Central bearded dragons (Pogona vitticeps) are commonly kept as companion pets but also serve roles in research, education, and zoological institutions. Because of this, they are increasingly presented for veterinary care for an array of disease processes. A postmortem retrospective of bearded dragons from a single institution described 47 causes of death in 36 animals. In that study, the most common cause of death was inflammatory diseases.
(69%). However, in this study, degenerative diseases still accounted for 47% of the total causes of mortality. In total, 14/36 animals had abnormalities of the cardiovascular system described, with the majority being inflammatory (n = 7) or degenerative (8) in etiology. This study, however, did not describe the total prevalence of cardiovascular disease as it only included postmortem samples. Additionally, a larger scale retrospective study of 529 bearded dragon patients from 3 institutions identified cardiovascular disease in 4 cases (0.76% cases), but the specific cardiovascular diagnoses and method of diagnosis were not described.

Cardiovascular diagnostic testing in bearded dragons, including normal references for echocardiogram, has been described. Additionally, a potential therapeutic for heart failure, furosemide, has been evaluated in a pharmacodynamic study. However, the details surrounding cardiovascular diseases in captive bearded dragons are limited to individual case reports and pathology retrospective studies, leading to an overall paucity of information regarding these diseases. The objective of this study was to describe the clinical features of cardiovascular disease in bearded dragons from 6 veterinary institutions and to characterize the diagnostic findings, pathologic findings, comorbidities, treatment, and survival time. An additional objective was to determine if there was an association between clinical features and type of cardiovascular disease. The hypothesis was that cardiovascular disease in bearded dragons would be uncommon and that aneurysms would be the most common disease diagnosed and associated with a high mortality rate.

**Methods**

**Case selection**

The electronic medical records at 6 veterinary teaching hospitals were searched to identify captive bearded dragons diagnosed with cardiovascular disease from January 1, 2007, through May 1, 2022, from institutions A, B, C, D, and E and from June 28, 2010, through August 28, 2022, from institution F. Keywords used in this search at each institution included any of the following: aneurysm, cardiac, vascular, cardiomegaly, arrhythmia, murmur, exophthalmia, atherosclerosis, arteriosclerosis, cardiomyopathy, effusion, pleural, pericardial, coelomic effusion, heart disease, heart failure, congestive, rupture, centesis, furosemide, pimobendan, enalapril, benazepril, echocardiogram, electrocardiogram, ECG, and echo. Bearded dragons were included in the study if diagnosed with cardiovascular disease on antemortem diagnostic imaging (eg, echocardiogram, ultrasound, CT) or postmortem examination. The total number of bearded dragons evaluated during the inclusion periods was also collected from each institution.

**Medical records review**

The complete medical record for each included animal was reviewed, and pertinent information was extracted. The visit date on which the first diagnosis of disease on diagnostic imaging was made was used to calculate survival time. Those that were diagnosed on postmortem were not included in survival analyses. Additionally, those who were immediately euthanized after diagnostic results were not included in the survival analyses. Diagnostic results were included if performed within 14 days of the cardiovascular diagnosis. All patients were examined by a board-certified clinician (DACZM) or under the supervision of a board-certified clinician. An echocardiogram was performed by a board-certified cardiologist or cardiology resident under board-certified cardiologist supervision at each institution. Diagnostic imaging was performed or evaluated by a board-certified radiologist or a radiology resident under the supervision of a board-certified radiologist. Histopathology and gross necropsies were performed by a board-certified pathologist or a pathology resident under direct board-certified pathologist supervision at each institution. Pathology reports were then rereviewed by a single pathologist (DM) and categorized into larger types of cardiovascular diagnoses. Type of cardiovascular disease was selected based on a combination of antemortem and postmortem diagnostic findings and included myocarditis, epicarditis, aneurysms, pericardial effusion, atherosclerosis, myocardial degeneration and necrosis, neoplasia, vasculitis, vascular mineralization, arteriosclerosis, endocardiosis, visceral gout, intimal fibrosis, endocarditis, and cardiovascular malformations. Concurrent diseases were determined from full necropsy reports. Cause of death was divided into etiologies based upon a combination of necropsy reports and antemortem diagnostics. In some cases, more than 1 cause of death was selected if more than 1 disease was deemed a major contributing factor to patient demise. This was also determined based on interpretation of the necropsy reports, described severity of disease, and any antemortem diagnostics available at the time of death.

