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▶ **To cite this version:**

HAL Id: hal-04454443
https://hal.inrae.fr/hal-04454443v1

Submitted on 21 Mar 2024

JAVMA

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Epidemiological, clinical, radiographic, echocardiographic findings and outcome in client-owned guinea pigs (*Cavia porcellus*) with cardiac disease: 80 cases (2010–2021)

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OBJECTIVE
To characterize epidemiological, clinical, radiographic, and echocardiographic features of cardiac diseases in guinea pigs examined at a referral exotics center.

ANIMALS
80 guinea pigs.

PROCEDURES
Medical records of guinea pigs that had echocardiography performed between June 2010 and January 2021 were reviewed.

RESULTS
The percentage of guinea pig patients with cardiovascular disease was 2.8%. Clinical signs included dyspnea (46/80), lethargy (18/80), and anorexia (10/80). The most common physical examination finding was heart murmur (10/80). Radiographic abnormalities included subjective cardiomegaly (37/67), pleural effusion (21/67), and increased lung opacity (40/67). Median (range) vertebral heart score on right lateral (48/67) and ventrodorsal (39/67) projections was 9.0 vertebrae (6.6 to 13.2 vertebrae) and 10.8 vertebrae (7.9 to 13.2 vertebrae), respectively. The most common echocardiographic diagnosis was cardiomyopathy (30/80), categorized as restrictive (11/30), hypertrophic (10/30), or dilated (9/10). Other cardiac diseases included cor pulmonale (21/80), pericardial effusion (18/80), congenital heart disease (6/80), acquired valvular disease (3/80), and cardiovascular mass (2/80). Congestive heart failure was present in 36 of 80. Median survival time from diagnosis was 2.5 months (95% CI, 1.1 to 6.2 months). Animals that died from heart disease had a significantly shorter survival time than those that died from a noncardiac disease (*P* = .02).

CLINICAL RELEVANCE
On radiographs, cardiomegaly, pleural effusion, and alveolar or interstitial lung pattern should be considered as indications for echocardiography in guinea pigs. Cardiomyopathy (restrictive, hypertrophic, or dilated), cor pulmonale, and pericardial effusion were the most common echocardiographic diagnoses. Further studies on diagnosis and treatment of cardiovascular diseases in guinea pigs are needed.

Information on cardiac diseases in guinea pigs (*Cavia porcellus*) is limited to few clinical cases and small case series in the literature.[1–5] An overall percentage of 1.2% of guinea pig patients with heart diseases has been reported in 1,000 pet guinea pigs, with an increase in percentage with age (0.9% in guinea pigs younger than 2 years, 1% between 2 and 5 years, and 4.8% over 5 years).[6]

The diagnosis of cardiac disease in guinea pigs is challenging. Clinical signs of heart disease are nonspecific, and radiographic signs have not been characterized yet in this species. Two recent studies[7,8] conducted in healthy guinea pigs provided methods for radiographic measurement of cardiac size using vertebral heart score (VHS) and established reference ranges for VHS. Neither plain radiographs

nor use of VHS has been assessed and validated in guinea pigs with cardiac disease. As in other small mammals, echocardiography is needed for a definitive diagnosis of cardiac disease in guinea pigs. However, echocardiography in guinea pigs is not routinely performed in general practice due to limited availability of dedicated equipment and the requirement for specific skills training, such as knowledge of guinea pig thoracic anatomy, as well as general ultrasonographic training. Two studies[9,10] have reported echocardiographic values in healthy guinea pigs, in 12 anesthetized animals and in 22 conscious animals. Based on our review of the literature, the echocardiographic findings in guinea pigs with different heart diseases have not been reported.

The objectives of this study were to (1) characterize the epidemiological features; (2) describe the clinical, radiographic, and echocardiographic findings; and (3) determine the clinical outcome and survival times in guinea pigs with heart disease.

Materials and Methods

Case selection

The database of the Centre Hospitalier Vétérinaire (CHV) ADVETIA was searched to identify all guinea pigs that had undergone an echocardiographic examination between June 2010 and January 2021. Patients were selected for inclusion by 2 of the authors, a small mammal veterinary resident (JRN) and a board-certified veterinary cardiologist (VG). Patients were included if they had a complete echocardiographic examination with an available echocardiographic report. Animals for which the echocardiography did not detect any abnormality or was not conclusive were excluded. Medical records, radiographs, and echocardiographic images and video clips were reviewed.

Medical records review

Data retrieved from the medical records of the selected guinea pigs included signalment (age at time of echocardiographic examination, sex, and body weight), presenting clinical signs, significant physical examination findings, results of radiographic and echocardiographic examinations, presence of congestive heart failure (CHF), and presence of any primary respiratory disease.

Radiographic examination

Radiographic examinations were performed using a diagnostic x-ray apparatus (ARIA 4343; Demas Srl), a tabletop technique of 56 to 68 kVp and 2.5 mAs, and a 1-m focal-film distance. Images were stored in a picture archiving communication system (PACS) and analyzed by use of a dedicated medical image viewer (Vue PACS version 12.1.6; Koninklijke Philips NV). Right lateral (RL) and ventrodorsal (VD) radiographs, obtained within the 7 days preceding the echocardiography, were selected for review by a board-certified veterinary radiologist (HG). The size of the cardiac silhouette was assessed first subjectively (ie, cardiomegaly or

normal size), then the VHS was calculated according to previous recommendations.[7,8] Cardiac long axis (from the ventral border of the left main stem bronchus to the cardiac apex) and short axis (at the mid-third of the long axis and perpendicular to it) were expressed in units of vertebral length, to the nearest 0.1 vertebra, by repositioning these scales over the thoracic spine, starting at the cranial end plate of T4 on the same projection. Cardiac long axis and short axis measurements were summed to yield the VHS in each view (RL-VHS and VD-VHS). Presence of abnormal lung patterns (interstitial, bronchial, vascular, and alveolar) and presence of pleural effusion were recorded.

Echocardiographic examination

All echocardiographic examinations were performed on conscious, nonsedated guinea pigs by a board-certified veterinary radiologist (HG or YR) or board-certified veterinary cardiologist (VG) using either a 4- to 12-MHz phased-array transducer (Ultrasound system VE 90; General Electric) or 4- to 9-MHz phased-array transducer (Aplio 300 Ultrasound; Canon Medical Systems Corp).

