Cardiac evaluation of anesthetized Grevy’s zebras (*Equus grevyi*)

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Objective—To determine ECG and echocardiographic measurements in healthy anesthetized Grevy’s zebras (*Equus grevyi*).

Animals—20 healthy zebras.

Procedures—Auscultation, base-apex ECG, and echocardiography were performed on anesthetized zebras.

Results—Low-grade systolic murmurs were detected in the left basilar region in 4 of 20 zebras. Evaluation of ECGs from 19 zebras revealed sinus rhythm with a predominantly negative QRS complex and a mean ± SD heart rate of 67 ± 10 beats/min. Echocardiograms of sufficient image quality were obtained for 16 zebras. Interventricular septal thickness in diastole, left ventricular chamber in diastole and systole, left atrial diameter, and left ventricular mass were significantly and moderately correlated with estimated body weight (r values ranged from 0.650 to 0.884). Detectable swirling of blood in the right and sometimes the left ventricles was detected in 9 of 16 zebras, whereas physiologic regurgitation of blood was detected for the aortic valve in 3 zebras, pulmonary valve in 2 zebras, mitral valve in 2 zebras, and tricuspid valve in 1 zebra.


**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tr>
<td>IVSd</td>
<td>Interventricular septal thickness during diastole</td>
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<tr>
<td>LVIDd</td>
<td>Left ventricular internal diameter during diastole</td>
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<tr>
<td>LVIDs</td>
<td>Left ventricular internal diameter during systole</td>
</tr>
<tr>
<td>LVFWd</td>
<td>Left ventricular free-wall thickness during diastole</td>
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<td>CI</td>
<td>Confidence interval</td>
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Although all 3 zebra species are in the same genus as that of domestic horses (*Equus caballus*), we are not aware of any published studies of cardiac structure and function of zebras. As a result of their endangered status, a herd of Grevy’s zebras (*Equus grevyi*) have been maintained at the White Oak Conservation Center in Yulee, Fla. Annual examinations and the provision of veterinary care yielded an opportunity to noninvasively evaluate the hearts of those zebras. The objectives of the study reported here were to characterize ECG and echocardiographic findings in healthy Grevy’s zebras with the intent to provide reference values for use in the evaluation of zebras suspected of having cardiac disease.

Materials and Methods

**Animals**—Twenty healthy Grevy’s zebras housed at the White Oak Conservation Center were anesthetized for an annual examination, hoof trimming, and dental examination. Zebras were anesthetized in a field setting by use of etorphine hydrochloride, detomidine, and acepromazine maleate. Agents were administered by use of dart injection. The addition of a cardiac evaluation to the annual examination was approved by the Institutional Animal Care and Use Committee at the White Oak Conservation Center.

**Procedures**—Each zebra was positioned in right lateral recumbency for all procedures. Sex and age were recorded. Body weight was estimated by experienced handlers on the basis of the size of the zebra, amount of effort required to manipulate the zebra into the appropriate position, and experience with body weights of zebras weighed at necropsy. Precise weight measurement by use of a scale was not available in the field setting.

**Cardiac auscultation**—Cardiac auscultation was performed on each zebra. Auscultation was used for the detection of heart murmurs.

**ECG**—Base-apex ECG was performed by use of a portable ECG unit and needle electrodes. The ECG measurements were obtained by 1 investigator (DBA).
at a paper speed of 25 mm/s and sensitivity of 5 or 10 mm/mV, depending on the size of the deflections. The mean value of 3 measurements was calculated for each ECG variable.

Echocardiography—Echocardiography was performed by 1 investigator (HWM) by use of a portable ultrasound machine equipped with 1.5- to 3.6-MHz phased-array sector probes. Images were obtained on the right side of each zebra with the zebra in right lateral recumbency with the forelimbs elevated from the ground by an assistant. Images were obtained from the left side with the zebra maintained in the same position. Standard views and images used for horses were obtained in this group of zebras and included right parasternal long-axis 4-chamber view, right parasternal long-axis 5-chamber (outflow) view, right parasternal short-axis view of the left ventricle (at the level of the papillary muscles and mitral valve), M-mode right parasternal short-axis view of the left ventricle (at the level of the papillary muscles and mitral valve), right parasternal short-axis view of the heart base (at the level of the aortic and pulmonary valves), right parasternal angled view of the right ventricular outflow tract with pulsed-wave Doppler recordings of the pulmonary outflow velocity spectra, left-sided parasternal long-axis inflow and outflow views, and left cranial view with pulsed-wave Doppler recordings of the spectra of blood velocity in the aorta. Angle correction was not used for pulsed-wave Doppler recordings. All valves observed in each view were examined by use of color-flow Doppler ultrasonography for evidence of regurgitant jets and turbulent blood flow. Valves were also examined for structural abnormalities. Evidence of detectable swirling of blood in the right and sometimes the left ventricles was recorded.