**Statistical analysis**

For continuous data, normality was assessed with the Shapiro-Wilk test using commercial software (GraphPad Prism 9.0). Resulting descriptive data were reported as mean for Gaussian data and median for non-Gaussian data, both with corresponding ranges. A Kaplan-Meier survival analysis was performed for animals with an antemortem diagnosis of cardiovascular disease. Patients with a postmortem diagnosis were excluded from this analysis. Fisher exact tests were used to determine whether there was a difference in the probability of dying due to cardiovascular disease between patients with and without aneurysms or with or without myocarditis. Additionally, the Fisher exact test was used to determine the probability of being obtunded between patients with and without aneurysms or with or without pericardial effusion. ORs presented with 95% CIs were reported. A binary logistic regression was used to determine whether PCV was related to aneurysms, WBC related to myocarditis, cholesterol
concentration related to atherosclerosis, and age related to aneurysms or myocarditis. Additionally, logistic regression was utilized to determine if uric acid or glucose was associated with the type of cardiovascular disease (eg, myocarditis, atherosclerosis). Variables evaluated were selected based on trends in this retrospective study and past studies. Results of the simple logistic regression, if significant, were also reported as ORs. Statistical significance was designated by values of \( P \leq 0.05 \).

**Results**

**Patient population**

During the inclusion years, a total of 1,655 bearded dragons were evaluated for wellness or sick visits. Keywords were identified in 349 records, of which 276 did not identify a cardiovascular lesion and 19 of which lacked a definitive diagnosis (Figure 1). In total, 54 patients were included in the study resulting in a total prevalence of 3.3%. Institution A diagnosed 9/149 cases (prevalence 6%; Fort Collins, CO), B had 8/220 cases (3.6%; Raleigh, NC), C had 16/317 cases (5%; Gainesville, FL), D had 3/293 cases (1%; Knoxville, TN), E had 15/276 cases (5.4%; Davis, CA), and F had 3/400 cases (0.7%; Urbana, IL).

Animal age was described in 51 cases with 3 cases listing “adult” only. The mean age was 4.75 years (range, 0.6 to 11). Sex was described in 53 cases, with more females \( n = 31/53 \) (58.5%) than males \( n = 22/53 \) (41.5%) being diagnosed with cardiovascular disease. Only 3 animals were neutered, and all were female.

**History and presenting complaints**

Only 1 case lacked a complete history of presenting complaints. The most common history findings were changes in mentation \( n = 25/53 \) (47.1%) and hypoxia to anorexia \( n = 21 \) (39.6%). Other presenting complaints included weight loss \( n = 9 \) (17%), ocular signs \( n = 7 \) (13.2%), regurgitation \( n = 7 \) (13.2%), darkening of the cervical region \( n = 5 \) (9.4%), and diarrhea \( n = 5 \) (9.4%). Uncommon historic findings included lack of defecation \( n = 4 \) (7.5%), presence of a mass \( n = 4 \) (7.5%), distended coelom \( n = 3 \) (5.7%), weakness \( n = 3 \) (5.7%), respiratory signs \( n = 3 \) (5.7%), neurologic signs \( n = 2 \) (3.8%), collapse \( n = 2 \) (3.8%), melena \( n = 1 \) (1.9%), and oral lesions \( n = 1 \) (1.9%). Four animals had no preclinical signs and were found deceased.

**Physical examination**

Physical examination findings were available in 46 cases, with intake vitals available in 33 cases. The mean weight was 440 grams (range, 130 to 722 grams). The mean heart rate was 62 beats/min (8 to 120 beats/min), and the mean respiratory rate was 15 breaths/min (0 to 40 breaths/min). All heart rates were obtained by ultrasonic Doppler flow. In a single animal, no heart rate was recorded, but a Doppler arrhythmia was described in the physical exam. A single animal presented apneic, with a respiratory rate listed as 0 breaths/min. Surface infrared temperature was taken in only 5 cases, with a median temperature of 29.3 °C (range, 16.67 to 32.2 °C). Body condition score (BCS) was described in 35 cases with 4 cases listing body condition “good” and 2 as “poor.” The median BCS when scored out of 5 was 3 (range, 1 to 4) and out of 9 was 3.5 (range, 1 to 7). BCS has not yet been validated in bearded dragons and is extrapolated from small animal medicine with normal BCS being 3/5 and 4 to 5/9.

