigator (MMD) performed all echocardiographic examinations and measurements.

Echocardiographic measurements—The M-mode measurements of the left ventricle were determined from a 2-D short-axis image of that ventricle at the level just ventral to the chordae tendinae. Diastolic measurements were obtained at end diastole immediately prior to the QRS complex as determined on a simultaneously recorded ECG reading, and systolic measurements were obtained at peak upswing of the left ventricular free wall.

The means of the M-mode measurements (each measurement was obtained from each of 3 nonconsecutive cardiac cycles) were used to calculate the following variables: left ventricular fractional shortening = (LVIDd – LVIDs) X 100/LVIDd, LVM = (1.04 X [{IVSd + LVIDd + LVFWd}^{3} – LVIDd^3]) – 13.6, and mean left ventricular wall thickness = (IVSd + LVFWd)/2. In a study[27] in which the LVM and mean left ventricular wall thickness of horses were evaluated by echocardiography and during necropsy, the correlation between the calculated echocardiographic variables and heart weight was 0.8.

Stroke volume was calculated automatically with echocardiographic software by use of the Teicholz method as described.[28] Although this method has not been validated in adult horses, it has been evaluated in foals.[28]

Data analysis—Descriptive statistics were calculated. A Fisher exact test was used to compare the sex distribution between horses in the elite and nonelite groups, and a *t* test was used to compare the mean age and height at the withers and means for echocardiographic variables between horses in the elite and nonelite groups. For these analyses, values of $P < 0.05$ were considered significant. Multivariable logistic regression was used to create a model for horse status (elite vs nonelite) as a function of echocardiographic variables. Because the echocardiographic, or independent, variables were highly correlated, backward stepwise variable selection was used and the level of significance was set at 0.10 to ensure that predictive models that contained combinations of independent variables were given due consideration. A Hosmer-Lemeshow goodness of fit test was used to assess the fit of the proposed final multivariable models. The predictive ability of the entire model was assessed rather than its individual components because of the correlation among the independent variables. All analyses were performed with statistical software.[c]

Results

Animals—Initially, 38 horses (8 mares and 30 geldings) were evaluated, of which 23 were classified in the elite group and 15 were classified in the nonelite group.

Table 1—Mean (range) echocardiographic variables for 23 elite and 11 nonelite Arabian horses that competed in endurance racing.

Variable	Elite horses	Nonelite horses	*P* value
IVSd (cm)	2.8 (2.4–3.4)	2.7 (2.3–3.4)	0.29
LVIDd (cm)	11.5 (10.6–12.2)	10.7 (9.6–12.1)*	0.004
LVFWd (cm)	2.2 (1.8–3.0)	2.1 (1.8–2.5)	0.19
IVSs (cm)	4.2 (3.5–4.5)	4.2 (3.3–5.1)	0.88
LVIDs (cm)	7.2 (6.1–8.6)	6.7 (6.0–7.8)*	0.01
LVFWs (cm)	3.9 (3.5–4.5)	4.0 (3.3–4.9)	0.71
LVEF (%)	63 (51–73)	65 (59–72)	0.49
LVFS (%)	37 (28–45)	38 (33–44)	0.57
LVSV (mL)	487 (409–574)	428 (337–546)*	0.01
LVM (g)	3,128 (2,446–3,812)	2,611 (2,106–3,387)*	0.01
LVMWTd (cm)	2.5 (2.1–3.0)	2.4 (2.2–2.7)	0.14
RVIDd (cm)	3.3 (1.9–5.4)	3.3 (2.1–5.1)	0.92
RVIDs (cm)	2.6 (0.7–4.4)	2.5 (0.6–4.3)	0.70
EPSS (cm)	0.58 (0.15–1.0)	0.58 (0.25–0.9)	0.97
Aortic diameter at end diastole (cm)	8.4 (7.7–10.1)	8.4 (7.4–9.6)	0.77
Left atrial diameter at the heart base at end systole (cm)	4.7 (3.1–6.9)	4.4 (3.1–5.6)	0.52
LA/Ao	0.55 (0.36–0.85)	0.52 (0.34–0.67)	0.47
Pulmonary artery diameter (right; cm)†‡	6.1 (5.4–6.8)	6.3 (5.5–6.8)	0.32
Pulmonary artery diameter (left; cm)†§	7.0 (6.0–7.9)	7.0 (5.7–7.9)	0.97
Ao LVOT (cm)†	7.6 (6.8–8.8)	7.7 (7.3–8.2)	0.68
Ao left (cm)†	7.8 (7.1–8.7)	7.9 (7.4–8.5)	0.67
LA long axis (cm)†	12.1 (11.3–12.7)	11.9 (10.9–13.8)	0.48
Heart rate (beats/min)	37 (25–44)	37 (32–43)	0.75

All horses had competed in endurance racing for at least 2 years prior to study initiation and were between 7 and 17 years old. Horses were classified in the elite group if they had won or finished within 30 minutes or 10% of the winning time in 1 of 4 selected AERC-sanctioned 160-km (100-mile) endurance races in 2010. Horses were classified in the nonelite group if they did not meet the criteria for the elite group and had never won or finished with 2 hours of the winning time in an AERC-sanctioned 160-km endurance race in 2010. All variables were determined on the basis of data obtained by M-mode echocardiography unless otherwise noted. Values represent the mean of measurements obtained from 3 nonconsecutive cardiac cycles.

