Surgical and nonsurgical management of patent ductus arteriosus in cats: 28 cases (1991–2012)

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Objective—To characterize the clinical features and outcome of cats treated for patent ductus arteriosus (PDA) with attenuation (extravascular or intravascular) versus medical treatment only.

Design—Retrospective case series.

Animals—28 client-owned cats with congenital PDA.

Procedures—Medical records for cats with PDA diagnosed by means of echocardiography were reviewed. Data retrieved included signalment; history; clinical signs; results of physical examination, ECG, echocardiography, and thoracic radiography; response to medical management if attempted; type of attenuation procedure if attempted (surgical or intravascular); procedural details; intraoperative and postoperative (≤ 2 weeks) complications; and long-term (> 2 weeks) complications. Follow-up was obtained from medical records and via telephone interviews.

Results—All 28 cats were referred for evaluation of a cardiac murmur, but 17 of 26 (65%) for which initial clinical signs were available did not have overt signs at initial evaluation. Multiple congenital cardiac defects were identified in 6 of 23 (26%) cats. Seventeen of 26 (65%) cats were documented as treated with 1 or more vascular attenuation procedures; vascular attenuation was not attempted in 11 cats receiving an angiotensin-converting enzyme inhibitor or loop diuretic (n = 2) or no medical treatment (9). Surgical ligation was successful in 11 of 15 cats, and coil embolization was successful in 2 cats. Procedural or postoperative complications included death (n = 2), left-sided laryngeal paralysis (2), voice change (1), fever (1), hemorrhage (4), and chylothorax (1). Long-term follow-up was available for 16 of 28 (57%) cats. Three of 4 cats that did not undergo surgical attenuation died of cardiac-related disease.

Conclusions and Clinical Relevance—Results suggested that PDA occurs rarely in cats, and clinical signs and diagnostic findings were consistent with those previously reported for dogs. Surgical versus nonsurgical treatment did not result in a significant difference in life expectancy in this small cohort. Evaluation of laryngeal function after surgical ligation is recommended. Further study of the outcome associated with various treatment options in a larger population of patients is recommended. (J Am Vet Med Assoc 2015;247:278–285)

Patent ductus arteriosus is the most common congenital heart defect in dogs, accounting for 25% to 30% of congenital malformations.1,2 This defect has a significantly lower reported prevalence in cats (0.2 cases/1,000 cats).3 Patent ductus arteriosus with left-to-right shunting of blood causes pulmonary overcirculation and left ventricular and left atrial volume overload, leading to eccentric hypertrophy of the left side of the heart. In dogs, untreated PDA usually results in development of congestive heart failure by 1 year of age and has been reported to result in death in 64% of patients within 1 year after initial examination in a study of 98 dogs.4 It has been reported that the best outcomes are obtained when treatment with occlusion of the PDA is performed as soon as possible after diagnosis.5 Very little has been published regarding treatment and outcome of this condition in cats.6,7,8

Treatment of PDA consists of complete attenuation of blood flow through the ductus arteriosus via extravascular (surgical ligation) or intravascular (catheter-delivered devices designed to stimulate thrombosis) occlusion. Historically, open surgical attenuation was the treatment of choice; however, catheter-based methods for vascular occlusion, which use coils or ductal occluding devices, are currently being used with increasing frequency in veterinary patients because of their minimally invasive application and lower incidence of major operative complications.9 The most serious complication of surgical PDA attenuation reported10 in
small animal patients is rupture of the ductus arteriosus or great vessels during dissection, resulting in life-threatening hemorrhage. In dogs, the reported mortality rate associated with open surgical ligation of a PDA is 0% to 7%. Although intravascular attenuation has been described in cats, a major limiting factor is the ability to achieve adequate vascular access, which can be challenging in small patients. The overall prognosis for canine PDA patients is considered good with either surgical ligation or transarterial attenuation. Aside from a limited number of case reports, documentation of outcome in cats with PDA, whether untreated or treated with extravascular or intravascular attenuation, is lacking.

The objectives of the study reported here were to document the clinical findings associated with a diagnosis of PDA in feline patients and to describe short- and long-term follow-up with or without treatment by means of vascular attenuation.

