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Objective—To determine factors associated with long-term survival in dogs treated surgically for patent ductus arteriosus (PDA).

Design—Retrospective case series.

Animals—52 dogs treated surgically for left-to-right shunting PDA.

Procedure—Data pertaining to age, breed, sex, body weight, clinical examination findings, type and duration of medical treatment, results of thoracic radiography and echocardiography, and surgical and postoperative complications were collected from records. Follow-up information was obtained from medical records or telephone interviews with owners or referring veterinarians.

Results—22 dogs had mitral valve regurgitation. Mean weight and age were not significantly different between dogs with or without mitral valve regurgitation. Twenty-four (46.2%) dogs had clinical signs related to cardiac insufficiency. Left atrial dilatation was observed in 56.3% of dogs that were radiographed. Sonographic imaging was used to diagnose left atrial dilatation in 23 dogs and left ventricular dilatation in 28 dogs. The 1- and 2-year survival rates were 92% and 87%, respectively. Diagnosis of mitral valve regurgitation before surgery was not associated with the probability of survival. Age, weight, lethargy, preoperative treatment with angiotensin-converting enzyme inhibitors, and right atrial dilatation on radiographs at the time of surgery were negatively associated with probability of survival.

Conclusions and Clinical Relevance—Surgical treatment of PDA was curative in young dogs without clinical signs of heart failure. Surgical correction of PDA should be recommended as early as possible after diagnosis.

Criteria for Selection of Cases

Medical records of all dogs examined because of PDA at the Colorado State University Veterinary Teaching Hospital between 1995 and 2003 were reviewed. Dogs were included in the study if they had a left-to-right shunting PDA and were treated surgically. Dogs treated by means of coil embolization were excluded from the study.

Procedures

Age, breed, sex, body weight, results of clinical examination, type and duration of medical treatment, and surgical and postoperative complications were recorded. Information pertaining to exercise intolerance, lethargy, dyspnea, weight loss, and retarded growth was also included.

Results of radiographic and echocardiographic imaging of the thorax were recorded. Mitral valve regurgitation was diagnosed if there was auscultation of a left apical holosystolic murmur or observation of valvular regurgitation on echocardiography. Perioperative surgical complications were recorded.

Follow-up information was obtained from medical records or via telephone interviews with owners and referring veterinarians. Survival time was defined as the number of days between surgery and the date of death or the last follow-up call. The cause of death was recorded as related or unrelated to PDA. If no information could be collected after the dog left the hospital, it was considered lost to follow-up.

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Statistical analysis—A computer software package was used to perform the statistical analyses. Analysis of variance was used to compare age and weight at the time of initial examination between dogs with and without mitral regurgitation. The χ² test was used to compare the percentage of females in the study dogs with that in the general hospital population. Kaplan-Meier actuarial survival analyses were performed to evaluate the long-term survival rate of surgically treated dogs with PDA. A log-rank test was used to compare survival curves of dogs with and without mitral insufficiency. Twenty-seven variables related to signalment, history, mitral regurgitation, results of radiography and echocardiography performed at the time of initial examination, and pre- and postoperative treatments were evaluated by means of Cox proportional hazard analyses for their usefulness as indicators of the probability of survival for dogs with PDA. A hazard ratio (HR) and 95% confidence intervals were calculated for each variable. Values of P < 0.05 were considered significant. Dogs that were alive at the end of the study or lost to follow-up or that died from a cause unrelated to the PDA or cardiac disease were censored for the Kaplan-Meier actuarial survival analysis and the Cox analysis. Results are given as mean ± SD.

