Cardiac disease is frequently diagnosed in client-owned ferrets (*Mustela putorius furo*). Studies conducted to evaluate cardiac function in ferrets include echocardiographic,1,2 ECG,3 and radiographic4 findings for clinically normal ferrets as well as a small number of case reports5–7 of ferrets with cardiac disease. To our knowledge, a study to describe the prevalence of various forms of spontaneously occurring cardiac disease in ferrets or the most commonly detected echocardiographic abnormalities in ferrets has not been conducted. Information regarding the types of cardiac disease most frequently diagnosed in ferrets has been limited to anecdotal reports8–11 by cardiologists and practitioners. Dilated cardiomyopathy has been described in case reports7,a and anecdotally has been described as one of the more frequently diagnosed cardiac diseases in ferrets.9,11 Other forms of cardiac disease in ferrets, such as hypertrophic cardiomyopathy and chronic valvular disease, have been diagnosed but not described in peer-reviewed literature. Arrhythmias in ferrets have been discussed6–11 but have not been examined in a clinical study to determine the relative prevalence of various ECG abnormalities in a client-owned population. The purpose of the study reported here was to retrospectively describe the echocardiographic and ECG findings in a large group of client-owned ferrets evaluated at a clinical practice and to determine which findings were most frequently associated with CHF.

### Materials and Methods

**Case selection**—Medical records for all ferrets that had a cardiac evaluation (echocardiogram with or without ECG) performed between January 1994 and November 2009 were reviewed. Ferrets were included in the study if their records contained at least a signalment and an echocardiographic diagnosis. Arrhythmias in ferrets have been discussed6–11 but have not been examined in a clinical study to determine the relative prevalence of various ECG abnormalities in a client-owned population. The medical records of all ferrets that had a cardiac evaluation (echocardiogram with or without ECG) performed between January 1994 and November 2009 were reviewed. Data analyzed included signalment; primary clinical sign or physical examination finding that prompted cardiac evaluation; echocardiographic diagnosis; ECG diagnosis; radiographic diagnosis (if radiographs were obtained within 1 month before or after the echocardiogram); presence of congestive heart failure (CHF) defined as pulmonary edema, pleural effusion, or ascites determined to be of cardiac origin; and any available follow-up echocardiographic or ECG diagnoses.

### Results

Valvular regurgitation (VR) was the most common abnormal echocardiographic finding and was diagnosed in 49 of 95 ferrets, of which 44 had aortic VR, 24 had mitral VR, and 23 had >1 valve affected. Congestive heart failure was diagnosed in 17 of 95 ferrets, which included all 4 ferrets that had dilated cardiomyopathy. Of the 65 ferrets with ECG results, 26 had atrioventricular block, of which 7 had third-degree atrioventricular block and 6 had CHF, syncope, or weakness.

### Conclusions and Clinical Relevance

The most frequent echocardiographic abnormality found in ferrets was VR, most commonly affecting the aortic and mitral valves. Dilated cardiomyopathy was infrequently diagnosed but was generally associated with CHF. The most frequent ECG abnormality was atrioventricular block, and third-degree atrioventricular block was often associated with CHF, weakness, or syncope. (J Am Vet Med Assoc 2012;241:1484–1489)
cardiac evaluation), echocardiographic diagnosis, ECG diagnosis (when available), radiographic diagnosis (if radiographs were performed within 1 month before or after the echocardiographic examination), presence of CHF (defined as pulmonary edema, pleural effusion, or ascites determined to be of cardiac origin), and follow-up echocardiographic or ECG diagnoses (when available). For the purpose of the study reported here, all ferrets were reported as either male or female with no distinction made regarding neutered status, although it was assumed that all study ferrets were castrated or spayed because virtually all client-owned ferrets are neutered.

Echocardiographic examination—All echocardiographic examinations were performed by either a board-certified veterinary cardiologist or a cardiology resident under the supervision of a board-certified veterinary cardiologist. Except for 3 instances, all echocardiographic and ECG examinations were performed on conscious, nonsedated ferrets. The exceptions were 1 ferret that was sedated with midazolam and 2 ferrets that were anesthetized, both of which subsequently had an echocardiographic examination performed while they were conscious and nonsedated. Ferrets were typically restrained for the echocardiographic examination in lateral recumbency; however, for less compliant patients, examinations were performed with the ferrets grasped by the scruff of the neck and suspended above the examination table.