Standard echocardiographic examination included 2-D, M-mode, color Doppler, and spectral Doppler. All echocardiographic still images and video clips were stored and reviewed using the same PACS and medical image viewer as for radiographs. All images and clips were analyzed by the cardiologist who assigned a final diagnosis. M-mode was used for measurements of the left ventricle (LV) internal diameter in diastole and systole, the thickness of the interventricular septum, and the LV free wall in diastole and systole, as previously described.[10] Left ventricular hypertrophy was diagnosed when the interventricular septum and/or the LV free wall thickness exceeded 2.4 mm in diastole, corresponding to the upper limit of the published reference ranges.[10] The LV shortening fraction was automatically calculated. The right ventricle (RV) internal diameter in diastole and RV wall thickness in systole were also measured on transventricular M-mode images. Considering the lack of reference values for the right heart dimensions in the literature, the RV was considered dilated when its internal diameter exceeded 3 mm in diastole and hypertrophic when its free wall thickness exceeded 2.5 mm in systole. The left atrium-to-aorta ratio was calculated using a 2-D right parasternal transaortic short-axis view for measuring left atrial size as previously described in dogs in early diastole,[11] and presence of left atrial dilation was considered for any ratio exceeding 1.6, according to published reference range.[10] Measurements of the aortic and pulmonary trunk (PT) diameters were performed on a 2-D right parasternal transaortic short-axis view, as previously described in dogs.[12] Considering the lack of published reference values for the PT diameter, dilatation of the PT was considered for any PT-to-aorta ratio exceeding 1.0, according to the echocardiographic measurements the authors obtained in 39 healthy guinea pigs. The left and right atrial diameters were measured at end-diastole at the level of the atrioventricular valves using the 2-D right parasternal 4-chamber view, and the right atrium-to-left atrium ratio was then calculated.[13] The RA was considered dilated when the right atrium-to-left atrium ratio

was above 1.5. Spectral Doppler examination of the aortic and pulmonary flows was performed as previously described in guinea pigs.[10] The aortic flow was used to calculate heart rates. The 4 cardiac valves were assessed by color flow Doppler for the presence of any insufficiency. When possible, any measurement that was not mentioned in the echocardiographic report was taken retrospectively on the stored images. The presence of pericardial effusion, pleural effusion, thoracic mass, and ascites was also recorded.

The final echocardiographic diagnosis that was assigned to each animal after review of all images and completion of complementary measurements could be different from the initial diagnosis. Hypertrophic cardiomyopathy was diagnosed when left ventricular wall hypertrophy was noticed with no eliciting cause, as proposed in cats.[14] Similarly, dilated cardiomyopathy was diagnosed in animals with LV systolic dysfunction, as indicated by an increase in LV internal diameters with normal to reduced LV wall thickness and atrial dilation.[14] Restrictive cardiomyopathy was considered in cases showing normal LV dimensions (internal diameter and wall thickness in diastole and systole) and left atrial or biatrial enlargement in the absence of significant degenerative mitral valve disease.[14] Animals with right heart dilation and/or RV hypertrophy associated with clinical respiratory signs and/or radiographic changes indicative of pulmonary/pleural disease were classified as cor pulmonale. Idiopathic pericardial effusion was diagnosed in animals with a significant amount of pericardial effusion that was not related to neoplasia or CHF secondary to an underlying heart disease. In animals with several echocardiographic examinations, the final diagnosis was also made on the basis of the overall course of the disease and the most relevant echocardiographic findings.

Congestive heart failure

Presenting complaint, physical examination findings (eg, dyspnea, heart murmur, weight loss, and peripheral edema), radiographic findings (eg, pleural effusion, lung congestion, pulmonary edema, and ascites), and echocardiographic findings (eg, left or right atrial dilation) were used to determine whether CHF was present.

Follow-up data collection

The dead or alive status of guinea pigs and the date and cause of death were either retrieved from medical records when available or sought from owners by telephone when possible. Guinea pigs for which the dead or alive status could not be obtained at the end of the study period were considered lost to follow-up and were consequently excluded from the survival study.

Survival time

Cardiac disease–specific survival time was defined as the time between echocardiographic diagnosis and death or euthanasia attributable to cardiac disease.

Statistical analysis

Statistical analysis was conducted in R[15] by one of the authors (AA). The percentage of cardiovascular disease in guinea pig patients was calculated by dividing the number of guinea pigs selected for the study by the total number of guinea pigs examined at CHV ADVETIA during the study period.

All variables were assessed for normality using the Shapiro-Wilk test. Normally distributed data were expressed as mean ± SD (SD) and range, and data for which normality was rejected were expressed as median, IQR, and full range. For count data, percentages were reported. For nonnormal data, differences in the distribution of continuous variables between 2 groups were evaluated using the Wilcoxon rank sum test. A survival analysis was performed by use of the Kaplan-Meier method. Survival times were compared between animals that died from heart disease versus noncardiac disease by use of the log-rank test. Univariate Cox proportional hazard modeling was performed to identify factors associated with survival time, with a log transformation of the age to respect the proportional hazard assumptions. The R packages *survival* and *survminer* (R Foundation for Statistical Computing) were used for these tasks. Significance level was considered with α = 0.05.

Results

Study population

Ninety-nine guinea pigs met the inclusion criteria. Nineteen animals were excluded because of unremarkable echocardiography, leading to a study population of 80 guinea pigs. During the study period, 2,864 guinea pigs were presented at CHV ADVETIA, giving a percentage of cardiac diseases diagnosed by echocardiography of 2.8% (80/2,864) in guinea pigs in our hospital.

Epidemiological data

Eight different types of cardiac disease were identified by echocardiography. Epidemiological data of guinea pigs are presented for the study population and each type of cardiac disease **(Table 1)**.

Table 1—Epidemiological and clinical characteristics of the study population.