Echocardiographic measurements were performed in triplicate by use of the leading edge–to–leading edge technique; mean of the 3 values was calculated. Measurements obtained from the right parasternal short-axis view at the level of the papillary muscles by use of M-mode ultrasonography included IVSd, interventricular septal thickness during systole, LVIDd, LVIDs, LVFWd, and left ventricular free-wall thickness during systole. Fractional shortening was calculated as follows: \( \left( \frac{LVIDd – LVIDs}{LVIDd} \right) \times 100 \). Ejection fraction was calculated as follows: \( \left( \frac{\text{left ventricular volume during diastole} - \text{left ventricular volume during systole}}{\text{left ventricular volume during diastole}} \right) \times 100 \). The Teicholz equation was used to calculate volumes from M-mode measurements as follows: left ventricular volume = \( 7 \times \frac{LVID^2}{2.4 + LVID} \). The E-point–to–septal separation was obtained from the right parasternal short-axis view at the level of the mitral valve (M-mode ultrasonography). The value was determined for left atrial diameter measured at end diastole from the left-sided parasternal inflow. Left ventricular mass was calculated by use of M-mode measurements for a method (method 1) described elsewhere. The equation for method 1 was as follows: left ventricular mass = 1.04 × \( \left( \frac{\text{LVIDd} + \text{LVFWd} + \text{IVSd}}{2} \right) - 13.6 \). Left ventricular mass was also calculated by use of another method (method 2) described in other studies. The equation for method 2 was as follows: left ventricular mass = 1.11 \( \left( \frac{\text{LVF–Wd} + \text{IVSd}}{2} \right) - \{0.83 \times \text{left ventricular endocardial area}\} \); the mean of 2 measurements was used for this calculation. Peak flow velocity in the pulmonary artery and aorta were recorded.

Statistical analysis—The mean value was calculated for the 3 ECG and echocardiographic measurements from each zebra, and this mean value was used to calculate the group mean for each variable. Echocardiographic and ECG data were tested for normality by use of the Kolmogorov-Smirnov test. Normally distributed data were used to calculate the mean, SD, and 95% CI for each variable. Simple linear regression and Pearson correlation tests were used to investigate relationships between echocardiographic variables and estimated body weight. Agreement between methods 1 and 2 for left ventricular mass was investigated by use of Bland-Altman analysis. Bias and limits of agreement were expressed graphically as a percentage of the means of the 2 methods because an increase in variability of the differences was evident as the magnitude of the measurement increased. Statistical software was used for analysis. Values of \( P < 0.05 \) were considered significant.

Results

Animals—Seven zebras were males, and 13 were females. Zebras ranged from 1.5 to 20 years of age (mean ± SD, 6.1 ± 5.4 years). Zebras received 4.6 ± 0.6 mg of etorphine, 15.2 ± 0.7 mg of detomidine, and 10.0 ± 0.0 mg of acepromazine by dart injection. Two zebras were administered a second injection at half the initial dose because the dart was only deployed to 50%. Five zebras received an additional 4 mg of detomidine, 4 were administered 100 to 150 mg of ketamine hydrochloride, and 2 were administered a solution of guaifenasin (300 to 350 mL/h, IV) to improve muscle relaxation or achieve a deeper plane of anesthesia. Results of CBC and serum biochemical analysis were unremarkable for all 20 zebras.

Echocardiographic image quality for 4 female zebras was considered poor; therefore, echocardiographic results were calculated for only 16 zebras (7 males and 9 females). The 16 zebras ranged from 1.5 to 20 years of age (mean ± SD, 5.6 ± 3.6 years). Mean estimated weight for the 16 zebras used for echocardiographic measurements was 360 ± 40 kg.