**Materials and Methods**

**Case selection and medical record review**—Medical records of cats evaluated for PDA at 3 veterinary referral institutions (University of California-Davis, University of Pennsylvania, and the Animal Medical Center) from May 1991 to March 2012 were identified via search of the medical records database at each hospital. Cats were included in the study if PDA was diagnosed by means of visualization of the shunt on an echocardiogram by a board-certified veterinary cardiologist. Clinical features and complications of surgical ligation for 1 cat included in this study were previously described in a case report. Data retrieved from the medical records included history; signalment; body weight; initial clinical signs; results of initial physical examination, ECG, echocardiography, and thoracic radiography; response to medical management if attempted; type of attenuation procedure if attempted (open surgical or vascular attenuation); procedural information for any attenuation procedures (including surgeon's level of training, implants placed, surgery duration, and intraoperative or procedural complications); short-term complications (≤ 2 weeks after the procedure); and long-term complications (> 2 weeks after the procedure). An attenuation procedure was considered successful if the patient survived the procedure and the shunt was no longer visible on repeated echocardiography after the procedure. Follow-up information was obtained from medical records or via telephone interviews with owners and referring veterinarians. Attempts were made to contact the owners of all the cats, and data, if applicable, were collected on signs of further cardiac disease, age at time of death (or euthanasia), and cause of death (or euthanasia). The ages of patients currently alive were determined as of January 1, 2013 (date of last follow-up).

**Cardiac assessment**—Echocardiographic data recorded included empirical measurements such as left atrial and ventricular diameter and wall thickness, aortic diameter, intraventricular septal width, fractional shortening, and maximum PDA flow. Identification and classification of specific chamber enlargement and valve function were also recorded. Electrocardiographic data recorded included heart rate, rhythm, and any empirical measurements made. Available thoracic radiographs were evaluated by a board-certified veterinary radiologist at the respective institutions. Radiographic findings as reported in the record were recorded and analyzed.

**Statistical analysis**—Normally distributed data are presented as mean ± SD; nonnormally distributed data are presented as median and range. A Fisher exact test was used to compare binomial proportions, such as the proportion of successful outcomes with surgical experience (residents vs clinicians), and a binomial test was used to test for sex predilection. Procedure times between cats with or without a successful outcome were compared by means of a Student 2-group t test. Survival time for cats treated with vascular attenuation versus medically was evaluated with a proportional hazards regression model. Statistical software was used to perform all analyses. Values of P < 0.05 were considered significant.

**Results**

**Animals**—Thirty-one cats with PDA were evaluated between May 1991 and March 2012, including 24 patients from the University of California-Davis Veterinary Medical Teaching Hospital, 2 from the Animal Medical Center, and 5 from the University of Pennsylvania Matthew J. Ryan Veterinary Hospital. Three cats with PDA from the University of California-Davis were excluded from the study because they did not have an echocardiographic evaluation performed, resulting in 28 cases that met the study selection criteria. The breeds represented in this cohort of cats included domestic shorthair (n = 17), domestic longhair (+), Bengal (2), Himalayan (2), domestic medium hair (1), Burmese (1), and Abyssinian (1). Fifteen cats were female, and 13 were males. There was no sex predilection for PDA identified in this cohort (P = 0.71). The median body weight was 2.1 kg (4.6 lb; range, 0.6 to 5.7 kg [1.3 to 12.5 lb]; n = 16). At the time of initial auscultation of a heart murmur, 3 of the 16 cats for which initial body weight data were available in the medical record weighed ≤ 1 kg (2.2 lb), 4 of 16 weighed > 1 kg but ≤ 2 kg (≤ 4.4 lb), 4 of 16 weighed > 2 kg but ≤ 3 kg (≤ 6.6 lb), and 5 of 16 weighed > 3 kg.

**Clinical signs**—Clinical signs on initial evaluation by the referring veterinarian, as noted in the records at the referring primary care practice, were available for 26 of 28 cats. The majority of the cats (17/26 [65%]) were not initially evaluated by the referring veterinarian for historical clinical signs of cardiac disease as perceived by their owners, but were instead evaluated for unrelated reasons such as vaccination or elective neutering. Clinical signs noted by either the referring primary care veterinarians or clinicians at the referral hospitals of this report included tachypnea (9/28 [32%]), bradycardia (4/28 [14%]), bounding femoral pulses (4/28 [14%]), sneezing or coughing occasionally (4/28 [14%]), smaller stature than expected (3/28 [11%]), exercise intolerance (3/28 [11%]), increased respiratory effort (3/28 [11%]), diarrhea (2/28 [7%]),...
harsh sounds on auscultation (2/28 [7%]), dull mentation (1/28 [4%]), vocalizing (1/28 [4%]), fever (1/28 [4%]), and unrelated minor trauma (1/28 [4%]).