Variable	All cardiac diseases	Dilated cardio-myopathy	Restrictive cardio-myopathy	Hypertrophic cardio-myopathy	Acquired valvular heart	Pericardial effusion disease	Heart neoplasia	Congenital heart disease	Cor pulmonale
Guinea pigs n (%)	80 (100%)	9 (11.3%)	11 (13.8%)	10 (12.5%)	3 (3.8%)	18 (22.6%)	2 (2.5%)	6 (7.5%)	21 (26.3%)
Males n (%)	42 (52.5%)	3 (33.3%)	3 (27.3%)	7 (70.0%)	1 (33.3%)	7 (38.9%)	2 (100%)	4 (66.7%)	15 (71.4%)
Age (years; n = 80)	4.3 (0.4–7.2)	5.1 (3.9–6.6)	4.4 (1.3–7.1)	5.0 (2.3–6.8)	3.8 (2.5–7.2)	4.3 (2.1–7.2)	4.7 (4.0–5.3)	3.5 (0.9–4.9)	4.0 (0.5–5.9)
Body weight (kg; n = 74)	1.06 ± 0.24	0.97 ± 0.20[f]	1.08 ± 0.17[g]	1.12 ± 0.20[g]	1.01 ± 0.30[b]	1.11 ± 0.29[i]	1.38 ± 0.04[a]	1.00 ± 0.12[d]	1.02 ± 0.28[j]
Heart rate (bpm; n = 26)	281 ± 47	253 ± 69[c]	350 ± 85[a]	275 ± 35[a]	290 ± 1[a]	N/A	N/A	247 ± 15[b]	286 ± 37[h]

Data are presented as median and range for age and mean ± SD for body weight and heart rate.
bpm = Beats per minute. n = Number of guinea pigs. N/A = Not applicable, as median cannot be provided due to lack of data.
[a]Number of animals = 2. [b]Number of animals = 3. [c]Number of animals = 4. [d]Number of animals = 6. [f]Number of animals = 8. [g]Number of animals = 9. [h]Number of animals = 13. [i]Number of animals = 17. [j]Number of animals = 20.

In the study population, 42 of 80 (52.5%) animals were males and 38 of 80 (47.5%) were females. Seven (8.8%) animals were neutered, including 2 females and 5 males. Median age at time of echocardiographic examination was 4.3 years (IQR, 3.35 to 5.25 years) in the study population; age ranged from 0.4 to 7.2 years. No significant difference in age was found between males and females (4.3 years [IQR, 3.4 to 5.2 years] and 4.4 years [IQR, 3.55 to 5.25 years], respectively; P = .29). Mean ± SD body weight was 1.06 ± 0.24 kg; body weight ranged from 0.60 to 1.70 kg. Males were significantly heavier than females (1.12 ± 0.26 kg and 0.98 ± 0.20 kg, respectively; P = .01).

Presenting clinical signs and physical examination findings

The most common clinical signs were dyspnea (46/80 [57.5%]), lethargy (18/80 [22.5%]), and anorexia (10/80 [12.5%]). Physical examination findings thought to be related to the underlying cardiac disease included heart murmur (10/80 [12.5%]), weight loss (6/80 [7.5%]), peripheral edema (4/80 [5%]), and gallop rhythm (1/80 [1.25%]).

Radiographic findings

A total body radiographic study performed within the 7 days preceding the echocardiography was available in 67 of 80 (83.8%) animals. Relevant radiographic findings included subjective cardiomegaly (37/67 [55.2%]), pleural effusion (21/67 [31.3%]), and increased lung opacity (40/67 [59.7%]) with the main patterns distributed as follows: alveolar (18/40 [45%]), interstitial (16/40 [40%]), vascular (3/40 [7.5%]), bronchial (2/40 [5%]), and peribronchial (1/40 [2.5%]). Ascites was suspected in 6 of 67 (9%) animals. A cor pulmonale was diagnosed on echocardiogram in 19 of 67 guinea pigs. In this group, radiographs showed pleural effusion (8/19 [42.1%]), increased lung opacity (13/19 [68.4%]), or subjective cardiomegaly (8/11 [72.7%]). Heart disease other than cor pulmonale was diagnosed in 48 of 67 guinea pigs that had a radiographic examination. Twenty-nine of these animals (29/48 [60.4%]) showed radiographic thoracic changes consistent with CHF, such as increased lung opacity (24/29 [82.8%]) and pleural effusion (13/29 [44.8%]). Main lung patterns of CHF were distributed as follows: interstitial (14/24 [58.3%]), alveolar (7/24 [29.2%]), and vascular (3/24 [12.5%]).

The VHS could be measured in 48 of 67 (71.6%) guinea pigs on RL projection and in 39 of 67 (58.2%) animals on VD projection. In 19 of 67 guinea pigs, border effacement of the cardiac silhouette contour prevented measurement of VHS on both projections.

The poor delineation of the cardiac silhouette was considered to be due to pleural effusion (12/19), increased lung opacities silhouetting with the heart (4/19), or excessive retraction of inflated lung field secondary to severe cardiomegaly (3/19). In 9 of 67 guinea pigs, VHS could be measured on RL but not VD projection because of lung opacities (6/9) or poor lung field expansion due to severe cardiomegaly (3/9). Median RL-VHS measured in 48 guinea pigs was 9.0 vertebrae (IQR, 8.0 to 9.3 vertebrae); RL-VHS ranged from 6.6 to 13.2. Median VD-VHS measured in 39 guinea pigs was 10.8 vertebrae (IQR, 9.4 to 11.8 vertebrae); VD-VHS ranged from 7.9 to 13.2. The values of RL-VHS and VD-VHS obtained in each group of cardiac disease are presented **(Table 2)**.

Echocardiographic findings

The echocardiographic measurements obtained in each type of heart disease are presented for the left heart **(Table 3)** and right heart **(Table 4)**. The most common heart diseases were cardiomyopathies (30/80 [37.5%]), categorized as restrictive (11/80 [13.8%]), hypertrophic (10/80 [12.5%]), and dilated (9/80 [11.3%]).

The next most common cardiac disease was cor pulmonale (21/80 [26.3%]). The final or presumptive diagnosis of an underlying disease with the potential for pulmonary hypertension was available in 14 of 21 animals and included pneumonia (n = 6), pleuropneumonia (4), chronic bronchitis (1), thoracic lymphoma (1), pleural carcinomatosis (1), and lung mass of undetermined origin (1). The remaining 7 animals were presented for respiratory signs but no final or presumptive diagnosis of respiratory disease could be retrieved from the medical records.

A pericardial effusion that was not related to neoplasia or CHF secondary to an underlying heart disease was noticed in 18 of 80 (22.5%) guinea pigs and was associated with cardiac tamponade in 4 of 18 (22.2%) animals. In most cases (17/18 [94.4%]), a diagnosis of idiopathic pericardial effusion was presumed. One guinea pig had a final diagnosis of fibrosing lymphocytic-plasmocytic pericarditis at necropsy.