For the purpose of the present study, the echocardiographic diagnosis for each ferret was made on the basis of the results of the echocardiographic examination as interpreted and reported by the attending clinician. These diagnoses were generally made on the basis of the subjective impression of the sonographer, although in some instances, published reference limits for echocardiographic variables in ferrets were consulted. In most instances, VR was subclassified as mild, moderate, or severe on the basis of the subjective impression of the sonographer. For ferrets with VR that had >1 echocardiographic examination performed, the extent of VR was subclassified on the basis of the results of the initial echocardiographic examination. For instances in which the described VR spanned 2 categories (eg, mild to moderate), it was subclassified in the more severe category (eg, moderate).

For the purpose of the present study, ferrets originally diagnosed with either LVH or hypertrophic cardiomyopathy were classified as having LVH because other causes of hypertrophy could not be definitively ruled out. Initial diagnosis of LVH was made on the basis of the subjective interpretation of left ventricular wall thickening in at least 1 segment. Ferrets were classified as having ventricular enlargement if they had dilation of the left or right ventricle with no concurrent structural cause of volume loading (ie, without significant VR) identified and subjectively normal systolic function. Ferrets with >1 echocardiographic abnormality or diagnosis were included in all categories for which they had an abnormal finding. Ferrets were included in both the VR and ventricular enlargement categories if the VR was deemed too insignificant to be the likely cause of the ventricular enlargement or if ventricular enlargement was observed on the side of the heart opposite to the regurgitant valve.

ECG examination—Electrocardiographic recordings were typically performed with ferrets in right lateral recumbency; however, for less compliant patients, examinations were performed with the ferrets grasped by the scruff of the neck and suspended above the examination table. For the purpose of the present study, the ECG diagnosis for each ferret was made on the basis of the diagnosis as interpreted and reported by the attending clinician (board-certified cardiologist or cardiology resident under the supervision of a board-certified cardiologist). Ferrets on which >1 ECG examination was performed had each finding or diagnosis counted once for analysis purposes (ie, if a new diagnosis was made on a subsequent ECG, this was counted individually and in addition to the original diagnosis, but if the diagnosis remained the same but was observed twice, it was only counted once). Ferrets that had >1 ECG abnormality within 1 ECG recording had each abnormality classified separately.

Statistical analysis—Descriptive statistics were calculated by the use of a spreadsheet program. For each cardiac disease diagnosed via echocardiographic or ECG examination, the mean ± SD age of affected ferrets was reported.

Results

Animals—Echocardiographic examinations were performed on 106 ferrets between January 1994 and November 2009. Eleven ferrets were excluded from the present study because of incomplete records or inconclusive echocardiographic data; thus, data for the 95 ferrets that met the inclusion criteria were evaluated. Of the 95 ferrets included in the present study, 58 (61%) were male and 37 (39%) were female, and the mean ± SD age of the ferrets was 5.0 ± 1.8 years. The indication for cardiac evaluation was identified during record review for 83 ferrets, and some ferrets had >1 indication for cardiac evaluation. Clinical abnormalities that prompted cardiac evaluation included arrhythmia (n = 35 ferrets); heart murmur (32); cough, dyspnea, or increased respiratory rate (21); radiographic evidence of cardiomegaly (12); and pleural or abdominal effusion (6). Three ferrets were examined for routine cardiac screening, and 1 ferret was examined after heart disease was diagnosed by the referring veterinarian. Two ferrets each had 3 abnormalities, 23 each had 2 abnormalities, and 58 each had 1 abnormality that prompted cardiac examination.