A murmur was auscultated in all 28 cats by the referring veterinarian and was the reason for referral to a specialty center. Murmurs were first detected between 1 and 9 months of age (median, 3 months). Descriptions of the murmurs as recorded by the respective specialty hospitals were not standardized, and 27 of 28 of the cats had descriptions of the grade of the murmur recorded in the medical record. Of these 27 cases, 24 (89%) were described as grade 3/6 or higher. In 5 of 27 (19%) cases, the murmurs were described as grade 6/6; in 12 of 27 (44%) cases, the murmurs were described as grade 5/6; in 4 of 27 (15%) cases, the murmurs were described as grade 4/6; in 3 of 27 (11%) cases, the murmurs were described as grade 3/6; in 2 of 27 (7%) cases, the murmurs were described as grade 2/6; and in 1 of 27 (4%) cases, the murmur was described as grade 1/6. Nine of the 28 (32%) cats were described as having continuous murmurs, 7 of 27 (26%) were described as systolic murmurs, and 20 of 27 (74%) did not have descriptions of the portion of the cardiac cycle affected by the murmur. The description of the point of maximum intensity of the murmur on auscultation was available in 20 of 28 cases. In 7 of the 20 (35%) described murmurs, the point of maximum intensity was recorded on the right side of the chest, and in 13 (65%) cases, it was on the left. Other descriptors used to characterize the murmurs included a basilar location (9/28 [32%]), apical location (1/28 [4%]), machinery character (2/28 [7%]), and musical character (2/28 [7%]).

Radiographic findings—Radiographic findings recorded by a board-certified radiologist were available in 21 of 28 cases. Generalized cardiomegaly was identified in 19 of the 21 (90%) cases, and left-sided cardiomegaly was specified in 2 (10%) cases. The pulmonary vasculature was distended in 18 of 21 (86%) cases, and aortic bulging was present in 5 (24%) cases. Pulmonary infiltrates were identified in 11 of 23 (52%) cases and were further classified as pulmonary edema in 14 (19%) and pleural effusion in 2 (10%). Hepatomegaly was noted in 2 of 21 (10%) cases. One (5%) case report noted dorsal deviation of the trachea, and another noted left-sided renalomegaly (5%). One (5%) case of atelectasis was reported, as was 1 (5%) case of pericardioperitoneal diaphragmatic hernia.

ECG—Electrocardiographic results were available for 16 of 28 cases. Fifteen of the 16 cases for which ECG results were available had normal sinus rhythm, and 1 patient had infrequent premature ventricular complexes. The median recorded heart rate was 200 beats/min (range, 160 to 240 beats/min). Descriptive ECG findings were reported for 16 patients. The QRS complex was reported to be normal in only 2 of 16 patients. Of the remaining patients, 12 of 16 were found to have tall R waves suggestive of left ventricular enlargement. Three of 16 patients were found to have deep S waves suggestive of right ventricular enlargement. Four of the 12 patients with tall R waves also had wide P waves suggestive of left atrial enlargement. One patient was found to have generalized cardiomegaly as indicated by tall R waves, deep S waves, and wide T and P waves. Five patients had empirical ECG measurements performed (Table 1).

Echocardiography—A definitive diagnosis of a PDA was made via echocardiographic identification of blood flow through the ductus arteriosus in all 28 cases. Empirical echocardiographic measurements were available for 21 of 28 cats (Table 2). Data on additional cardiac abnormalities were available for 23 of the 28 cats in the study; in 6 of 23 (26%) cats, congenital abnormalities in addition to the PDA were identified. Cardiac wall hypertrophy was identified and described as follows: right ventricular hypertrophy (5/23 [22%]), left ventricular hypertrophy (14/23 [61%]), and left atrial hypertrophy (10/23 [43%]). Enlarged pulmonary arteries were identified in 5 of 23 (22%) patients, and pulmonary hypertension was present in 2 (8%). Aortic insufficiency was present in 4 of 23 (17%) patients. Three of 23 (13%) patients had ventricular septal defects, and an additional 3 (13%) had aortic stenosis. Subvalvular stenosis was present in 2 of 23 (9%) patients. Other