Congenital heart disease was diagnosed in 6 of 80 (7.5%) guinea pigs. Five animals had a single congenital heart disease, including tricuspid valve dysplasia (n = 2), ventricular septal defect (1), atrial septal defect (1), and pulmonic stenosis (1). One guinea pig showed the association of a ventricular septal defect with a pulmonic stenosis.

An acquired valvular disease was diagnosed in 3 of 80 (3.8%) animals, including severe aortic insufficiency (n = 1), degenerative mitral valve disease (1), and endocarditis (1).

Finally, a cardiovascular mass was noticed in 2 of 80 (2.5%) animals, including a pulmonary artery

Table 2—Values of the vertebral heart score (VHS) obtained in 48 guinea pigs with a cardiac disease diagnosed by echocardiography.

VHS score	Total	Dilated cardio-myopathy (n = 5)	Restrictive cardio-myopathy (n = 8)	Hypertrophic cardio-myopathy (n = 4)	Acquired valvular heart disease (n = 1)	Pericardial effusion (n = 14)	Heart neoplasia (n = 2)	Congenital heart disease (n = 3)	Cor pulmonale (n = 11)
RL-VHS (n = 48)	9.0 (6.6–13.2)	8.8 (7.6–9.1)	9.2 (8.4–9.8)	10.1 (9.2–11.2)	7.7 (7.7)	9.3 (6.6–10.1)	8.6 (8.2–8.9)	8.5 (7.8–8.6)	8.0 (6.7–13.2)
VD-VHS (n = 39)	10.8 (7.9–13.2)	10.8 (9.3–12.8)	10.3 (8.6–12.7)	12.2 (11.1–13.2)[a]	9.4 (9.4)	9.3 (9.1–13.2)[c]	9.6 (8.9–10.3)	10.8 (10.0–11.6)[a]	10.7 (7.9–12.4)[b]

The VHS could be measured on the right lateral projection (RL-VHS) in all 48 guinea pigs and on the ventrodorsal projection in 39 of 48 guinea pigs. The VHS values presented in this table were obtained in guinea pigs with varying types and severity of heart disease (ranging from mild form in few cases to severe heart disease with congestive heart failure and short survival time despite targeted treatment). Values of RL-VHS and VD-VHS are presented as median and range.

n = Number of guinea pigs.

[a]Number of animals = 2. [b]Number of animals = 7. [c]Number of animals = 12.

Table 3—Echocardiographic measurements of the left heart in 80 guinea pigs with heart disease diagnosed by echocardiography.

Variable	Dilated cardio-myopathy (n = 9)	Restrictive cardio-myopathy (n = 11)	Hypertrophic cardio-myopathy (n = 10)	Acquired valvular heart disease (n = 3)	Pericardial effusion (n = 18)	Heart neoplasia (n = 2)	Congenital heart disease (n = 6)	Cor pulmonale (n = 21)
Interventricular septum thickness at end-diastole (mm)	2.1 (1.6–2.7)[f]	2.1 (1.8–2.6)[h]	3.2 (2.1–4.0)	2.0 (1.9–3.4)	2.5 (1.6–3.4)[m]	2.4[a]	2.1 (1.6–3.4)	2.2 (1.4–3.3)[m]
Left ventricular internal diameter at end-diastole (mm)	12.9 (10.9–15.1)[f]	10.1 (9.2–12.8)[h]	10.4 (6.3–14.4)	13.1 (9.4–13.5)	10.1 (6.7–12.2)[m]	9.9[a]	10.6 (7.0–12.7)	9.6 (5.9–13.3)[o]
Left ventricular posterior wall thickness in diastole (mm)	2.4 (1.6–3.0)[f]	2.4 (1.8–3.0)[h]	3.4 (2.7–5.6)	2.3 (2.0–3.2)	2.9 (2.0–3.9)[m]	2.1[a]	2.6 (1.8–4.6)	2.8 (1.4–4.5)[m]
Interventricular septum thickness at end-systole (mm)	2.5 (1.6–3.8)[f]	3.2 (3.0–3.7)[h]	4.2 (2.1–5.3)	2.7 (2.5–4.6)	3.4 (2.4–6.2)[m]	3.5[a]	3.3 (2.8–4.7)	3.4 (1.7–4.8)[n]
Left ventricular at internal diameter end-systole (mm)	10.6 (8.0–13.3)[f]	7.1 (5.3–8.5)[h]	7.3 (4.6–9.5)	8.3 (5.8–9.9)	5.7 (2.1–8.1)[m]	6.9[a]	5.8 (4.8–8.2)	6.1 (3.5–9.4)[n]
Left ventricular posterior wall thickness in systole (mm)	3.3 (2.2–4.7)[f]	4.0 (3.1–4.7)[h]	4.5 (3.0–6.7)	3.6 (3.0–4.9)	4.4 (3.0–5.6)[m]	3.9[a]	4.3 (3.0–6.1)	4.1 (2.6–5.5)[o]
Fractional shortening (%)	21.8 (7.5–28.3)[f]	33.8 (28.7–43.4)[h]	34.5 (11.5–56.3)	36.8 (26.3–37.5)	40.7 (19.5–66.7)[m]	30.1[a]	36.0 (29.4–50.3)	40.7 (29.3–54.0)[m]
Left atrium (mm)	9.3 (4.8–11.8)[f]	9.7 (4.5–11.8)[g]	8.4 (5.3–11.5)[g]	N/A (4.2–10.1)[b]	6.8 (4.5–9.1)	6.0[a]	5.9 (3.8–6.7)	5.5 (4.2–9.0)[p]
Aorta (mm)	5.4 (4.8–6.3)[f]	5.7 (3.7–6.6)[g]	6.1 (5.3–7.0)[g]	6.1 (5.8–6.6)	5.3 (4.4–7.6)	6.2[a]	6.1 (5.1–8.0)	5.9 (4.1–7.9)
Left atrium-to-aorta ratio	1.7 (0.9–2.0)[f]	1.8 (1.0–2.0)[g]	1.4 (0.9–2.2)[g]	N/A (0.9–1.0)	1.2 (0.9–1.8)[l]	1.0[a]	0.9 (0.6–1.2)	1.0 (0.7–3.0)
Maximal aortic velocity (m/s)	0.5 (0.3–0.8)[c]	N/A (0.9–1.0)[b]	N/A (0.6–0.7)[b]	N/A (0.8–0.9)	N/A	2.4[a]	1.0 (0.1–1.9)[d]	0.9 (0.6–1.1)[k]

The echocardiographic values presented in this table were obtained in guinea pigs with varying types and severity of heart disease (ranging from mild form in few cases to severe heart disease with congestive heart failure and short survival time despite targeted treatment). Variables are presented as median and (range).

n = Number of guinea pigs. N/A = Not applicable, as median cannot be provided due the lack of data.