Echocardiographic diagnoses—Of the 95 ferrets evaluated, 20 (21%) had no echocardiographic abnormalities identified. Valvular regurgitation (n = 49 [52%]) was the most frequent echocardiographic abnormality diagnosed followed by ventricular enlargement (16 [17%]), LVH (14 [15%]), DCM (4 [4%]), and restrictive cardiomyopathy (2 [2%]; Table 1). Ten ferrets had >1 echocardiographic abnormality. Five of these were diagnosed with both VR and LVH, 4 were diagnosed with VR and ventricular enlargement (not deemed to be secondary to the regurgitant valve), and 1 was diagnosed with LVH and ventricular enlargement.
Of the 49 ferrets that had VR, 30 were male and 19 were female, and the mean age of VR-affected ferrets was 5.6 ± 1.6 years. Twenty-six (53%) of the ferrets with VR had 1 valve affected, and the other 23 ferrets had >1 valve affected; 1 ferret had all 4 valves affected, 6 had 3 valves affected, and 16 had 2 valves affected. For ferrets with VR, the aortic valve (n = 44 [90%]) was the valve most commonly affected, followed by the mitral valve (24 [49%]; Table 2). The extent of aortic VR was described in 39 of the 44 affected ferrets, of which 6, 21, and 12 were classified with severe, moderate, and mild VR, respectively. The extent of mitral VR was described in 19 of 24 affected ferrets, of which 2, 9, and 8 were classified with severe, moderate, and mild VR, respectively. Valvular regurgitation of the pulmonic valve was diagnosed in 6 ferrets, as was VR of the tricuspid valve.

Ventricular enlargement was diagnosed in 16 ferrets, of which 8 were described as having mild left ventricular enlargement of unknown cause or importance. Five of the 16 ferrets with ventricular enlargement had concurrent third-degree atrioventricular block, and ventricular dilation resulting from bradycardia was reported as the suspected cause of the ventricular enlargement. Another 5 ferrets with ventricular enlargement had concurrent second-degree atrioventricular block; however, in only 1 ferret (which had a conduction ratio of 2:1) was bradycardia considered severe enough to result in ventricular dilation and enlargement.

ECG diagnoses—Of the 95 ferrets evaluated, 65 (68%) had at least 1 ECG examination performed (Table 3). Seven ferrets had >1 ECG examination performed during the study period, resulting in interpretations for 72 ECG examinations. Five ferrets had >1 ECG abnormality within the same ECG recording. Sinus rhythm (including normal sinus rhythm and sinus tachycardia) was the sole diagnosis in 30 (46%) ferrets. The most common ECG abnormality identified was atrioventricular block, which was diagnosed in 26 (40%) ferrets. First-, second-, and third-degree atrioventricular block were diagnosed in 2, 19, and 7 ferrets, respectively; 1 ferret had concurrent first- and second-degree atrioventricular block. Three ferrets with second-degree atrioventricular block had follow-up ECG examinations performed. At the time of the follow-up examination, 1 ferret had developed third-degree atrioventricular block, 1 had a normal sinus rhythm (1.5 years after the initial ECG examination), and 1 continued to have second-degree atrioventricular block on 2 subsequent ECG examinations that were performed over a period of 1.5 years.

Ventricular premature complexes were diagnosed in 12 (18%) ferrets, of which 1 had ventricular tachycardia, 8 had isolated or occasional VPCs, and 3 were simply classified as having a ventricular arrhythmia. In 4 of the ferrets with VPCs, second- or third-degree atrioventricular block was concurrently diagnosed. Supraventricular premature complexes were diagnosed in 4 (6%) ferrets, of which 3 had isolated or occasional atrial premature complexes or SVPCs and 1 was simply classified as having a supraventricular arrhythmia.

CHF—Of the 95 ferrets evaluated, 17 (18%) had CHF; of which 10 were male and 7 were female. The mean ± SD age of ferrets with CHF was 6.2 ± 1.1 years. Of the 17 ferrets with CHF, VR was diagnosed in 11, DCM was diagnosed in 4, ventricular enlargement (presumed to be secondary to third-degree atrioventricular block) was diagnosed in 2, and LVH was diagnosed in 2. Dilated cardiomyopathy was always diagnosed as an isolated echocardiographic finding. One of the ferrets with ventricular enlargement and third-degree atrioventricular block also had aortic VR. One of the ferrets with LVH also had VR of the mitral, aortic, and tricuspid valves.