Physical examination abnormalities were described in the majority of cases; however, few were specific to the cardiovascular system. The most common presentation abnormality was obtundation.
Clinical pathology

A biochemistry panel was performed on 20 animals, but not all analytes were available for every animal (Table 1). While 19 animals had total calcium measured, 2 animals had measurements read as >16 mg/dL and were not included due to the inability to calculate the actual calcium concentration. Additionally, bile acids read as <35 μmol/L in all but the 2 animals represented. Cholesterol was not associated with the presence of atherosclerosis (n = 13; P = .308). Glucose (n = 20) and uric acid (17) were not statistically associated with any cardiovascular disease process.

A CBC count including a WBC was performed in 15 animals, and a PCV only was included in 1 case. The median WBC count was 15.77 X 10^3/μL (range, 1 to 90.1; reference interval, 3.9 to 28.4 X 10^3/μL). Twenty animals had a leukopenia (21.7%), 6 had a leukocytosis (48%), and 5 had a normal WBC count (18%). The hematocrit (PCV) was measured in 17/20 animals, and 15/20 animals had evidence of a left shift with either metamyelocytes or banded heterophils present. The median 

<table>
<thead>
<tr>
<th>Value</th>
<th>No. of bearded dragons</th>
<th>Median (range)</th>
<th>No. below reference</th>
<th>No. above reference</th>
<th>Lower to upper quartile/reference interval</th>
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</thead>
<tbody>
<tr>
<td>Sodium (mmol/L)</td>
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<td>156 (135-194)</td>
<td>4</td>
<td>5</td>
<td>148-158*</td>
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<td>6</td>
<td>3.4-4.6*</td>
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<td>Chloride (mmol/L)</td>
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<td>97 (75-154)</td>
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<td>2</td>
<td>102-116*</td>
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<td>9</td>
<td>3.6-5.6*</td>
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<td>11.9-16.5*</td>
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<td>Uric acid (mg/dL)</td>
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<td>7</td>
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<tr>
<td>Total protein (g/dL)</td>
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<td>5</td>
<td>6</td>
<td>4.1-6.9*</td>
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<td>Aspartate aminotransferase (U/L)</td>
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<td>27 (7-627)</td>
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<td>11</td>
<td>4-21*</td>
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<tr>
<td>Alkaline phosphatase (U/L)</td>
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<td>63 (1.6-457)</td>
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<td>0</td>
<td>200-719*</td>
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<tr>
<td>Creatinine kinase (U/L)</td>
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<td>2</td>
<td>262-4,034*</td>
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<tr>
<td>Cholesterol (mg/dL)</td>
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<td>4</td>
<td>155-373*</td>
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<tr>
<td>Bile acids (μmol/L)</td>
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<td>N/A</td>
<td>1-30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Obtained from Tamukai et al.20 †Obtained from Howard et al.21

Diagnostic imaging

In total, 21 animals underwent at least 1 type of diagnostic imaging, with 10 having more than 1 modality performed. Eighteen animals underwent a
coelomic ultrasound, 9 had radiographs performed, 4 had an echocardiogram, and 2 had a CT scan. Cumulatively, 10 animals (47.6%) had cardiovascular abnormalities described on diagnostic imaging. Representative images from these patients are shown (Figure 2). Normal references for radiographs22 and echocardiograms3 are available for comparison. Cardiovascular imaging abnormalities were diagnosed in 8/18 (44.4%) with coelomic ultrasound, 3/9 (33.3%) animals with radiographs, 4/4 (100%) animals with an echocardiogram, and 0/2 (0%) with CT. Four animals with cardiovascular imaging abnormalities were diagnosed with 2 or more diagnostic imaging modalities. Four animals had cardiomegaly, and 1 had pericardial thickening. Three animals had decreased contractility or systolic dysfunction. Effusion found on diagnostic imaging was common, with 16 animals having coelomic effusion and 5 having pericardial effusion. This included 4 animals that had both coelomic and pericardial effusion. A single case of pericardial effusion resulted in cardiac tamponade. The effusion was described as echogenic in 8 animals. Six animals had venous distension described in the following vessels: the tempo-orbital artery, vena cava, portal vein, or the coccygeal vessel. One of these animals had an abnormal nest of torturous vessels inserted on the caudal vena cava, suspected to be a vascular shunt or arteriovenous malformation. The animal with a dilated coccygeal vessel had a confirmed aneurysm of this vein on necropsy and the animal with the dilated tempo-orbital artery had an aneurysm confirmed surgically. One animal had a mass effect seen within the left atrium, sinus venosus, and vena cava that was presumed to be a thrombus. One animal had a hyperechoic region of the aorta that was confirmed to be an aneurysm on necropsy. Single incidents of a dilated left side of the heart, dilated sinus venosum and atrium, and a thickened aortic valve occurred. While not necessarily considered an abnormal finding, 3 animals had spontaneous echogenic contrast (“smoke”) visualized within the heart or vasculature on echocardiogram.