### Table 1—Electrocardiographic measurements in cats (n = 5) with congenital PDA in a study of cats (28) with congenital PDA evaluated between May 1991 and March 2012 at 3 referral hospitals receiving medical management alone versus surgical treatment.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PDA patients (n = 5)</th>
<th>Reference feline values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>200 (160–240)</td>
<td>120–220</td>
</tr>
<tr>
<td>PR interval (s)</td>
<td>0.08 (0.06–0.1)</td>
<td>0.05–0.09</td>
</tr>
<tr>
<td>P wave amplitude (mV)</td>
<td>0.2 (0.1–0.3)</td>
<td>0.02–0.12</td>
</tr>
<tr>
<td>QRS amplitude (mV)</td>
<td>1.9 (1.0–2.5)</td>
<td>0.9</td>
</tr>
</tbody>
</table>

*Data were not available for 23 cats. Patient values are median (range). Published feline values are the range or median.

### Table 2—Echocardiographic measurements for cats (n = 28) with congenital PDA evaluated between May 1991 and March 2012 at 3 referral hospitals receiving medical management alone versus surgical treatment.

<table>
<thead>
<tr>
<th>Variable</th>
<th>PDA patients (n = 28)</th>
<th>Reference feline values*</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVOD (mm)</td>
<td>3.6 ± 0.6</td>
<td>3 ± 0.2</td>
</tr>
<tr>
<td>IVSd (mm)</td>
<td>0.4 ± 0.1</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>LA: Ao</td>
<td>1.69 ± 0.23</td>
<td>1 ± 0.2</td>
</tr>
<tr>
<td>IVSs (mm)</td>
<td>0.57 ± 0.07</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>LVIDd (mm)</td>
<td>2.07 ± 0.25</td>
<td>2 ± 0.25</td>
</tr>
<tr>
<td>LVIDs (mm)</td>
<td>1.20 ± 0.17</td>
<td>1 ± 0.1</td>
</tr>
<tr>
<td>LVFWd (mm)</td>
<td>0.45 ± 0.1</td>
<td>0.45 ± 0.1</td>
</tr>
<tr>
<td>LVFPWs (mm)</td>
<td>0.68 ± 0.10</td>
<td>0.6 ± 0.1</td>
</tr>
<tr>
<td>Fractional shortening (%)</td>
<td>44 (16–63.7)</td>
<td>55 ± 10.2</td>
</tr>
<tr>
<td>PDA Vmax (m/s)</td>
<td>86 (50–137)</td>
<td>80 ± 20.0</td>
</tr>
</tbody>
</table>

*Patient data are median (range); reference feline data are mean ± SD. All measurements were obtained prior to any vascular attenuation procedures (if attempted). LVIDd = Left ventricular internal dimension in diastole. LVIDs = Left ventricular internal dimension in systole. LVFWd = Left ventricular posterior wall in diastole. LVFPWs = Left ventricular posterior wall in systole. PDA Vmax = Maximum velocity of flow through the PDA. — = Data not available.
cardiac abnormalities identified on echocardiographic evaluation (each n = 1) included pulmonary atresia–ventricular septal defect (previously known as tetralogy of Fallot17), pseudotruncus arteriosus, mitral valve dysplasia, mitral valve regurgitation, an abnormally arising pulmonary artery, increased aortic flow, a flattened interventricular septum, aortic bulging, pulmonary bulging, left heart failure, early hypertrophic cardiomyopathy, an aortic pulmonary window, dynamic right ventricular outflow obstruction, pulmonary artery stenosis, tricuspid valve insufficiency, an abnormally located aorta, hypoplastic pulmonary artery, and mitral valve stenosis. No additional diagnostic tests, such as angiography or MRI, to further elucidate these recorded abnormalities were performed in any patients.

**Treatment**—Cats were grouped according to whether they underwent vascular attenuation (n = 17) or not (n = 11). Nine of 11 cats that did not undergo vascular attenuation had no pharmacological intervention for their PDA. Medical management was attempted in 2 of 11 cats in which vascular attenuation was declined by the clients. One patient received furosemide orally, but unfortunately, the response to this treatment was not recorded and the patient was lost to follow-up. Another patient received enalapril (2.5 mg, PO, q 24 h) for 16 years. At 12 years of age, the cat developed minor pulmonary edema and was started on furosemide (12.5 mg, PO, q 24 h for 3 years), which was reported to have caused resolution of the pulmonary edema. The cat was reported to be very healthy until an event where the cat was found unconscious in lateral recumbency occurred and was euthanized at 16 years 4 months of age.