Results

Fifty-two dogs underwent surgery for treatment of PDA. Breeds represented were the Shetland Sheepdog (7 dogs), Toy Poodle (3), Labrador Retriever (3), mixed breed (5), German Shepherd Dog (4), Pomeranian (4), Dachshund (3), Golden Retriever (3), Maltese (3), Cocker Spaniel (2), American Eskimo Dog (1), Bulldog (1), Tibetan Terrier (1), Newfoundland (1), Australian Shepherd (1), Miniature Schnauzer (1), Boston Terrier (1), Chihuahua (1), Great Pyrenees (1), Bernese Mountain Dog (1), and Irish Setter (1). Thirty-seven dogs were female and 15 were males. Mean weight was 11.50 kg (range, 1.4 to 97 months). Mean age at the time of diagnosis was 16.2 ± 27.8 months (range, 1.5 to 109 months). There was a significant (P < 0.001; adjusted r² = 0.29) correlation between age and weight.

Twenty-two dogs (14 [63.6%] females and 8 [36.4%] males) had mitral valve regurgitation. Female dogs were overrepresented, compared with the general hospital population (51% female; P < 0.05). Mean weight of dogs with mitral valve regurgitation was 7.7 ± 7.9 kg, and mean age at the time of diagnosis was 9.73 ± 20.9 months (range, 1.4 to 97 months). For dogs without mitral valve regurgitation, mean weight was 11.50 ± 11.30 kg (22 ± 22.2 lb) and mean age at the time of diagnosis was 16.2 ± 27.8 months (range, 1.5 to 109 months). Mean weight (P = 0.181) and age (P = 0.363) at the time of diagnosis were not significantly different between dogs with or without mitral valve regurgitation.

Twenty-four (46.2%) dogs had clinical signs related to cardiac insufficiency at the time of surgery. Fifteen (28.8%) dogs were treated with diuretics (n = 14) or angiotensin-converting enzyme (ACE) inhibitors (8) at the time of surgery. Of the 22 dogs with mitral valve regurgitation, 8 were treated with a diuretic and 4 were treated with an ACE inhibitor. Seven dogs in which the PDA was causing clinical signs (eg, exercise intolerance, lethargy, or weight loss) received a diuretic and an ACE inhibitor. The left ventricular end-diastolic diameter index was not significantly different between dogs that received an ACE inhibitor (105.9 ± 83.3 mm/m²) and those that did not (108.4 ± 45.8 mm/m²; P = 0.924). The left ventricular end-systolic diameter index was not significantly different between dogs that received an ACE inhibitor (73.4 ± 50.5 mm/m²) and those that did not (65.9 ± 28.0 mm/m²; P = 0.646). The ratio of the diameter of the left atrium to the diameter of the aorta was not significantly different between dogs that received an ACE inhibitor (1.8 ± 0.5) and those that did not (1.6 ± 0.2; P = 0.11). Shortening fraction was significantly (P = 0.012) different between dogs that received an ACE inhibitor (28.0 ± 5.0%) and those that did not (39.3 ± 5.0%).

Two dogs had atrial fibrillation as indicated by an ECG at the time of initial examination, whereas sinus rhythm was detected in the other dogs. The 2 dogs with atrial fibrillation had clinical signs of exercise intolerance, had left atrial dilatation and pulmonary edema on radiographs, and were receiving diuretics and ACE inhibitors. One of the dogs with atrial fibrillation underwent echocardiographic examination. In that dog, shortening fraction was 6.8% and the ratio of the
Four dogs were lost to follow-up at 17, 29, 71, and 162 days. Twenty-eight dogs were alive at the time of writing (mean follow-up time, 1,156 days; range, 284 to 3,067 days). Two dogs died for reasons unrelated to cardiac disease at 1,733 and 2,458 days, respectively, after surgery. Four dogs died for reasons related to cardiac disease at 4, 8, 17, and 116 days, respectively, after surgery. The 1- and 2-year survival rates for dogs treated surgically for PDA were 92% and 87%, respectively (Figure 1). Diagnosis of mitral valve regurgitation before surgery was not associated with survival rate (P = 0.603; Figure 2). The 1- and 2-year survival rates were 94% for dogs with mitral valve regurgitation. The 1- and 2-year survival rates were 96% and 85%, respectively, for dogs without mitral valve regurgitation. Six dogs with mitral valve regurgitation and 9 dogs without mitral valve regurgitation had continued medical treatment (eg, an ACE inhibitor, diuretic, or both) after surgery. A left apical holosystolic murmur was auscultated during the immediate postoperative period in 9 of 22 (40.9%) dogs that had mitral valve regurgitation before surgery. No murmur was reported after surgery in dogs that did not have mitral valve regurgitation prior to surgery (P = 0.001).