[a]Number of animals = 1. [b]Number of animals = 2. [c]Number of animals = 4. [d]Number of animals = 5. [e]Number of animals = 6. [f]Number of animals = 8. [g]Number of animals = 9. [h]Number of animals = 10. [i]Number of animals = 11. [j]Number of animals = 13. [k]Number of animals = 14. [l]Number of animals = 16. [m]Number of animals = 17. [n]Number of animals = 18. [o]Number of animals = 19. [p]Number of animals = 20.

Table 4—Echocardiographic measurements of the right heart in 80 guinea pigs with heart disease diagnosed by echocardiography.

Variable	Dilated cardio-myopathy (n = 9)	Restrictive cardio-myopathy (n = 11)	Hypertrophic cardio-myopathy (n = 10)	Acquired valvular heart disease (n = 3)	Pericardial effusion (n = 18)	Heart neoplasia (n = 2)	Congenital heart disease (n = 6)	Cor pulmonale (n = 21)
Right ventricular diameter in diastole (mm)	3.8 (0.7–7.2)	5.1 (1.3–9.3)	3.3 (0.5–7.4)	3.9 (1.8–4.4)	3.7 (0.2–6.6)	N/A (4.1–8.6)	4.4 (0.1–6.7)	4.0 (0.7–8.3)[o]
Right ventricular wall in systole (mm)	1.8 (1.1–2.4)	2.2 (1.5–4.2)	2.3 (1.6–3.2)	2.1 (1.9–2.3)	2.1 (1.4–3.6)	N/A (1.6–1.9)	2.2 (1.7–3.4)	2.1 (1.5–3.0)[n]
Pulmonary trunk diameter in diastole (mm)	5.4 (4.6–6.7)[d]	4.9 (4.2–6.6)[f]	4.8 (4.4–5.3)	5.0 (4.9 – 5.0)	4.9 (4.1–5.6)[g]	N/A (4.0–5.2)	5.5 (4.0–7.5)	5.1 (4.1–6.8)[j]
Aortic diameter in diastole (mm)	5.8 (4.7–6.7)[d]	5.5 (4.8–6.2)[f]	5.2 (5.0–6.0)[c]	5.5 (5.2–5.6)	5.2 (4.6–7.5)[g]	N/A (4.5–5.8)	5.9 (4.9–7.3)	5.5 (4.1–6.6)
Pulmonary diameter trunk-to-aorta ratio	1.0 (0.8–1.1)[d]	0.9 (0.8–1.1)[f]	0.9 (0.8–1.0)[c]	0.9 (0.9–1.0)	0.9 (0.7–1.1)[g]	N/A (0.8–0.9)	0.9 (0.8–1.5)	1.0 (0.8–1.6)[j]
Right atrial end-diastolic diameter (mm)	8.6 (6.8–11.8)[b]	10.5 (7.4–11.1)[f]	9.3 (7.2–10.6)[c]	N/A (9.5–10.3)[a]	7.7 (3.8–10.5)[h]	N/A (8.8–14.1)	10.9 (8.5–12.3)[c]	8.9 (5.7–11.1)[j]
Left atrial end-diastolic diameter (mm)	8.6 (8.0–12.6)[b]	9.1 (6.3–10.8)[f]	10.6 (7.9–11.4)[c]	N/A (7.8–9.7)[a]	7.7 (6.2–10.4)[h]	N/A (4.3–6.4)	4.6 (4.2–8.0)[c]	7.3 (3.4–9.8)[j]
Right atrial-to-left atrial diameter ratio	0.8 (0.8–1.4)[b]	1.1 (0.7–1.7)[f]	0.9 (0.8–1.3)[c]	N/A (1.0–1.3)[a]	1.0 (0.5–1.3)[h]	N/A (1.4–3.3)	2.2 (1.5–2.9)[c]	1.2 (0.6–3.1)[j]
Maximal pulmonary trunk velocity (m/s)	0.8 (0.4–1.5)[b]	0.7 (0.6–0.9)[b]	0.9 (0.9–1.0)[c]	N/A (0.8–1.1)	N/A (1.0–1.8)[a]	N/A	2.8 (0.7–4.2)	0.9 (0.3–2.1)[j]

The echocardiographic values presented in this table were obtained in guinea pigs with varying types and severity of heart disease (ranging from mild form in few cases to severe heart disease with congestive heart failure and short survival time despite targeted treatment). Variables are presented as median and range.

n = Number of guinea pigs. N/A = Not applicable, as median cannot be provided due to the lack of data.

[a]Number of animals = 2. [b]Number of animals = 4. [c]Number of animals = 5. [d]Number of animals = 6. [e]Number of animals = 8. [f]Number of animals = 9. [g]Number of animals = 10. [h]Number of animals = 11. [i]Number of animals = 13. [j]Number of animals = 14. [k]Number of animals = 16. [l]Number of animals = 17. [m]Number of animals = 18. [n]Number of animals = 19. [o]Number of animals = 20.

mass (n = 1) and a myocardial sarcoma (1) that was confirmed at necropsy.

Congestive heart failure

Congestive heart failure was present in 36 of 80 (45%) guinea pigs, including 17 males and 19 females. Median age of animals with CHF was 4.3 years (IQR, 3.4 to 5.2 years), with age ranging from 0.5 to 7.2 years. The percentage of animals with CHF, either left-sided, right-sided, or global, for each type of heart disease is presented **(Figure 1)**. All guinea pigs with restrictive cardiomyopathy had signs of CHF at initial presentation. Congestive heart failure was noticed in 8 of 10 (80%) animals with hypertrophic cardiomyopathy and in 6 of 9 (66.7%) animals with dilated cardiomyopathy.