Cardiac auscultation—Four of 20 zebras had low-grade systolic murmurs in the left basilar region (1 with grade 1/6, 2 with grade 2/6, and 1 with grade 3/6). None of the 4 zebras with poor-quality echocardiographic images had a heart murmur. All murmurs were considered physiologic on the basis of subjective evaluation of the echocardiograms, which did not reveal any apparent abnormalities.

Only 1 of the 4 zebras with murmurs had regurgitant flow through a valve. Trace regurgitation through the aortic valve but with a structurally normal aortic valve was considered physiologic and unrelated to the low-grade systolic murmur in that zebra.
ECG—Electrocardiograms were obtained from all 20 zebras; however, 1 ECG recording was misplaced. Thus, results were reported for only 19 zebras. All 19 zebras had a sinus rhythm, and orientation of the QRS complex in the base-apex lead was primarily negative (Figure 1). The T waves were monophasic and positive in 12 of 19 zebras; however, 1 zebra had monophasic negative T waves, and 6 zebras had biphasic T waves. Fourteen zebras had positive monophasic P waves, and the other 5 had notched P waves. We did not detect second-degree atrioventricular block in the recording for any zebra.

All ECG variables were normally distributed, except for R wave amplitude. Values were determined for ECG variables of the 19 zebras (Table 1).

Echocardiography—Subjectively, none of the echocardiograms had evidence of any abnormalities. All views considered to be standard for echocardiography in horses were obtained in these zebras; however, right-sided images at the base of the heart were technically difficult to obtain and were of poor quality in all zebras. Echocardiographic image quality for 4 female zebras was considered poor for all views; therefore, results were determined for only 16 zebras. Only 9 zebras had images of sufficient quality to enable determination of left ventricular mass by use of method 2. All echocardiographic data were normally distributed, and values for the echocardiographic variables were summarized (Table 2).

Measurements significantly correlated with body weight included IVSd, LVIDd, LVIDs, left atrial diameter measured at end diastole from the left-sided parasternal inflow and outflow views, velocity of blood in the aorta, and left ventricular mass calculated by both methods. Bias between methods 1 and 2 for left ventricular mass was 708 g with wide limits of agreement (–64 to 1,481 g). Because there was an increase in variability of the differences as the magnitude of the measurement increased, results on the Bland-Altman graph were expressed as a percentage of the means in which bias was 44.5% with wide limits of agreement (16.5% to 72.4%; Figure 2). Detectable swirling of blood in the right and sometimes in the left ventricle was evident of 9 of 16 zebras for the left-sided parasternal inflow and outflow views. Physiologic regurgitation was detected in some zebras as a trace amount of regurgitant flow at the time of valve closure.
closure in association with a structurally normal valve. Three zebras had physiologic regurgitation through the aortic valve, 2 had physiologic regurgitation through the pulmonary valve, 2 had physiologic regurgitation through the mitral valve, and 1 had physiologic regurgitation through the tricuspid valve.

Discussion

To our knowledge, the study reported here is the first to provide ECG and echocardiographic measurements in healthy Grevy’s zebras. Findings from this study were similar to those reported for cardiac evaluation of domestic horses. Physiologic flow murmurs were detected in 4 of 20 (20%) healthy zebras, but this proportion was less than the value that has been reported for clinically normal horses (up to 53%). Chest conformation, positioning, and use of anesthesia in these zebras may have affected this result.

The QRS complex in the base-apex ECG from these zebras was predominantly negative with variable morphology of T waves and some notched P waves. Not surprisingly, these findings are identical to the congenic domestic horse, which has a class B ventricular activation pattern as a result of an extensive and deeply penetrating Purkinje network system. In contrast to reports in domestic horses, the mean heart rate was faster in the zebras reported here, and second-degree atrioventricular block was not detected. Lack of second-degree atrioventricular block has also been reported in domestic ponies; however, lack of second-degree atrioventricular block as well as the relatively high heart rate may have been influenced by the use of anesthetics in these zebras. The specific anesthetic protocol used in our study could explain some of these findings. Use of detomidine is associated with reflex bradycardia and second-degree atrioventricular block; however, the addition of acepromazine may have abated the vasoconstrictive effects and, therefore, the baroreflex activation induced by detomidine.