Follow-up information was obtained for 38 dogs (mean follow-up time, 959 ± 790 days; range, 4 to 3,067 days). Fourteen dogs were lost to follow-up after leaving the hospital (1.9 ± 0.7 days). In the long term, 4 dogs were lost to follow-up at 17, 29, 71, and 162 days. Twenty-eight dogs were alive at the time of writing (mean follow-up time, 1,156 days; range, 284 to 3,067 days). Two dogs died for reasons unrelated to cardiac disease at 1,733 and 2,458 days, respectively, after surgery. Four dogs died for reasons related to cardiac disease at 4, 8, 17, and 116 days, respectively, after surgery. The 1- and 2-year survival rates for dogs treated surgically for PDA were 92% and 87%, respectively (Figure 1). Diagnosis of mitral valve regurgitation before surgery was not associated with survival rate (P = 0.603; Figure 2). The 1- and 2-year survival rates were 94% for dogs with mitral valve regurgitation. The 1- and 2-year survival rates were 96% and 85%, respectively, for dogs without mitral valve regurgitation. Six dogs with mitral valve regurgitation and 9 dogs without mitral valve regurgitation had continued medical treatment (eg, an ACE inhibitor, diuretic, or both) after surgery. A left apical holosystolic murmur was auscultated during the immediate postoperative period in 9 of 22 (40.9%) dogs that had mitral valve regurgitation before surgery. No murmur was reported after surgery in dogs that did not have mitral valve regurgitation prior to surgery (P = 0.001).

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surgery. At the time of follow-up, 3 dogs were being treated with β-adrenergic receptor–blocking drugs, 5 with ACE inhibitors, and 4 with diuretics. One dog (with mitral valve regurgitation before surgery) had exercise intolerance and was coughing and lethargic.

Of the 27 discrete and continuous variables evaluated by means of Cox proportional hazard analyses, 5 were associated with probability of survival (Table 1). Arrhythmias could not be evaluated as a risk factor for long-term survival because of the low number of cases with rhythm disturbances.

Discussion

The long-term survival rate after surgical occlusion of PDA was 87%. Four dogs died from cardiac-related disease within 2 years of surgery. There were no deaths related to cardiac disease that were reported after the second year following surgery. Long-term survival rate was associated with age, weight, lethargy, preoperative treatment with ACE inhibitors, and right atrial dilatation on radiographs at the time of diagnosis. However, it was not associated with diagnosis of mitral regurgitation at the time of surgery. Our study population was similar in breed, age, and sex distribution to those in earlier reports.2,12,13

The reporting of survival rates from 89% to 95% after surgical ligation of PDA has led to the consideration of surgical correction as a cure for the defect.3,12,13 Surgical treatment is associated with a better long-term survival rate than medical treatment.3,13 Our results confirm that finding because only 4 dogs died of cardiac-related disease within 2 years of surgery and no additional deaths related to cardiac disease were reported after that. In 2 earlier studies,2,12 4% to 8% of dogs died within a month after surgery and no deaths resulting from cardiac disease were reported in the long term. A study4 of 37 dogs treated surgically for PDA revealed that the survival rate was 95% at 2 years and 60% at 10 years because dogs continued to die from cardiac-related disease beyond 2 years after surgery. Dogs in that study were older (mean, 18.4 months), and there was a higher prevalence of myocardial disease prior to surgery in that study population than in our study.