*Value is significantly ($P < 0.05$) less than that for elite horses. †Measurement obtained by 2-D echocardiography. ‡Measurement obtained from the right parasternal long-axis view of the right ventricular outflow tract at end diastole. §Measurement obtained from the left parasternal long-axis view at end diastole.

Ao left = Aortic diameter at the sinus of Valsalva obtained from the left parasternal long-axis view at end diastole. Ao LVOT = Aortic diameter at the sinus of Valsalva obtained from the right parasternal long-axis view of the left ventricular outflow tract at end diastole. EPSS = E point septal separation (mitral valve). IVSs = Interventricular septal thickness at end systole. LA/Ao = Ratio of left atrial diameter to the aortic diameter. LA long axis = Left atrial diameter obtained from the left parasternal long-axis, 2-chamber view at end systole. LVEF = Left ventricular ejection fraction. LVFS = Left ventricular fractional shortening. LVFWs = Left ventricular free wall thickness at end systole. LVMWTd = Left ventricular mean wall thickness at end diastole. RVIDd = Right ventricular internal dimension at end diastole. RVIDs = Right ventricular internal dimension at end systole.

Table 2—Final multivariable logistic regression model of echocardiographic variables associated Arabian horses that competed in endurance racing achieving an elite versus nonelite status.

Variable	Regression coefficient	*P* value	OR
LVFWd	1.31	0.083	3.706
LVIDs	3.78	0.006	43.756
LVFWs	–1.39	0.070	0.248
LVEF	3.24	0.017	25.431

Because the echocardiographic variables were highly correlated, backward stepwise variable selection was used to create the multivariable model, and the level of significance was set at 0.10. Hosmer-Lemeshow test statistic, 17.2 (degrees of freedom, 9; $P = 0.05$).

See Table 1 for remainder of key.

Four horses in the nonelite group were subsequently excluded from the study because the echocardiographic data obtained from those horses were inadequate for analysis; thus, the final study population consisted of 23 horses in the elite group and 11 horses in the nonelite group. The elite group included 5 mares and 18 geldings with a mean age of 10.8 ± 0.5 years (range, 7 to 17 years) and mean height at the withers of 60.7 cm (range, 58 to 64 cm). The nonelite group included 2 mares and 9 geldings with a mean age of 12.1 ± 1.1 years (range, 7 to 17 years) and mean height at the withers of 60.7 cm (range, 56 to 63 cm). The sex distribution ($P = 0.53$), mean age ($P = 0.25$), and mean height at the withers ($P = 0.60$) did not differ significantly between horses in the elite and nonelite groups.

Examination findings—Most of the horses had no remarkable cardiovascular abnormalities detected during physical examination. Two horses (1 each in the elite and nonelite groups) had an irregular heart rhythm characterized by premature beats, and 2 other horses (1 each in the elite and nonelite groups) had heart murmurs consistent with aortic valvular regurgitation (grade 3 of 6 decrescendo, diastolic murmurs best heard on the left side of the thorax over the base of the heart). On the 60-minute ECG recording, 1 horse in the elite group had supraventricular premature complexes and 1 horse in the nonelite group had ventricular premature complexes. The remainder of the horses had clinically normal sinus rhythms, although some had vagally mediated arrhythmias (ie, second-degree atrioventricular block or sinus block).

Of the 38 horses initially evaluated for the study, 37 had some degree of valvular regurgitation (aortic regurgitation, n = 27; mitral regurgitation, 10; pulmonic regurgitation, 15; and tricuspid regurgitation, 17) detected at 1 or more valves during the echocardiographic examination. For most of the horses, the extent of valvular regurgitation was considered trace to mild on the basis of the size of the jet detected by color flow Doppler; however, two 17-year-old horses (1 each in the elite and nonelite groups) were categorized as having mild to moderate aortic regurgitation. One horse in the nonelite group had frequent ventricular dysrhythmias that could negatively affect its performance and rider's safety. None of the horses in the elite group had clinically relevant cardiovascular abnormalities.