The proportion of ferrets with CHF within each echocardiographic diagnosis included 4 of 4 ferrets with DCM, 11 of 49 ferrets with VR, 2 of 14 ferrets with LVH, 2 of 16 ferrets with ventricular enlargement, and 0 of 20 ferrets with no echocardiographic abnormalities (Figure 1). One of the ferrets with DCM did not have CHF at the time of the initial echocardiographic examination but developed clinical signs and radiographic evidence suggestive of CHF.

### Table 1—Echocardiographic diagnoses for 95 client-owned ferrets (*Mustela putorius furo*) that had a cardiac examination performed between January 1994 and November 2009 at a referral veterinary practice in the northeastern United States.

<table>
<thead>
<tr>
<th>Echocardiographic diagnosis*</th>
<th>No. (%) of ferrets</th>
<th>No. of males</th>
<th>No. of females</th>
<th>Mean ± SD age (y) of affected ferrets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinically normal</td>
<td>20 (21)</td>
<td>13</td>
<td>7</td>
<td>3.7 ± 1.8</td>
</tr>
<tr>
<td>VR</td>
<td>49 (52)</td>
<td>30</td>
<td>19</td>
<td>5.5 ± 1.18</td>
</tr>
<tr>
<td>Ventricular enlargement</td>
<td>16 (17)</td>
<td>10</td>
<td>6</td>
<td>4.9 ± 2.0</td>
</tr>
<tr>
<td>LVH</td>
<td>14 (15)</td>
<td>6</td>
<td>8</td>
<td>5.6 ± 1.7</td>
</tr>
<tr>
<td>DCM</td>
<td>4 (4)</td>
<td>3</td>
<td>1</td>
<td>5.1 ± 0.2</td>
</tr>
<tr>
<td>Restrictive cardiomyopathy</td>
<td>2 (2)</td>
<td>2</td>
<td>0</td>
<td>5.7 ± 0.8</td>
</tr>
</tbody>
</table>

*Ferrets (n = 10) that had >1 concurrent diagnosis are represented in both categories.

<table>
<thead>
<tr>
<th>Severity of regurgitation</th>
<th>Aortic</th>
<th>Mitral</th>
<th>Pulmonic</th>
<th>Tricuspid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Moderate</td>
<td>21</td>
<td>9</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Severe</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Not classified</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>44</td>
<td>24</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>

*Twenty-six ferrets had 1 affected valve, and 23 ferrets had >1 affected valve; 1 ferret had all 4 valves affected, and 16 had 2 valves affected. Ferrets with >1 affected valve are represented in each category in which they were affected. See Table 1 for remainder of key.
< 6 months later when a follow-up echocardiographic examination was performed. Of the 11 ferrets that had CHF and VR, 8 had > 1 affected valve (1 ferret had 4 valves affected, 3 ferrets had 3 valves affected, 4 had 2 valves affected, and 3 had 1 valve affected). For the 3 ferrets with CHF and VR of only 1 valve, the mitral valve was affected in 2 and the aortic valve was affected in 1; the ferret with VR of the aortic valve also had concurrent third-degree atrioventricular block. Nine of the 11 ferrets with VR and CHF had aortic VR, 9 had mitral VR, 4 had tricuspid VR, and 2 had pulmonic VR. As noted previously, tricuspid VR and pulmonic VR were never identified as isolated affected valves in any of the ferrets with VR and CHF; and mitral VR and aortic VR were often identified concurrently (in 7 of the 11 ferrets with VR and CHF).

The proportion of ferrets with CHF within each ECG diagnosis included 2 of 2 with first-degree atrioventricular block, 2 of 19 with second-degree atrioventricular block, 3 of 7 with third-degree atrioventricular block, 5 of 12 with VPCs, 5 of 30 with sinus rhythm, and 0 of 4 with SVPCs (Figure 2). One ferret had concurrent first- and second-degree atrioventricular block and VPCs, and 1 ferret had concurrent third-degree atrioventricular block and VPCs. In addition to the 3 ferrets with concurrent third-degree atrioventricular block and CHF, another ferret with third-degree atrioventricular block had an abnormal pulmonary pattern in the right caudal lung lobe identified during radiographic evaluation. The radiologist classified that area as an area of possible pulmonary thromboembolism or atelectasis; however, the consulting cardiologist suspected pulmonary edema and recommended furosemide administration.