Five of the 17 patients that underwent vascular attenuation were documented to have received furosemide aimed at modifying cardiovascular physiology prior to their procedures. Drug dosage and method of administration (SC, PO, or IV) were not standardized. Response to treatment was available for only 1 cat receiving furosemide SC, in which the heart rate was documented to decrease into the reference range after initiation of furosemide treatment. Treatment did not continue after attenuation for any of the cats. Twelve of the 17 cats that underwent vascular attenuation, including the 2 that underwent coil embolization, did not receive medications to modify cardiac function prior to their procedure.

One of the 17 cats that received a vascular attenuation procedure underwent only coil embolization as described by Schneider and Hildebrandt,6 14 cats received a single surgical procedure for ligation of the PDA, 1 cat underwent 2 open surgical ligation procedures, and 1 cat underwent multiple vascular attenuation procedures encompassing both surgery and coil embolization. Surgical procedural descriptions were consistent with the technique described by Jones and Buchanan7 in all but 2 cats, for which there was insufficient record detail of the surgical procedure itself to characterize the technique. Of the 2 coil embolizations performed, 1 was performed by a cardiology resident and the other by a board-certified veterinary cardiologist. Eighteen open surgical procedures were performed in 16 patients, including the patients that had multiple procedures performed. Seven open surgical ligations were performed by residents, of which 4 successfully attenuated the PDA. Eleven open surgical ligations were performed by board-certified veterinary surgeons, and 9 successfully attenuated the PDA. No significant (P = 0.58) difference in overall success proportion between surgical procedures performed by residents and board-certified surgeons was found. Two cats underwent multiple attenuation procedures. One cat underwent failed attempts at surgical ligation twice before coil embolization was subsequently performed, which resulted in successful PDA attenuation. Another cat underwent 2 attempted surgical ligations before being euthanized because of life-threatening hemorrhage in the immediate postoperative period. Another cat that underwent open surgical ligation still had flow through the PDA following the procedure; however, no further attenuation procedures were attempted. One cat died during the surgical ligation procedure owing to laceration of the PDA and inability to control the resultant hemorrhage. The median operative time of all surgical attenuation procedures (n = 28) was 105 minutes (range, 30 to 275 minutes). Surgical ligation procedures classified as successful had a median recorded duration of 115 minutes (range, 70 to 275 minutes; n = 13). Surgical ligation procedures classified as unsuccessful had a median recorded duration of 76 minutes (range, 50 to 135 minutes; n = 5). Duration of procedure time was not significantly (P = 0.48) associated with a successful outcome. The duration of the coil embolization procedures for the 2 patients was recorded as 70 and 240 minutes.

The median age at the time of surgical attenuation was 5 months (range, 1.5 to 10 months). The recorded body weight at time of initial open surgical ligation ranged from 0.75 to 4.4 kg (1.65 to 9.7 lb), with a median of 2.5 kg (5.5 lb; n = 15); only the initial body weight from cats that underwent multiple ligations was included. Failed open surgical ligations in which flow through the PDA persisted postoperatively occurred in cats weighing 1.7, 1.8, 2.5, and 4.4 kg (3.7, 4.0, 5.5, and 9.7 lb). There was no significant (P = 0.73) difference in body weight for patients undergoing successful versus unsuccessful procedures. The recorded body weights of the 2 cats at the time of the coil embolization procedures were 4.0 and 4.4 kg (8.8 and 9.7 lb).

Perioperative complications occurred in 4 of the 15 patients that underwent open surgical ligation and were all related to hemorrhage. Two of the cases of hemorrhage resulted in death or euthanasia, including intraoperative death in one cat and euthanasia within 24 hours after the procedure because of life-threatening hemorrhage in the immediate postoperative period in another cat. One cat was reported to develop mild hemorrhage from the medial wall of the ductus that was controlled intraoperatively, and qualifying information was not provided for the final case. Postoperative complications were additionally recorded in 6 of the 13 surviving patients. These included 2 patients with left-sided laryngeal paralysis (1 of these cases was previously reported4), 1 cat that had signs of dysphagia and a voice change after surgery, and 1 cat that had a fever of 40.1°C (104.2°F). Another patient developed postoperative chylous effusion and had residual left to right flow through the PDA present on echocardiography. The final patient had an incompletely attenuated
PDA that required 2 additional attenuation procedures (1 additional surgical ligation attempt and 1 coil embolization procedure). No postoperative complications were reported in patients after the coil embolization procedure.