Greater age and weight had a negative association with survival in our study. The HR for those 2 variables was 1.001 and 1.081, respectively, which makes their association with survival questionable. In an earlier study,2 the mortality rate was 22% in dogs that weighed > 23 kg (50.6 lb) and 8% in the overall study population. In that study, the mortality rate in dogs older than 2 years was 18%. In another study13 involving 201 dogs, age and weight were not correlated with mortality rate. However, in that study, postoperative complications and death occurred in dogs that had hemorrhage during surgery. In the authors’ experience, dissection of the DA is technically less difficult in young dogs because the vessel is less friable and the surrounding tissues are less fibrous. These results led to the conclusion that although age was not directly associated with an increased risk of death from PDA, it may increase the risk of intraoperative hemorrhage and subsequent death.12,13 Another group of investigators evaluated dogs of different age groups (ie, 0 to 6 months, 6 to 12 months, and older than 12 months) and reported that age was not associated with survival rate in that study population.14 However, dogs that died were older than 46 months old at the time of surgery, and there was a large number of adult dogs with myocardial failure prior to surgery. The high prevalence of heart failure may have been a confounding factor in that study, obscuring age as a risk factor for survival. In another study,17 the severity of clinical signs of heart failure increased with age in dogs with PDA.

Poor cardiac output, arrhythmias, and endocarditis have been proposed as influencing the surgical outcome for ligation of PDA in dogs.3,10 In other studies,12 heart failure was associated with a 40% mortality rate within 1 week of surgery and there was a 50% mortality rate in dogs with mitral valve regurgitation and atrial fibrillation.3,12 Lethargy at the time of surgery appeared to be negatively associated with survival after surgical occlusion of PDA in our study. Other clinical signs associated with cardiac disease did not appear to have a negative association with long-term survival rate, even when they were reported more commonly by owners. Unfortunately, the distribution of the data in our study was such that an HR for exercise intolerance could not be calculated. Impairment of fractional shortening was not associated with lower long-term survival; however, medical treatment with an ACE inhibitor prior to surgery was significantly associated with a worse prognosis for long-term survival. Angiotensin-converting enzyme inhibitors improve the survival rate of patients with heart failure and prevent worsening of heart failure associated with mitral regurgitation.12,25 In the present study, patients that received an ACE inhibitor at the time of surgery represented a subpopulation of dogs with a lower shortening fraction, suggesting that those dogs had more advanced disease. In another study,5 5 dogs were in heart failure; of those, the 2 that died within a week of coil embolization had been receiving medications for heart failure. In a study7 of dogs in which there was a high prevalence of myocardial failure, a diagnosis of heart failure at the time of initial examination was not associated with survival rate. However, in that study,6 dogs with heart failure that were treated surgically still had a higher risk of dying from cardiac disease in the long term.

Arrhythmias could not be evaluated as a risk factor in our study because only 2 dogs had atrial fibrillation at the time of initial examination. Atrial fibrillation is associated with atrial dilatation and progression of heart failure.23,24 The 2 dogs with atrial fibrillation had pulmonary edema on radiographs and were being treated with diuretics and an ACE inhibitor at the time of examination. Those 2 dogs died 8 and 17 days after surgery.

With the exception of right atrial enlargement, radiographic findings did not appear to be prognostic factors in our study. The prevalences of cardiomegaly, left atrial dilatation, enlarged pulmonary vessels, and a prominent aortic bulge in our dogs were similar to previously reported values.8,15,17 However, none of those findings were negatively associated with survival in our study. Objective criteria, such as the vertebral body-to-heart ratio,2 are preferred for evaluating heart