A single animal that received an echocardiogram had a detectable arrhythmia. In this case, an ECG was performed, and a sinus arrhythmia was diagnosed. The remaining animals with Doppler-detected arrhythmias did not receive an ECG.

Figure 2—Representative lesions of diagnostic imaging findings of cardiovascular disease in bearded dragons (Pogona vitticeps). A—Echocardiogram of a bearded dragon in congestive heart failure with an aneurysm. The left atrium (LA) and ventricle (V) are both dilated. Moderate pericardial effusion (PE) is present. The aorta (Ao) is moderately distended with a hyperechoic structure of a suspected aneurysm that was confirmed on necropsy (An). B—Echocardiogram of a bearded dragon with cardiac tamponade. There is significant globoid pericardial effusion (PE) surrounding a compressed ventricle (V). Before pericardiocentesis the ventricular fractional area change was 3% to 4%. C—Lateral horizontal beam radiograph of a female spayed bearded dragon demonstrating marked cardiomegaly with dorsal deviation of the trachea (arrow). Notice the forelimbs are pulled cranially to appropriately visualize the heart. On necropsy, this animal was diagnosed with severe granulomatous epicarditis with acute hemorrhage within the pericardial sac and moderate arteriosclerosis.
The second most common organ with described abnormalities on diagnostic imaging was the hepatobiliary system (n = 12). Changes in attenuation were most common with hypointensity of the liver seen on CT in 1 animal and hyperintensity of the liver on ultrasound in 5. Five animals had gallbladder debris or sediment. A mass or mass effect was visualized in 6 animals with the majority being coelomic (n = 4), 1 with a mass of the caudal dorsal head, and 1 with both a gastric mass and a peribital mass. Five animals had abnormalities of the gastrointestinal tract, 1 had musculoskeletal changes appreciated, and 1 had multiple comet tails (B-lines) on the ultrasound of the lungs. Three animals had follicles appreciated on diagnostic imaging. Two animals had renomegaly, 1 had renal speckling on ultrasound, and 1 was diagnosed with a cloacolith.

**Cardiovascular diagnosis**

The majority of cases (81.5%) were diagnosed on necropsy alone (n = 44). Four cases (7.4%) were diagnosed on echocardiography and necropsy, 3 were diagnosed on coelomic ultrasound and necropsy (5.6%), and 3 were diagnosed on diagnostic imaging only (echocardiogram or ultrasound, 5.6%). In total, 84 diagnoses of cardiovascular disease were found in 54 animals with 32 having a single diagnosis, 15 having 2 diagnoses, 6 having 3 diagnoses, and a single animal having 4 diagnoses. The most common diagnoses were myocarditis (n = 14) followed by pericardial effusion (9), atherosclerosis (7), epicarditis (7), myocardial degeneration/necrosis (7), neoplasia (6), and vasculitis (6). Other diagnoses included vascular mineralization (n = 4), arteriosclerosis (3), endocardiosis (3), visceral gout affecting the heart (3), intimal fibrosis (2), vegetative endocarditis (1), and a single case of arteriovenous malformation (Table 2). Only 3 animals were diagnosed with congestive heart failure. Two of these animals were diagnosed on echocardiography and necropsy and 1 on necropsy alone.

Myocarditis was further classified based on the inflammation type with the majority being lymphocytic (n = 5 [35.7%]) or histiocytic and granulomatous (4 [28.6%]). Other types of inflammation included granulomatous and heterophilic (n = 2), heterophilic and lymphocytic (2), and histiocytic and lymphocytic (1). One animal with heterophilic and granulomatous inflammation had intralesional fungal hyphae within the myocardium and was PCR positive for *Nannizziopsis guarroi*. Two animals with myocarditis had a systemic *E pogonae* infection. Myocarditis was described as mild in most cases (n = 11) with the remaining cases being marked to severe (3). WBC count was not associated with the presence of myocarditis (P = .925); however, only 2 animals with myocarditis had a complete CBC performed with a WBC reported. Both of those animals had a WBC of > 20 X 10^9/L (reference interval, 3.9 to 28.4 X 10^9/L).