Regression results—Results of comparisons of echocardiographic variables between horses in the elite and nonelite groups were summarized **(Table 1)**. For horses in the elite group, the LVIDd, LVIDs, LVM, and LVSV were significantly greater, compared with those for the horses in the nonelite group. Significant differences in echocardiographic variables were not detected between mares and geldings within the entire study population or within each group (elite or nonelite).

The final multivariable logistic regression model of echocardiographic variables associated with horses achieving an elite versus nonelite status was summarized **(Table 2)**. When the model was applied to the study population to predict the status of individual horses, it correctly predicted the status (ie, the status predicted by the model was the same as the group classification determined by the race results) of all 23 horses in the elite group and 8 of 11 horses in the nonelite group.

Discussion

Results of the present study indicated that elite Arabian endurance horses had LVIDd, LVIDs, LVSV, and LVM that were significantly greater than those for nonelite Arabian endurance horses. Although the determination of stroke volume by use of the Teicholz method has not been validated in adult horses, the same calculation was used for all horses in the present study; therefore, the stroke volume data should be valid for comparison purposes within this population. The finding that the left ventricles of horses in the elite group were larger than those of horses in the nonelite group might indicate that the horses in the elite group had greater cardiovascular ability and aerobic capacity, which translated into superior performance during endurance racing, compared with those of horses in the nonelite group. To our knowledge, the present study is the first to determine that heart size can be used as a predictor of performance in horses that compete in endurance racing.

Most of the horses in the present study had at least 1 heart valve with trace or mild regurgitation identified during echocardiographic examination. This finding is similar to results of studies that involved Standardbred[25,29] and Thoroughbred[3,29] racehorses. Investigators of another study[30] that involved > 500 Thoroughbred racehorses failed to find an association between heart murmur grade and racing performance. However, that study[30] included only horses that were actively racing, and horses with heart murmurs caused by substantial pathological abnormalities that would affect performance were likely excluded from the study population.

One horse in the nonelite group that was actively competing in endurance races had frequent ventricular dysrhythmias that could negatively affect its performance and rider's safety. Although an exercise test was not performed on this horse, the dysrhythmia was considered clinically important because evaluation of data obtained from the 60-minute ECG recording identified frequent ventricular ectopic beats that persisted during periods of sympathetic stimulation when the heart rate was increased to 100 beats/min.

The present study had several limitations beyond its small sample size that should be discussed. Because the study was not longitudinal in nature, the cardiac response to exercise could not be evaluated. It would be interesting to assess exercise-induced cardiac changes, especially if the effects of changes in plasma volume and heart rate could be standardized. The sport of endurance racing is complex, and horses can be eliminated from competition for various reasons, including those unrelated to heart size or function. For example, a horse with musculoskeletal or metabolic abnormalities might not have excelled in the sport and been classified in the nonelite group even though the size of its heart might have been equivalent to that of horses in the elite group. Also, the goals for competitors in endurance racing may differ; some endurance race participants compete with the goal of finishing the race within the maximum time limit, whereas others compete with the goal of finishing the race the quickest. Therefore, the classification of the horses in the present study might have been biased by the varying goals of individual riders. It is also possible that different training protocols for horses competing in endurance races might result in varying extents of cardiac hypertrophy. We tried to minimize this possibility by only including horses in the study that had competed in endurance races for at least 2 seasons; however, the variable training protocols for individual horses might have confounded our results. Finally, we were unable to acquire body weights because of the study design and used height at the withers as a surrogate measure of body size. Our results indicated that height at the withers did not differ significantly between horses in the elite and nonelite groups. Investigators of another study[7] reported that indexing echocardiographic variables by body weight did not improve the correlation between heart size and $\dot{V}o_2max$. Furthermore, in the present study, sex was not associated with any of the echocardiographic variables, which suggested that the effect of body weight on echocardiographic variables may be minimal.

The multivariable logistic model created in the present study for predicting whether a horse would be classified as either an elite or nonelite performer in endurance racing on the basis of its heart size as determined by various echocardiographic measurements was developed and validated with the same data set, which likely inflated the correct prediction probabilities. Also, because the independent variables in the model were correlated (ie, colinear), the individual slope estimates are not meaningful by themselves, and the overall model was assessed for its predictive ability. This model should be further validated with echocardiographic data obtained from another population of similar horses to better ascertain its predictive ability for the general population of Arabians involved in endurance racing.

In the present study, heart size as determined by echocardiographic examination was associated with the performance of Arabian endurance horses in a manner similar to findings for Thoroughbred and Standardbred racehorses. Further investigation is necessary to validate the regression model developed in this study and ascertain its ability to correctly predict the performance of Arabian endurance horses.

a. Spacelabs Healthcare, Snoqualmie, Wash.
b. Vivid I, General Electric Healthcare, Little Chalfont, Buckinghamshire, England.
c. SAS, version 9.2, SAS Institute Inc, Cary, NC.

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