Treatment

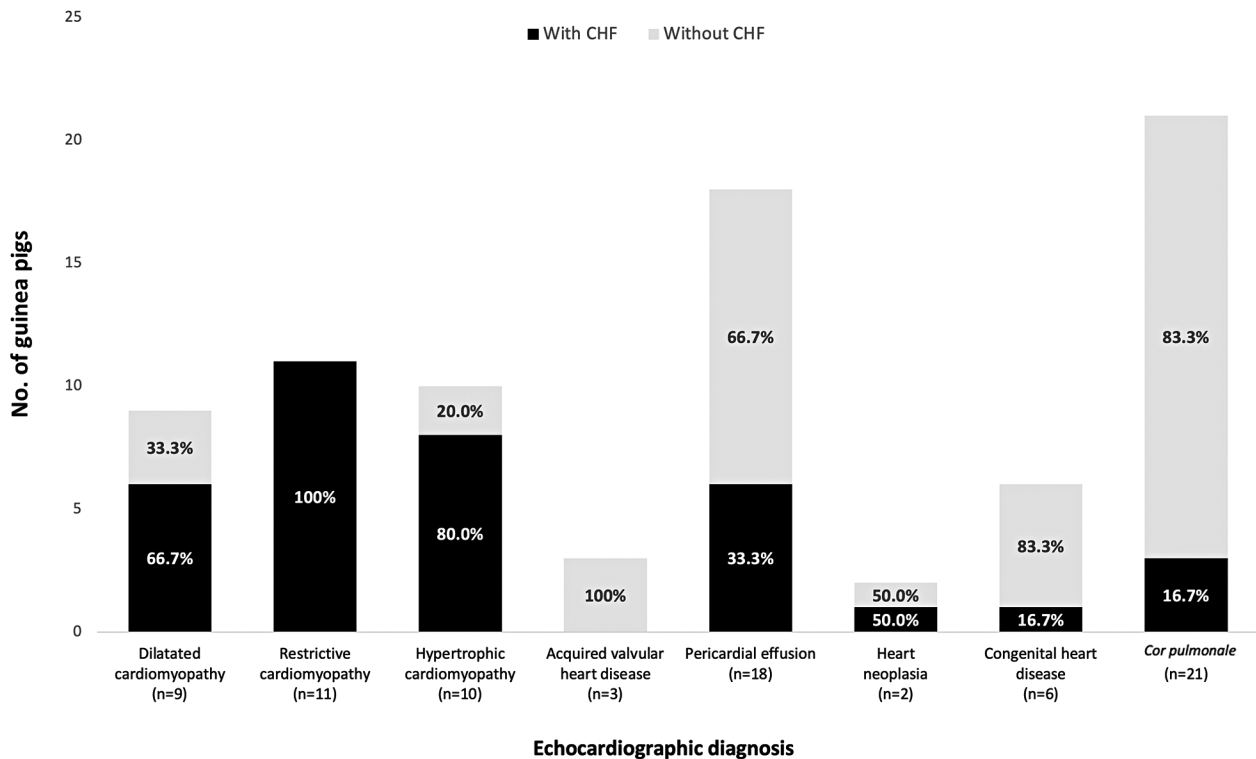Sixty-five of 80 (81.3%) animals received medical treatment. Furosemide was given to 41 (41/65 [63%])

Figure 1—Distribution of guinea pigs with (black bars) and without (gray bars) congestive heart failure (CHF; left-sided, right-sided, or global) for the different types of heart disease diagnosed by echocardiography. n = Number of guinea pigs.

animals, including the 36 animals with CHF. Pimobendan and an angiotensin-converting enzyme inhibitor (benazepril, imidapril, or ramipril) were given to 32 of 65 (49.2%) and 12 of 65 (18.5%) animals, respectively, either alone or in association with furosemide. A single antibiotic (doxycycline, azithromycin, enrofloxacin, marbofloxacin, cephalosporin, or trimethoprim/sulfonamide) was given to 39 of 65 (60%) animals, based on the clinical and radiographic suspicion of pneumonia or in animals with pericardial effusion of undetermined origin.

Survival analysis

Two guinea pigs were lost to follow-up. At the time of final follow-up, 74 of 78 (94.9%) animals were dead and 4 of 78 (5.1%) were alive. Cause of death was determined in the 74 guinea pigs. Death was related to cardiac disease in 46 of 74 (62.2%) animals and was either spontaneous (35/46 [76%]) or by euthanasia (11/46 [24%]) as requested by the owners. Causes of death not related to the underlying heart disease included gastrointestinal disease (15/28), dental disease (4/28), neoplasia (3/28), urinary tract disease (3/28), endocrinopathy (1/28), neurological disease (1/28), and trauma (1/28).

Survival time from diagnosis of cardiac disease in 78 guinea pigs is presented elsewhere **(Supplementary Figure S1)**. Overall median survival time was 2.5 months (95% CI, 1.1 to 6.2 months). Median survival time in guinea pigs with heart-related death was 1 month (95% CI, 0.24 to 2.3 months). Median survival time in guinea pigs with death related to a noncardiac disease was 7.7 months (95% CI, 3.8 to 12.1 months). Animals that died from heart disease had a significantly shorter survival time than those that died from a noncardiac disease (P = .02), as shown **(Figure 2)**.
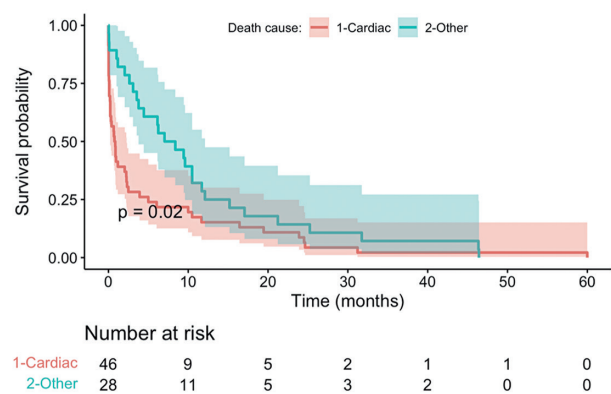

Figure 2—Kaplan-Meier curves illustrating survival times in guinea pigs diagnosed with heart disease from diagnosis for individuals with heart-related death (n = 46; red line) and for individuals with noncardiac disease–related death (28; green line). Median survival time in guinea pigs with heart-related death was 1 month (95% CI, 0.24 to 2.23 months). Median survival time in guinea pigs with death related to a noncardiac disease was 7.7 months (95% CI, 3.8 to 12.1 months). Survival time was significantly shorter in guinea pigs that died from heart disease than in guinea pigs that died from a noncardiac disease (P = .02). Ninety-five percent CIs are displayed in light red for the red line and in light blue for the blue line.