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Mitral valve regurgitation was not associated with long-term survival in dogs surgically treated for PDA. In our study, 42.3% of dogs had mitral valve regurgitation at the time of initial examination, a figure that is in the range (29% to 43%) reported for dogs evaluated for PDA closure.\textsuperscript{6,13,15} Mitral valve regurgitation is attributed to dilatation of the mitral valve annulus and tethering of the papillary muscle secondary to left ventricular dilatation.\textsuperscript{6,23} Mitral valve regurgitation is a recognized risk factor for long-term survival.\textsuperscript{16} In a study of 37 dogs, it was reported that evidence of mitral valve regurgitation on echocardiography at the time of initial examination may be associated with a reduction of survival. Mitral valve regurgitation in that study was associated with detection of mitral valve endocardiosis during follow-up examinations. Long-standing mitral valve regurgitation may lead to endocardiosis, a condition associated with a worse prognosis because such lesions are usually irreversible. In another study,\textsuperscript{4} 43% of dogs were 1 year of age or older at initial examination and the mean age was 18.4 months, whereas in our study, only 19.3% of dogs were older than 1 year. In our study, dogs with mitral valve regurgitation were not older than the rest of the study population. In the other study,\textsuperscript{16} a high proportion of dogs had myocardial failure at the time of initial examination, indicating more advanced disease in those patients. Results of echocardiographic examinations in earlier studies\textsuperscript{2} revealed that mitral valve regurgitation regresses in most patients treated surgically with either ligation or coil embolization. In one of those studies,\textsuperscript{6} 3 months after PDA closure, the persistence of small jets of regurgitant flow through the mitral valve was observed in only 3 dogs, and 3 dogs that had mitral valve regurgitation and had heart failure at initial examination were not being medicated 1 month after surgery.\textsuperscript{7} The percentage of dogs with mitral valve regurgitation was reduced from 38% to 5% after PDA closure in the other study.\textsuperscript{5} Correction of PDA likely permits reverse remodeling of the left ventricle, and the mitral valves return to functional competency. The return to normal cardiac dimensions and elimination of mitral valve regurgitation after successful closure of PDA have been reported.\textsuperscript{5} Because a diagnosis of mitral valve incompetence in the absence of myocardial failure did not affect long-term survival of dogs treated surgically for PDA in our study, it was presumed that mitral valve regurgitation regressed over time.

The rate of surgery-related complications in our study was low, compared with rates reported in other studies.\textsuperscript{6,13,15,16,27} The perioperative mortality rate in dogs in our study was 0%, despite the occurrence of acute intraoperative bleeding in 8 dogs. Surgeries were performed by experienced surgeons, which contributes to lower surgical mortality rates.\textsuperscript{7} In our study, hemorrhage occurred in surgeries on older animals. Dogs that are older or in which the PDA is large may be at higher risk for bleeding during surgery.\textsuperscript{4,10,15} It has been hypothesized that the structure is more friable and of larger size in older dogs than in younger dogs. Intraoperative bleeding was controlled by means of vascular clamps placed on the aorta and pulmonary artery. The DA was transected and oversewn with 3-0 or 4-0 monofilament nonabsorbable suture. In our study, none of the dogs that had acute intraoperative hemorrhage died in the first 5 days after surgery, although early deaths were reported by Birchard et al.\textsuperscript{11} Different techniques have been recommended to control bleeding at the time of dissection or ligature of the DA.\textsuperscript{5,28}

Limitations of our study include the retrospective design, which makes investigators dependent on the details included in records, especially those concerning complementary examinations before and after surgery. Echocardiographic results would have provided more accurate information regarding cardiac function in the dogs. Conclusions regarding the reversibility of systolic dysfunction could not be made from our data. It is known that mitral valve regurgitation is a risk factor for progression of heart failure and the survival of patients with dilated cardiomyopathy;\textsuperscript{29} therefore, if mitral valve regurgitation had persisted in our dogs, the survival rate of affected dogs would have been lower than the survival rate of dogs without valvular regurgitation at the time of surgery. We were not able to compare outcomes for different surgical techniques because only 1 technique has been traditionally used at our institution for ligation of PDA. The technique of coil embolization is presently performed, but the number of dogs that had undergone that procedure at the time of the study was too low for those records to be included.

Surgical treatment of PDA was curative in young dogs without clinical signs of heart failure. Mitral valve regurgitation at the time of surgery was not negatively associated with survival rate in the absence of myocardial disease. Preoperative treatment with an ACE inhibitor was associated with poor long-term survival rate. Surgical correction of PDA should be recommended as early as possible after diagnosis, and mitral valve regurgitation is not a contraindication for surgery.


References

6. Corri LB, Merkley D, Nelson OL, et al. Retrospective evalu-