**Discussion**

In the present study of 95 client-owned ferrets, VR was the most frequently identified echocardiographic abnormality and was diagnosed in 49 (52%) of the ferrets that had a cardiac evaluation performed between January 1994 and November 2009 at our referral practice. These results were in accordance with anecdotal descriptions by other investigators who reported examining ferrets with VR frequently in clinical practice. For ferrets with VR, the aortic valve was most
commonly affected followed by the mitral valve, and many ferrets had VR of > 1 valve. Aortic VR has been anecdotally described as a common incidental finding on echocardiographic examinations of ferrets, and indeed, in the present study, most of the ferrets with aortic VR had no clinical signs associated with VR. Of 9 ferrets with aortic VR and CHF, 7 had concurrent regurgitation of another valve (most commonly the mitral valve) of equal to or greater extent than that of the aortic valve and 1 had concurrent aortic VR and third-degree atrioventricular block. Of the 11 ferrets with VR and CHF, only 1 (a ferret with concurrent severe aortic VR and mild mitral VR) had aortic VR that was sufficient enough to be suspected as the primary contributing factor for CHF. Therefore, it would appear that isolated aortic VR is rarely associated with CHF in ferrets; however, aortic VR may become hemodynamically important in conjunction with substantial mitral VR.

Dilated cardiomyopathy was an uncommon echocardiographic abnormality in the ferrets of the present study, affecting only 4% of the study population; however, all 4 ferrets with DCM had concurrent CHF. These results suggest that, although DCM may be an infrequent finding in client-owned ferrets, it is often associated with CHF and should be considered as a differential diagnosis for ferrets with respiratory difficulty. The low prevalence of DCM in the ferrets of the present study contradicts anecdotal reports by other investigators, in which DCM is cited as a common cardiac abnormality in ferrets. One possible explanation for the discrepancy in results is that DCM may be decreasing in prevalence in client-owned ferrets, possibly because of changes in the genetics of ferrets used in breeding programs or changes in husbandry (ie, nutrition). Another possible explanation for the low prevalence of DCM in the ferrets of the present study was that most of the ferrets evaluated had no clinical signs of heart disease, whereas in other practices, most ferrets that undergo echocardiographic examination may be those with clinical signs of CHF. In the present study, had echocardiographic examinations been performed only on ferrets with clinical signs of CHF (eg, cough, dyspnea, or increased respiratory rate), the proportion of DCM-affected ferrets would have been much higher. Finally, DCM prevalence in ferrets may be affected by geographic location, and the present study was conducted at a single veterinary hospital in the northeastern United States. In the present study, LVH was diagnosed in 14 (15%) ferrets. Hypertrophic cardiomyopathy could not be confirmed in these ferrets because histologic examination was not performed. Although data on blood pressure and thyroid hormone concentration were not available for these ferrets, LVH secondary to systemic hypertension or hyperthyroidism has not been reported in ferrets. During echocardiography, volume contraction can give the appearance of a small left ventricular chamber and thickened ventricular walls and is known as pseudohypertrophy. In cats, hydration status can influence the results of echocardiographic examinations, and for at least 1 ferret in the present study, the sonographer specifically described dehydration as a possible contributor to the appearance of LVH.

In the present study, ventricular enlargement was diagnosed in 16 (17%) ferrets; one-third of these also had third-degree atrioventricular block, and bradycardia was suspected as the cause of ventricular dilation and enlargement. For an additional ferret with concurrent ventricular enlargement and second-degree atrioventricular block with a 2:1 conduction ratio, the cardiologist suspected that bradycardia was involved in cardiac remodeling. Half of the ferrets with ventricular enlargement were described as having mild ventricular dilation of unknown cause or importance. Because reference limits for echocardiographic variables were not consistently consulted (or were not published at the time), the present study may be those with clinical signs of CHF, whereas only 1 ferret with third-degree atrioventricular block generally had clinical signs of cardiac disease. Six of 7 ferrets with third-degree atrioventricular block had CHF, weakness, or syncope, whereas only 1 ferret with third-degree atrioventricular block was subclinically affected. Pacemaker implantation has been described as a treatment for third-degree atrioventricular block in 1 ferret. In the present study, insufficient follow-up data for ferrets with second-degree atrioventricular block were available to determine whether these ferrets are at risk for developing third-degree atrioventricular block, and the issue warrants further research.