Using univariate analysis, no significant association was found between survival time from diagnosis and any of the following characteristics: sex, log(age), body weight, heart rate, presence of CHF, final diagnosis, and presence of left atrial dilation defined as left atrial-to-aortic root ratio above 1.6.

Discussion

Based on our review of the literature, this study was the first survey to describe epidemiological, clinical, radiographic, and echocardiographic features of cardiac diseases on a large population of client-owned guinea pigs and to provide information on survival time.

The percentage of guinea pig patients with heart disease in the current study was more than twice the percentage reported by Minarikova et al[6] in guinea pigs with heart disease (2.8% and 1.2%, respectively). Both studies were conducted in a referral center. The difference in percentage of guinea pig patients with heart disease might be related to the difficulty in suspecting heart disease in guinea pigs due to the absence of specific symptoms and the commonly normal cardiac auscultation in guinea pigs with cardiac disease. Compared with other species, the percentage of guinea pig patients with heart disease in our study was close to the percentage reported in rabbits with heart disease (2.6%)[16] and much lower than the percentages reported in dogs and cats with heart disease, which are approximately 4 times that observed in the current study.[17–19] This lower percentage of guinea pig patients with heart disease might be explained by the fact that some cases with mild to moderate cardiac disease could have been underdiagnosed due to the nonspecific clinical signs in this species.

No sex, age, or body weight predisposition was observed, neither in the study population nor in any of the categories of heart disease described in the current study.

The most common clinical signs were dyspnea, lethargy, and anorexia, which was in accordance with previously published data in guinea pigs.[20,21] Similarly to rabbits,[16] clinical signs of heart disease were nonspecific in guinea pigs, explaining the challenge in diagnosing heart disease in lagomorphs and rodents. Contrary to dogs and cats with heart disease in which an abnormal auscultation is commonly noticed, a heart murmur was rarely heard in guinea pigs with heart disease (13.8%) and a gallop rhythm was noticed once. This might be explained by the high heart rates in guinea pigs (mean heart rate of 281 beats/min in this study; normal guinea pig heart rate 240 to 310 beats/min) compared with dogs and cats. In 2 of 80 guinea pigs (one presented for hematuria and the other for alopecia), heart disease was incidentally suspected on screening whole body radiographs and confirmed echocardiographically. Considering the rarity of auscultation abnormalities and the lack of specificity of clinical signs in guinea pigs suffering from heart disease, concomitantly with echocardiography, whole body radiographs, electrocardiograms to search for dysrhythmias that can be undetectable on auscultation, blood pressure measurement to detect hypotension due to poor cardiac output or relative blood pressure estimated based on carotid doppler, and abdominal ultrasound to search for liver congestion are recommended in case of nonspecific clinical signs to diagnose or rule out heart disease.[22] A thoracic radiographic examination was available in 67 guinea pigs. Subjective cardiomegaly was observed in 37 of 67 (55.2%) animals. This percentage might suggest that subjective radiographic assessment of the heart size is not a very sensitive method for detecting heart disease in guinea pigs. The VHS could not be measured in almost one-third (19/67) of the RL projections and half (28/67) of the VD projections, mostly because of pleural effusion or increased lung opacity masking the heart margins. On 9 radiographs (6 VD and 3 RL projections) with no pleural effusion or increased lung opacity, border effacement of the cardiac silhouette preventing VHS measurement was noticed. Severe cardiomegaly was observed on echocardiography in the 9 cases, suggesting that a severely enlarged heart could induce caudal retraction of the cranial lung field, making the cranial and lateral margins of the heart not clearly visible. The cranial location of the heart in the thoracic cavity of healthy guinea pigs, illustrated by a carina projecting over the third intercostal space and a frequently ill-defined cranial border of the heart, might be a predisposing factor to caudal retraction of the cranial lung field and poor visualization of cardiac margins in the presence of severe cardiomegaly. These results highlight the relative limitation of radiography and the importance of echocardiography in detecting cardiac diseases in guinea pigs and suggest that echocardiography should be recommended in any guinea pig with thoracic changes impeding assessment of cardiac size.

When compared with the reference values published by De Silva et al,[8] RL-VHS in the current study showed a median above the reference median (9.0 vs 7.4 vertebrae), an IQR above the reference IQR (8 to 9.3 vs 7.1 to 7.6), and a range encompassing the reference range with higher upper values (6.6 to 13.2 vs 6.6 to 8.0). Additionally, 43 of 48 (89.5%) animals had an RL-VHS over 7.6 (third quartile of the reference IQR) and 41 of 48 (85.4%) animals had an RL-VHS above 8.0 (upper value of the reference range). These results suggest that RL-VHS might be useful in detecting cardiomegaly in guinea pigs. Comparison of the VD-VHS obtained in 39 guinea pigs with published reference values was less relevant, as the only data available in the literature is the mean VD-VHS ± SD published by Masoudifard et al[9] in 20 mature guinea pigs (9.2 ± 0.23 vertebrae). The median and IQR of VD-VHS obtained in our study (10.8 vertebrae and 9.4 to 11.8, respectively) were above the mean reference value, but the range of VD-VHS (7.9 to 13.2) widely encompassed the published reference values. Considering the overlapping of VHS values between the current study and those conducted in healthy guinea pigs, further studies are required to determine the accuracy of the VHS for radiographic evaluation of cardiomegaly in guinea pigs.

Pleural effusion and/or increased lung opacity were noticed on radiographs in 44 of 67 guinea pigs. A radiographic diagnosis of CHF was made in 29 of 44 animals based on left heart changes on echocardiogram and current pleural and/or pulmonary radiographic changes consistent with fluid overload. In guinea pigs with CHF that showed an increased lung opacity (n = 24), lung vessel enlargement was noticed in very few cases (3/24 [12.5%]). This result

might relate to the small size of lung vessels in this species leading to a low sensitivity of radiography in detecting lung congestion. The most common lung patterns observed in animals with left-sided CHF were interstitial (14/24 [58.3%]) and alveolar (7/24 [29.2%]). Further studies are required to describe in detail radiographic pulmonary findings in guinea pigs with decompensated heart disease and determine whether cardiogenic pulmonary edema would have a particular distribution in this species.