Aneurysms were most common within the aorta (n = 5 [45.5%]). Other locations included the carotid artery (1; also had an aortic aneurysm), dorsal head (1), cephalic and jugular vein (1), and pulmonary artery (1). A tail aneurysm of the caudal artery was diagnosed in 1 animal; this case has previously been included in a case report.⁷ One animal had an aneurysmal dilation with rupture of the right atrium and torturous jugular, portal, and abdominal veins. Another had an aneurysmal dilation of the right atrium with a ruptured aneurysm of the vena cava. Nine aneurysm cases (81.8%) had a resulting hemorrhage or were described as dissecting (Figure 3). Three animals with aneurysms also had atherosclerosis. The most common location of atherosclerosis was also the aorta (n = 5), with the remaining 2 cases involving additional great vessels. Age was not associated with a diagnosis of aneurysms (P = .913) or myocarditis (P = .577). The presence of aneurysms was not associated with obtunded mentation (P = .91), PCV (P = .951), or anemia (P = .99).

When evaluating for the presence of coelomic and pericardial effusion on imaging and postmortem diagnostics, a total of 21 animals had effusion present. There was no difference in the presence or absence of obtundation (n = 14) for bearded dragons with and without pericardial effusion (P = 1.000). There was no evidence that any of the disease processes were related to a greater probability of effusion (P > .05).

All cases of myocardial neoplasia were metastatic in origin. The most common type of neoplasm was a gastric neuroendocrine tumor (n = 3). The remaining cases of neoplasia originated from hepatic carcinoma, retrobulbar sarcoma, and T-cell leukemia.

**Concurrent disease**

Full necropsies were available for 51 bearded dragons, with concurrent abnormalities diagnosed in all animals. Multiple organ system abnormalities were found in most animals with 2 animals having 1 organ system abnormality, 5 animals with 2, 9 animals with 3, 10 with 4, 10 with 5, 4 with 6, and 1 with 7.

<table>
<thead>
<tr>
<th>Type of cardiovascular disease</th>
<th>No. of bearded dragons</th>
<th>Cardiovascular cause of death</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myocarditis</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Aneurysm</td>
<td>11</td>
<td>10</td>
</tr>
<tr>
<td>Pericardial effusion</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Epicarditis</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Myocardial degeneration and necrosis</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Atherosclerosis</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Neoplasia</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Vasculitis</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Vascular mineralization</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Arteriosclerosis</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Endocardiosis</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Visceral gout</td>
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<td>0</td>
</tr>
<tr>
<td>Intimal fibrosis</td>
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<td>1</td>
</tr>
<tr>
<td>Vegetative endocarditis</td>
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<td>1</td>
</tr>
<tr>
<td>Arteriovenous malformation</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

In total, 54 bearded dragons were diagnosed with 84 types of cardiovascular disease from 2007 to 2022. Cardiovascular disease was the cause of death in 18 animals.
1 each with 8 or 9 organ system abnormalities. The most common organ systems affected were the liver (n = 42 [82.4%]), gastrointestinal tract (33 [64.7%]), respiratory system (27 [53%]), and renal/urinary system (26 [51%]) (Supplementary Table S1). Other organ systems or areas of disease included the musculoskeletal system (n = 13), reproductive tract (12 [23.5%]), coelom (9 [17.6%]), integument (7 [13.7%]), spleen (6 [1.2%]), endocrine system (5 [10%]), CNS (3 [5.9%]), and ocular system (4 [7.8%]). Overall, 7 animals had thromboembolic disease (13.7%), and 13 had evidence of sepsis (25.5%).

Treatment

Only 5 animals (9.3%) received cardiovascular-specific treatment in this study. Two animals received a pericardiocentesis. One of these animals was in cardiac tamponade based upon an echocardiogram, and 5 mL of pericardial fluid was obtained under alfaxalone sedation. The ventricular fractional area change precentesis was 4%, which increased to 19% postpericardiocentesis. Furosemide was administered in 1 animal (2 mg/kg, PO, q 12 h, for 2 weeks) and pimobendan in another (0.2 mg/kg, PO, q 12 h, for 13 days). One animal received a single dose of clopidogrel (2 mg/kg PO) due to suspicion of thrombotic disease on echocardiogram which was confirmed on necropsy.