Temperament of the zebras prohibited the assessment of heart rate or rhythm without chemical restraint. Mean ECG amplitudes and durations were most similar to those for domestic ponies, except for QRS and QT durations, which were slightly longer than those for ponies and more similar to those of domestic horses. Although it was difficult to obtain clear echocardiographic images at the base of the heart, adequate image quality for the assessment of chamber and wall dimensions as well as Doppler assessment was possible for most of the zebras. Ease of imaging may have been improved had the zebras been in a standing position, which is most often used for cardiac imaging in horses; however, this was not possible because of the need to chemically immobilize the zebras.

Echocardiographic findings reported here should be interpreted in light of the anesthetic protocol used, and we recommend that future cardiac evaluation of zebras use similar protocols to control for inotropic and chronotropic alterations induced by anesthetic drugs. For example, detomidine can induce dose-dependent cardiovascular depression. Although systolic function in the zebras reported here appeared to be adequate, the effect of anesthetic drugs in these zebras could not be assessed because it was not possible to perform echocardiography in unanesthetized zebras. We believe the technique described here is applicable for the evaluation of captive zebras.

Detectable swirling of blood in the right and sometimes the left ventricles was evident in more than half (9/16 [56%]) of the zebras, which is similar to the frequency in Thoroughbreds. This detectable swirling of blood in the ventricles is not considered to be an abnormal finding in awake horses. It has been associated with age, sex, racing, and pregnancy in clinically normal horses but has also been associated with exercise.

Figure 2—Bland-Altman plot for 2 methods used for determination of left ventricular mass in Grevy’s zebras. Each square represents results for 1 zebra. The horizontal solid black line represents the mean value, and the horizontal dotted lines represent values 1.96 × SD above and below the mean, respectively.
induced pulmonary hemorrhage in racehorses. Given the high percentage of zebras in the study reported here that had detectable swirling of blood in the ventricles and otherwise normal echocardiographic results, this phenomenon may be considered a normal finding in this species as well. Anesthesia and the resultant effects on heart rate and inotropy, however, may have contributed to the visibility of intraventricular swirling of blood.

Physiologic regurgitation through a valve has been described in clinically normal horses and was detected in some zebras in the study reported here. This finding was not as common in these zebras (4/20 [20%]), compared with the proportion in horses (up to 78%). Additionally, whereas physiologic regurgitation through the tricuspid valve appears to be more common than for the other valves in clinically normal horses (13% to 78% of horses have physiologic tricuspid regurgitation), it was the valve that least commonly had physiologic regurgitation in the study reported here (1/19 [5%]). Echocardiographic detection of the trace amount of regurgitant blood flow associated with valve closure is dependent on high-quality images and examination of cardiac valves by use of several views. We found that the right-sided images at the base of the heart were difficult to obtain, possibly because of positioning of the zebras. This difficulty may explain the lower detection of physiologic regurgitation through the valves, especially the tricuspid valve, compared with results reported in horses.

Some echocardiographic variables, IVSd, LVIDd, LVIDs, left atrial diameter, and left ventricular mass, were found to be moderately correlated with body weight estimates. Although this finding is logical and similar patterns have been reported for horses and ponies, it should not be interpreted with caution because exact body weights were not determined. The use of a scale would have been ideal in the field setting.

Values for echocardiographic variables for the zebras were generally smaller than values reported for clinically normal horses. This was expected because of the size difference between zebras and horses (mean estimated body weight of zebras in the study reported here was 360 kg, compared with a mean body weight of 500 kg for a typical horse). Agreement was poor between the 2 methods for determination of left ventricular mass, and the wide limits of agreement make it difficult to derive an accurate correction factor by use of the bias. On the basis of these results, the 2 methods should not be used interchangeably in the same patient. Because the 2 methods were not compared with a criterion-referenced standard, neither method should be considered more accurate than the other.

The study reported here has limitations that should be recognized. Because Grevy's zebras are a rare species, the sample size was small, and this may affect the accuracy of the derived reference ranges. Another limitation was the use of estimated body weights, rather than actual measured values. Despite these limitations, we were able to obtain ECG and echocardiographic findings for this clinically normal group of captive Grevy's zebras. This information will be useful in the future as reference material for the evaluation of zebras suspected of having cardiac disease.

References