Echocardiography is an essential component of small animal cardiovascular diagnostic evaluations.[14,19] It has already been shown to be feasible and allow a clear visualization of cardiovascular structures in unsedated guinea pigs.[10] The most common echocardiographic diagnosis in the current study was cardiomyopathy (37.5%), categorized as restrictive (13.8%), hypertrophic (12.5%), and dilated (11.3%). Valvular disease accounted for only 3.8% of heart diseases. These percentages of guinea pig patients with cardiomyopathy are much different from that reported in rabbits[16] and dogs,[19] in which valvulopathies have been described as the most clinically relevant heart diseases. High heart rates in guinea pigs could make mild valvular regurgitation difficult to detect on Doppler examination and lead to underdiagnosis of valvular insufficiency. However, no acquired valvular disease responsible for CHF was observed in our study. This result makes guinea pigs more comparable to cats, in which the prevalence of primary cardiomyopathy reported in a study[23] conducted on 408 cats with heart failure was 62%.

Cor pulmonale was the second most common echocardiographic category of heart disease in the current study, with a percentage of 26.3% (21/80). All animals with cor pulmonale were presented with respiratory signs, and pleural effusion and/or increased lung opacity were commonly seen on radiographs (15/19 [78.9%]). On echocardiography, right heart dilation was noticed without any other anomaly and was considered to be related to pulmonary hypertension secondary to respiratory disease, as commonly described in other species.[24] Unfortunately, the high heart rates and small size of the right heart precluded accurate evaluation of tricuspid valve flows and detection of tricuspid regurgitation using Doppler modes. Consequently, no estimation of systolic arterial pulmonary pressure could be obtained.

The percentage of guinea pig patients with congenital heart disease in our study was 7.5% (6/80), which was lower than the percentage reported in cats with heart failure (48/408 [12%])[23] and higher than the percentage of congenital heart diseases reported in rabbits (2/59 [3.4%]).[16] The diagnosis of congenital heart disease might be challenging in lagomorphs and rodents due to the small size of these animals and requires high-resolution echocardiographic equipment. The authors are aware that the percentage of guinea pig patients with congenital heart disease in the current study might have been underestimated.

Congestive heart failure was present in 45% of guinea pigs and was most frequently observed in animals with cardiomyopathy. In animals with cor pulmonale, right-sided CHF as indicated by pleural effusion, ascites, or pericardial effusion was diagnosed in 3 of 21 (14.3%) animals. In the 8 animals that had cor pulmonale with pleural effusion, analysis of pleural fluid was performed in only 2 cases. The risk of thoracocentesis in a dyspneic animal or the small volume of effusion prevented pleurocentesis and pleural fluid analysis in most cases. In 7 of 8 guinea pigs with pleural effusion and cor pulmonale, pleural effusion was attributed to a primary respiratory disease rather than to CHF. However, due to the absence of cytological analysis of pleural fluid, some cases with right heart disease and right-sided CHF with pleural effusion and without detectable ascites could have been misdiagnosed as cor pulmonale with primary pleural disease.

The survival analysis showed a median survival time from diagnosis of 2.5 months in the overall population. Survival time in animals with heart-related death was significantly shorter than survival time in animals that died from a noncardiac disease (median survival time of 1 month and 7.7 months, respectively). Factors such as age, sex, body weight, heart rate, presence of CHF, final diagnosis, and severe left atrial dilation did not appear to have any significant influence on survival time neither in the whole population (n = 80) nor in guinea pigs suffering from cardiomyopathy (30). The lack of identification of specific risk factors might be partially related to the heterogeneity of the study population, which included 8 different cardiac disease categories that might be associated with highly variable outcomes and prognoses. As an example, an animal suffering from pneumonia associated with a cor pulmonale might show full clinical recovery after appropriate treatment. The cardiomyopathy group was also heterogeneous, as it contained 3 different cardiomyopathies that might be associated with different and specific survival times in guinea pigs. This major heterogeneity and the relatively low survival times for the whole population could explain why CHF had no effect on survival times, contrary to what is described in other species.

This study had several limitations, mostly due to its retrospective design. The assignment of each guinea pig to specific groups of cardiac diseases was based on criteria used in other species and might have been inappropriate, particularly when specific echocardiographic criteria in guinea pigs were lacking. Additionally, some echocardiographic measurements were not recorded during the initial examination and could not be performed retrospectively because relevant images or video clips were not available.

Few detailed conclusions about the usefulness of the VHS in guinea pigs can be retrieved from the current study, mostly because of the study design that led to selection of a heterogeneous population of guinea pigs with a wide variety of cardiac disorders and degrees of cardiac disease severity. The VHS obtained in the study population should be regarded as preliminary results that should encourage further studies specifically dedicated to assessing the accuracy of the VHS for detecting clinically significant cardiac disorders in guinea pigs.

Furthermore, the small size of each heart disease group was associated with low statistical power, which may have altered the ability to detect significant associations of some variables with survival time. Finally, no treatment effect could be evaluated in the current study due to insufficient available data. Further studies, preferably prospective, should be designed to better characterize the different types of heart diseases in guinea pigs and may lead to a different classification from that proposed in our study.

This retrospective study was the first survey on cardiovascular diseases of a large population of client-owned guinea pigs that underwent echocardiography at a veterinary hospital. The prevalence of cardiac diseases was 2.8%, indicating that heart diseases are not uncommon in this species. Radiographic detection of cardiomegaly, pleural effusion, or alveolar or interstitial lung patterns should prompt the clinician to recommend echocardiography. Cardiomyopathy (restrictive, hypertrophic, or dilated), cor pulmonale, and pericardial effusion appeared as the most common heart diseases in guinea pigs. Additional studies are needed to evaluate the accuracy of VHS in detecting cardiomegaly on radiographs, better characterize the echocardiographic features of each type of cardiovascular disease, and evaluate medical treatment of heart failure in guinea pigs.

Acknowledgments

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Supplementary Materials

Supplementary materials are posted online at the journal website: avmajournals.avma.org