**Outcome**—Follow-up information was available for 16 of 28 cats. Eleven of these 16 cats underwent surgical ligation and lived from < 1 day to 191 months after attenuation. Data were available for 2 cats that underwent coil embolization; 1 lived for 108 months, and the other survived to discharge from the hospital but was lost to follow-up at 18 months of age. Two cats undergoing surgical ligation died during the perioperative period prior to discharge. In the attenuation group (ligation and coil embolization), the median survival time for cases that survived the postoperative period was not estimable because there were no recorded deaths. Five cats receiving no treatment or medical treatment had a median survival time of 45 months (range, 15 to 196 months). There was no significant ($P = 0.41$) difference in the survival time of cats that underwent surgical ligation ($n = 15$) versus those that received medical treatment only ($n = 11$). Cause of death was known for 8 patients. Three of these 8 cats underwent surgical ligation, and the other 5 cats received only medical management. One died from laceration of the PDA during surgery and another from gastrointestinal lymphoma at 192 months after surgery; a third was euthanized because of life-threatening hemorrhage in the immediate postoperative period. Data were available on the cause of death of 1 cat that underwent coil embolization; it was euthanized at 108 months of age because it was unable to stand and was emaciated, with white mucous membranes; severe nonregenerative anemia and thrombocytopenia of unknown etiology were diagnosed. Of the 15 cats in the attenuation group that survived to discharge from the hospital (including those treated with surgery and coil embolization), 7 were still alive at the time of study follow-up, 2 were known to have died for reasons unrelated to their PDA, and 6 were lost to follow-up a median of 7 weeks after discharge (range, 0 to 15 weeks). Of the 11 cats not receiving an attenuation procedure, only 1 was known to be alive at the time of study follow-up, 4 were known to have died, and 6 were lost to follow-up a median of 3.5 weeks after discharge (range, 2 to 9 weeks). Data on the cause of death were available for 4 cats whose owners did not elect to attempt surgical attenuation: one cat was euthanized following an event where it was found laterally recumbent and nonresponsive; 1 was euthanized because of progressive heart failure resulting in dyspnea, cyanosis, and pleural effusion; 1 died secondary to ventricular arrhythmias; and 1 was euthanized because of development of a aortoiliac thrombus.

Of the 5 cats that did not undergo surgical intervention, 3 were documented to have died during the follow-up period; of the 10 cats receiving surgical intervention that survived the postoperative period, none were documented to have died during the follow-up period. Comparison of these 2 groups was not significant ($P = 0.072$). A Kaplan-Meier plot contrasting these 2 groups was plotted (Figure 1).

Association of procedural success with date of procedure was assessed. Although 2 of 4 procedures were successful when performed prior to 2002, compared with 8 of 13 of procedures in 2002 or later, this difference was not significant ($P = 1.0$). Although 4 of the 5 deaths in this study occurred prior to 2002, the relationship between survival rate and grouped (above and below median) year of procedure (prior to 2002 vs 2002 or later) was not significantly ($P = 0.27$) different. In addition, there was no significant ($P = 0.59$) difference in the death or survival rate across all years.

**Discussion**

Results of the present study, which retrospectively evaluated the clinical signs and outcomes associated with treatment of PDA in 28 cats treated at 3 high-volume academic and referral surgical practices over 21 years (1991 to 2012), suggested that this condition is uncommon in cats. Whereas vascular attenuation of the PDA did not significantly extend survival in this study, our results suggested that both surgical ligation and coil embolization may be effective methods for the treatment of PDA in cats.

The results of this study did not indicate any breed or sex predilections for this condition. Previous authors$^{13,18}$ have reported PDA in domestic shorthair and domestic longhair cats, but sex predilection has not been evaluated. In dogs with PDA, a female-to-male ratio of 3:1 has been noted in several studies.$^{6,5}$ Neuter status was not analyzed in this study; however, most of these patients had PDAs detected at a young age, prior to when neutering would be performed. All of the patients described in the present report had a heart murmur diagnosed prior to 1 year of age, in contrast to 2 studies in dogs in which PDAs were identified in large proportions of dogs (32%$^{10}$ and 25.5%$^{19}$) as adults.
Patent ductus arteriosus causes volume overload and ventricular hypertrophy of the left side of the heart, and untreated cats. The pathophysiology of PDA is such that the volume overload will result in most animals developing pulmonary hypertension and congestive heart failure, and it is unlikely that cats will differ from dogs in their cardiovascular physiology with regard to this disease process. Results of a recent large retrospective study of 520 dogs with PDA indicated that PDA closure confers an important survival benefit and results in long-term reverse cardiac remodeling in most treated dogs. As a result, vascular attenuation of PDA in feline patients is still recommended despite the lack of significant differences demonstrated in this study.