A single animal underwent surgical ligation with suture of a dorsal cephalic aneurysm, presumed to be the temporo-orbital artery. During dissection, the lateral wall of the aneurysm ruptured, and hemostasis was achieved with hemostat compression of the vessel and surgical ligation. Postoperatively, the animal developed surgical site swelling, incisional bleeding, and pale mucous membranes. A repeat ultrasound and CT scan 3 weeks postsurgery demonstrated continued swelling of a vascular structure with no Doppler flow consistent with a clot. The animal recovered and survived 1,188 days.

Other treatments instituted included fluid therapy (n = 12 [22.2%]), antibiotics (9 [16.7%]), full µ opioids (6 [11.1%]), supportive feeding (4 [7.5%]), meloxicam (4 [7.5%]), and sedative medications (3 [5.6%]). Of the animals that received antibiotics, only 2/9 (22.2%) had myocarditis and only 2/9 (22.2%) died of sepsis. One animal each received allopurinol, prednisone, sucralfate, maropitant, and SAME/
silybin. One animal was placed in a compressive coelomic bandage for a hemocoelom. Minimal complications were reported with treatment. One animal that received SC fluids developed SC edema following therapy. This animal had an aneurysm, epicarditis, myocardial degeneration, and atherosclerosis.

Outcome

As the majority of animals were diagnosed on postmortem examination or euthanized immediately following diagnosis, survival time was available in only 9 cases. Of these, 1 case was lost to follow-up at 62 days. Euthanasia was elected in 38 cases, while 15 cases died. The median survival time of the 9 cases was 26 days (range, 1 to 1,188 days; 95% CI, 0 to 63.98; SE = 19.38; Figure 4).

Overall, 62 causes of death were identified in 52 cases with 10 cases having 2 causes of death. Two cases were either lost to follow-up or the cause of death was unknown and excluded from this portion of the study. The most common cause of death was cardiovascular disease (n = 18/52 [34.6%]; Table 2). Of the bearded dragons with aneurysms, the majority died due to cardiovascular disease (10/11 [90.1%]). Animals with aneurysms were more likely to die due to cardiovascular disease compared to those without aneurysms (OR, 43.75; 95% CI, 4.88 to 392.65; P < .001). Conversely, animals with myocarditis were less likely to die from cardiovascular disease (OR, 0.104; 95% CI, 0.012 to 0.874; P = .02).

The second most common causes of death were sepsis (n = 12 [23.1%]) and neoplasia (12 [23.1%]). In animals with myocarditis, the most common cause of death was sepsis (6/14 [42.9%]). Other causes of death included gastrointestinal disease (4 [7.7%]), renal disease (5 [9.6%]), reproductive disease (2 [3.8%]), hepatic disease (2 [3.8%]), musculoskeletal disease (2 [3.8%]), and parasitic disease (2 [3.8%]). A single animal each died due to viral disease, respiratory disease, or trauma.

Discussion

In this study, the prevalence of cardiovascular disease was 3.3% in captive bearded dragons over the years 2007 through 2022 at these institutions. While this may suggest cardiovascular disease is uncommon, the prevalence ranged from 0.7% to 6% between institutions. The disparity in prevalence echoes past studies that have found either a low prevalence (0.76%) or commonly diagnosed lesions on postmortem evaluation (38.9%). The medical definition of the word “common” in regards to prevalence is lacking. When describing adverse events, common indicates a risk of less than 1/10 to 1/100. By these standards, cardiovascular lesions in bearded dragons in this study were uncommon. As bearded dragons grow in popularity, this prevalence may increase in the future as continued advancements in diagnostic modalities and quality of care may lead to earlier diagnoses.

While the total prevalence of cardiovascular disease in this study was low, less than 20% of cases were diagnosed antemortem. Only 3 of those cases were diagnosed on imaging alone, and the remainder also received a necropsy diagnosis. While normal references exist for echocardiograms and ultrasounds in bearded dragons, cardiovascular disease may not be on every clinician’s differential list for a presenting condition. Given the low number of animals diagnosed antemortem, the total prevalence of this disease may be higher than reported. Out of 21 animals that underwent diagnostic imaging, 47.6% were diagnosed with cardiovascular abnormalities, which may suggest that this diagnostic should be considered in suspected cases. Of the diagnostic modalities, 100% of the animals that received an echocardiogram were diagnosed with abnormalities. Ultrasound detected cardiovascular abnormalities in 44.4% of the cases. This may suggest that a complete coelomic ultrasound, including the heart, may be a good screening tool and echocardiograms should be recommended if there are any cardiovascular abnormalities. It is important to note that all the animals that received an ultrasound were done under the supervision of or by a board-certified radiologist at these institutions. At a minimum, in suspected cases, a point-of-care ultrasound to evaluate for pericardial and coelomic effusion and/or dilation of the vasculature should be considered. The challenge in diagnosis likely lies in the inconsistent and nonspecific clinical signs of animals with cardiovascular disease and this differential may not be readily considered for an ill bearded dragon.