In the present study, 5 of 12 ferrets with CHF also had VPCs. These ferrets may have had multiple confounding factors, such as variable concurrent structural cardiac disease or other ECG abnormalities (eg, atrioventricular block). However, given the relatively high proportion of ferrets with VPCs that had concurrent CHF in the present study, it may be prudent to recommend echocardiographic examination and thoracic radiographs for any ferret with VPCs detected during ECG evaluation.

Atrial fibrillation was not detected in any of the ferrets of the present study and appears to be a rare ECG abnormality in ferrets. Transient atrial fibrillation was detected in 1 ferret in association with a narcotic over-
dose\textsuperscript{14} and has been anecdotally reported in ferrets by other practitioners.\textsuperscript{9}

Limitations of the present study include its retrospective design, the incomplete data available for some ferrets, and the small number of ferrets in some of the echocardiographic or ECG classification groups. Thoracic radiography was not performed on all study ferrets; therefore, it is possible that subclinical cases of CHF were not detected. Although routine M-mode measurements were performed on all study ferrets, these were not consistently compared with published reference limits. In some instances, the echocardiographic examinations were performed prior to the availability of published reference limits for ferrets, and in later examinations, these reference limits were not uniformly consulted during the diagnostic process. In the present study, the echocardiographic examinations were performed by multiple sonographers, and diagnoses were made on the basis of the subjective impressions of the attending cardiologists. Results of studies\textsuperscript{15–17} conducted to evaluate echocardiographic examinations of human patients suggest that visual estimation of variables such as ejection fraction correlates closely with formal or quantitative methods of evaluation, thus demonstrating the value of visual assessment by a skilled sonographer. Similarly, reference limits for ECG values for ferrets were rarely consulted during the diagnostic process, but this likely had no effect on most ECG interpretations, with the possible exception of first-degree atrioventricular block. For the 2 ferrets with first-degree atrioventricular block, the diagnosis was confirmed by comparison of ECG findings with published reference limits,\textsuperscript{13} but first-degree atrioventricular block in other ferrets may have been missed if the attending cardiologist did not detect the characteristic prolonged PR interval.

The frequency with which certain echocardiographic and ECG abnormalities were diagnosed in the present study may have been affected by the client and patient population. The present study was conducted at a large referral practice that has a department that specializes in the treatment of avian and exotic species. Many of the ferrets evaluated in the present study had no clinical signs of cardiac disease, which likely increased the number of clinically normal or mild cardiac disease diagnoses. Geography may also have affected the prevalence of observed cardiac abnormalities. Dirofilariasis has been reported in ferrets\textsuperscript{16–20}; however, the present study was conducted in an area where heartworm disease is not endemic in ferrets, and dirofilariasis was not diagnosed in any of the study ferrets.

Valvular regurgitation, most commonly affecting the aortic and mitral valves, was the most frequent echocardiographic abnormality detected in client-owned ferrets that received a cardiac evaluation. Although DCM was infrequently diagnosed in ferrets of the present study, it was often associated with CHF and therefore has important clinical ramifications. Atrioventricular block was a frequent ECG abnormality detected in the study ferrets, and third-degree atrioventricular block was often associated with CHF or clinical signs such as weakness or syncpe. Knowledge of the most common echocardiographic and ECG abnormalities associated with clinical signs of cardiac disease or CHF in ferrets should aid veterinary practitioners in making recommendations regarding cardiac evaluation and treatment.

\begin{itemize}
  \item Excel 2003, Microsoft Corp, Redmond, Wash.
\end{itemize}

References