Only 2 cats in this study underwent coil embolization, and both procedures were considered successful. We suggest that this success rate may have decreased if more patients were included in the study. In a study of 204 dogs, it was reported that a single transcatheter coil embolization procedure was successful in 84% of dogs, with a mortality rate of 2.6%. Seventeen feline patients in our study underwent open surgical ligation. Six procedures in 4 cats were considered unsuccessful, and 2 of these unsuccessful procedures resulted in death or euthanasia. These rates were considerably higher than for dogs (n = 204), in which surgical ligation was associated with a mortality rate of 5.6% and success rate of 94%. These differences could be due to the smaller size of the feline patients, making surgical dissection and ligation of the PDA more technically challenging. The overall number of cats that underwent vascular attenuation (surgical or coiling) was limited in this study (17/28), and of the 15 patients that did survive the peri-operative period, 7 were still alive at the time of study follow-up. This may have obscured any significant difference in survival time between treatment groups.

Body weight in the feline patients at the time of the attenuation procedure was not significantly associated
with a successful outcome, nor was it associated with which procedure was elected. Previously reported body weights ranged from 0.2 to 40 kg (0.44 to 88 lb) for dogs undergoing open surgical ligation and from 0.2 to 36.4 kg (0.44 to 80.1 lb) for those undergoing a intravascular occlusion procedure.\(^{10}\) As for our patient population, the body weight of these canine PDA patients was also not significantly associated with procedural success or survival time.\(^ {10}\)

No procedural complications were reported in the 2 feline patients undergoing coil embolization in this study. In dogs, ligation of both femoral arteries, infection at the femoral arteriotomy, coil embolization into the pulmonary vasculature, coils protruding into the aorta, coil deployment into the femoral artery, minor hemorrhage, transient hemoglobinuria, thrombocytopenia, septicemia, severe hemorrhage, cardiac arrest, and coil migration into the celiac artery have been reported.\(^ {10,24}\) We speculate that feline patients would have similar reported complications as their canine counterparts if more patients were to undergo these procedures.

Documented procedural complications in the feline patients of this study that underwent open surgical ligation included left-sided laryngeal paralysis, voice change, difficulty swallowing, fever, hemorrhage, and postoperative chylous effusion. In dogs, left thoracic limb lameness, suture reaction, postoperative hypoxia, incisional seroma, minor hemorrhage, transient hemoptysis, severe hemorrhage, cardiorespiratory arrest, chylothorax, laryngeal paralysis, atrial or ventricular fibrillation, and postoperative mesenteric torsion are reported.\(^ {10,11}\) The most common surgical complication with PDA ligation in dogs is intraoperative hemorrhage, with a reported incidence of 6% to 11%.\(^ {12,13}\)

In our study, hemorrhage was documented as a complication in 4 of 15 patients undergoing open surgical ligation procedures, which is higher than the incidence reported in dogs, and may have been a consequence of the smaller size and more difficult dissection in feline patients. An alternative approach to suture passage (Jackson-Henderson method) has been recommended as a technique to minimize the risk of trauma to the medial wall of the PDA during dissection, but whether it is actually associated with fewer overall complications is a subject of debate in the veterinary literature.\(^ {10,12,17}\) We did not identify any cats in this cohort in which a Jackson-Henderson approach was performed. We found no significant difference in the proportion of overall success of surgical ligation of PDAs performed by a surgical resident versus those performed by a board-certified surgeon. This is similar to results reported in dogs by Birchard et al,\(^ {12}\) who found no association between surgeon experience and intraoperative hemorrhage associated with PDA dissection. Contrarily, Hunt et al\(^ {14}\) found that although severe hemorrhage had a relatively low incidence as a complication in canine patients, the primary surgeon was a resident in each instance it occurred. No difference in outcome was found between dissections performed by residents and board-certified surgeons in our study, and this may be associated with the relatively low numbers of cases in each group for analysis as well as the retrospective nature of this study, which may have limited our ability to accurately determine whether a resident or board-certified surgeon truly performed the dissection of the ductus.