Unfortunately, few clinical signs were consistently seen with cardiovascular disease in this study. For example, abnormal mentation, which is a nonspecific finding, was the most common presenting sign and physical exam finding. Physical exam findings directly related to the cardiovascular system such as arrhythmias (5 cases) were uncommon. However, the normal sinus rhythm in bearded dragons is minimally described to date. While normal reference ranges for ECG variables are available, it is unknown whether a respiratory sinus arrhythmia is normal in this species,

Figure 4—Kaplan-Meier survival curve for 9 bearded dragons (Pogona vitticeps) with cardiovascular disease from 2007 to 2022. The median survival time of the 9 cases was 26 days (range, 1 to 1,188 days; 95% CI, 0 to 63.98; SE = 19.38).
although anecdotally the authors do not commonly observe this finding. Unfortunately, only 1 animal in this study received a formal ECG, which may have led to an inaccurate diagnosis of arrhythmias in this population. Additionally, physical exam findings that may be appreciated in mammalian species with cardiovascular disease, such as exercise intolerance, do not appear to be as common in bearded dragons. Anecdotally, periorcular swelling or exophthalmia has been suggested to be a possible sign of cardiovascular disease in reptiles. However, actual reports of these clinical signs coinciding with cardiovascular disease in reptiles are rare. Some reptilian species, namely *Iguana* spp., have a large retrobulbar orbital sinus. Therefore diseases that cause dilation of this sinus or increased pressure may result in exophthalmia. In addition to cardiovascular disease, renal disease with secondary hypertension has been suggested as a cause of exophthalmia. However, the majority of case reports describing exophthalmos in bearded dragons were secondary to infectious disease or neoplasia opposed to cardiovascular disease. Similarly, in this study, periorcular swelling or exophthalmia was only reported in 13.2% of animals as a presenting complaint and only documented as a physical examination finding in 8.7% of animals. If the exophthalmia in these animals is secondary to hypertension and increased retrobulbar pressure, it is impossible this clinical sign could be intermittent and therefore not always appreciated on physical examination. However, in the present study, exophthalmia, likely due to dehydration, was more commonly described (21.7%), contradicting previous assumptions regarding the association of exophthalmia and cardiovascular disease in this species.

Overall, aside from diagnostic imaging, other diagnostic modalities demonstrated inconsistent results in these cases. This is not unexpected as most types of cardiovascular disease do not result in drastic biochemical or hematologic changes. In cases of effusions, a fluid analysis or PCV and total solids of the fluid may assist in the diagnosis of a ruptured aneurysm. Two animals from the same collection in this study were PCR positive for *E. pogonae*, and both animals with myocarditis and 1 was diagnosed with vasculitis on necropsy. *Encephalitozoon pogonae* is an emerging disease that has been previously associated with infectious vasculitis, aneurysms, epicarditis, and myocarditis in this species and should be considered as a differential diagnosis for bearded dragons with not only cardiovascular disease but systemic illness.

Myocarditis refers to inflammation of the myocardium, which may be transient or result in permanent cardiomyocyte damage or death. Myocarditis frequently occurs in animals with multisystemic disease, including systemic viral, bacterial, or protozoal infections and is a frequent finding with sepsis. In the present study, only 1/14 myocarditis cases died due to cardiovascular disease and the most common primary cause of death was sepsis (6/14), supporting the systemic nature of this condition. Clinical signs associated with myocarditis in other species are commonly nonspecific and a presumptive ante-mortem diagnosis is often made based on physical examination findings, progression of disease, echocardiographic abnormalities, ECG abnormalities, and an elevated cardiac troponin. It is therefore unsurprising that the majority of these cases were diagnosed postmortem in this study.

The liver was the most common noncardiac organ system affected (82.4%), with 29 cases of hepatic lipidosis diagnosed postmortem. Additionally, liver abnormalities were the most common noncardiovascular diagnostic imaging finding. In patients with cardiac compromise, hepatic dysfunction may also occur due to the important physiologic relationship between the 2 organs. However, only 3 animals in this study were diagnosed with congestive heart failure, making cardiohepatic syndrome an unlikely cause of hepatic disease in this study. In a large-scale retrospective study of 571 bearded dragon necropsies, 38.4% had hepatic lipid changes. Therefore, the occurrence of hepatic disease in the present study is unlikely directly related to cardiovascular disease and more likely represents the prevalence of this condition in this species. Additionally, some degree of lipid accumulation may be normal in bearded dragons and the cases in this study were not reevaluated with a more recent grading system for hepatic lipid.

Aneurysms were a common diagnosis in this study, and most animals with aneurysms died due to cardiovascular disease. While aneurysms are anecdotally encountered, their prevalence has not previously been reported. Their etiology is unknown in this species; however, concurrent infectious disease was uncommon in these animals. While atherosclerosis or arteriosclerosis may predispose animals to aneurysmal formation due to the increased rigidity or inflammation of the vessels with these conditions, only 3/11 animals with aneurysms had concurrent atherosclerosis or arteriosclerosis. In other species, hypertension is associated with the presence of aneurysms. Unfortunately, blood pressure in reptiles is challenging to measure noninvasively and often precludes clinical diagnosis of hypertension. No animals in the present study had a blood pressure measurement reported and the association between hypertension and aneurysms is unknown in this species. Age was not a risk factor for the development of aneurysms in this study. In humans, family history is considered a risk factor for aneurysms and there may be a genetic basis for disease development resulting in abnormal collagen and elastin composition of the vessels. In a recent postmortem retrospective study of aneurysms in bearded dragons, all animals had degeneration of the vascular wall with disruption to the normal collagen and elastin. This degeneration likely contributes to the formation of aneurysms in this species and may be related to a connective tissue disorder. The genetic diversity of central bearded dragons within the US is unknown and inbreeding may lead to a predisposition to heritable traits in this species. Further studies are needed to evaluate the pathophysiology and etiology of this disease.
As the majority of cases were diagnosed post-mortem, evaluating the prognosis of bearded dragons with cardiovascular disease is challenging. Follow-up time varied greatly and was only available in 9 animals resulting in a small sample size for survival analysis. Therefore, assumptions regarding survival outcomes based on this small data set are cautioned. Additionally, there were a limited number of animals that received cardiovascular-specific treatment. There are minimal pharmacodynamic studies that evaluated appropriate cardiovascular therapeutics in reptiles. The single animal in the present study administered furosemide received a subtherapeutic dose according to a recent pharmacodynamic study suggesting that 5 to 10 mg/kg may be required to result in a diuretic effect. Interestingly, only 2 cases with myocarditis were treated with antibiotics in the present study. While not all myocarditis cases were bacterial in origin, antimicrobial agents may be indicated in these cases. However, as previously stated, an antemortem diagnosis of myocarditis is challenging until further diagnostics, such as cardiac troponins I have been validated in this species.

There were several limitations of this study, the majority due to its retrospective nature. Incomplete medical records and lack of complete histories led to challenges in drawing conclusions regarding the commonality of presentation of these diseases. The sample size of this study included all referral institutions that saw primarily wellness or sick animal visits and may not represent the true prevalence of disease in all captive populations. Additionally, as the minority of cases were diagnosed antemortem, minimal conclusions can be drawn as to the efficacy of antemortem diagnostic tools. Given the nonspecific clinical signs of this disease, diagnosis is challenging as this may not be considered a differential for an ill animal’s presentation. While this is the largest cohort of bearded dragons with cardiovascular disease to date, sample size likely contributed to the lack of statistical associations in this study as there were small numbers of animals available for certain variables evaluated.

The results of this study suggest that cardiovascular disease should be considered a differential in ill bearded dragons with nonspecific clinical signs. Diagnostic imaging is recommended in these cases with an echocardiogram ideally performed following a diagnosis of cardiomegaly or effusion. Both myocarditis and aneurysms are the most common cardiovascular disease in this species, with myocarditis more likely in the presence of systemic illness. Given the high mortality in bearded dragons with aneurysms, prognosis may be guarded with this diagnosis. Additional studies evaluating the etiology of these diseases, as well as appropriate therapeutic interventions are needed.

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Supplementary Materials

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