The incidence of unilateral laryngeal paralysis secondary to PDA attenuation in dogs and cats is not well described or commonly evaluated. Laryngeal paralysis as a complication of PDA ligation has been reported in 1% of dogs in 1 report\(^ {14}\) of 98 cases. Left-sided laryngeal paralysis may be more likely to occur in feline patients, which are often smaller in body size at the time of attenuation, and retraction and dissection in a more limited surgical field may be more likely to result in trauma to the recurrent laryngeal nerve. Both cats definitively noted to develop this complication in the present study had few to no clinical signs. One cat, previously reported,\(^ {15}\) did not have any postoperative respiratory signs while hospitalized but was noted to have an intermittent upper respiratory purring sound and occasional cough within approximately 1 week after discharge from the hospital. The second cat also did not have any respiratory clinical signs while in the hospital, but because we were alert to the issue, a laryngeal examination was performed on this patient 1 day after surgery with the client’s consent. Laryngeal examination at this time demonstrated an absence of unilateral (left-sided) arytenoid motion with normal arytenoid abduction on the right side. No preoperative abnormalities in arytenoid motion had been noted at anesthetic induction in this patient, and no postoperative clinical signs were reported by the clients. This cat was reevaluated by the cardiology service 4 months after surgery, where successful attenuation of the PDA was confirmed via echocardiography, and at that time, no respiratory signs were noted or appreciated by the attending clinician. Numerous offers were made to perform a repeated upper respiratory examination on this patient, but the clients were unwilling to bring the cat back for evaluation and the cat was lost to follow-up. Quite likely, a third cat noted to have postoperative voice change and difficulty swallowing may have had iatrogenic recurrent laryngeal nerve damage as well, although the record does not specify whether laryngeal function was evaluated. The body weights of these 3 cats at the time of PDA attenuation were 0.75, 1.2, and 1.4 kg (1.65, 2.6, and 3.1 lb). Low birth weight is a known risk factor for iatrogenic laryngeal paralysis secondary to PDA ligation in neonatal human patients.\(^ {16}\) In a study\(^ {20}\) of 86 neonatal human patients, iatrogenic laryngeal paralysis was diagnosed on postextubation fiberoptic laryngoscopy after PDA ligation in 16% and was asymptomatic in 14% of affected infants. Given the relative lack of specific clinical signs in the 2 patients definitively identified with this complication in the present study and the small body size at which surgical attenuation is often performed, this complication may have been undiagnosed in other cats. If all 3 of the cats described were considered to have recurrent laryngeal nerve damage during PDA dissection on the basis of the described clinical signs, this study would have found this complication in 11% (3/28) of cats undergoing an open surgical procedure. A prospective study is needed to assess the true incidence and risks for this complication in companion animals. On the basis of our experience, a postoperative laryngeal examination under sedation is
recommended so that affected patients may be correctly identified and clients advised regarding monitoring and appropriate follow-up.

As with any retrospective study, the present study had certain limitations. Patent ductus arteriosus is a rare condition in cats; multi-institutional collaboration encompassing medical records from a period of 21 years was required to obtain data on 28 cases. Uniform treatment protocols were not followed, record-keeping was inconsistent, the rationale for specific treatment decisions was often not available, and many cases were lost to follow-up. Factors such as the size of the PDA, severity of physiologic shunting, and clinical signs may have influenced recommendations for or against surgical correction in individual cats. All of the patients that did not undergo surgical correction reportedly died of complications that were likely to be secondary to progressive cardiac disease. The data available from the 3 cats that underwent surgical ligation of the PDA indicated that 2 died of surgical complications and 1 died of gastrointestinal lymphoma. It is difficult to speculate on the underlying cause of death for the cat that underwent coil embolization. Nevertheless, this study provides initial information on the clinical signs, diagnostic results, and treatment outcomes in feline PDA patients.

Despite the lack of significant differences documented in this specific patient cohort, the physiology of PDA is such that without attenuation, cats are highly likely to have pulmonary overcirculation and develop congestive heart failure. Treatment of PDA confers an important survival benefit,23 and we suggest that vascular attenuation is indicated in cats with this congenital abnormality. Additionally, feline PDA patients should be evaluated after surgical ligation for laryngeal dysfunction secondary to iatrogenic recurrent laryngeal nerve damage. Further prospective investigation of this disease in feline patients is recommended.

References