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Risk factors for intraoperative hemorrhage and perioperative complications and short- and long-term outcomes during surgical patent ductus arteriosus ligation in 417 dogs

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OBJECTIVE
To evaluate the short- and long-term outcomes of dogs undergoing surgical ligation for a left-to-right shunting patent ductus arteriosus (PDA), identify risk factors for intraoperative hemorrhage and intra- and postoperative complications, and report overall mortality rates.

ANIMALS
417 client-owned dogs undergoing surgical ligation for a left-to-right shunting PDA between January 2010 and January 2020.

PROCEDURES
Data recorded included patient signalment, echocardiogram findings, intraoperative complications and mortality, postoperative complications, and short- and long-term outcomes.

RESULTS
There was no association between age and risk of intraoperative hemorrhage (P = .7), weight and intraoperative hemorrhage (P = .96), or increasing left atrium-to-aortic (LA:Ao) ratio and intraoperative hemorrhage (P = .08). Intraoperative hemorrhage occurred in 10.8% of patients. Intraoperative mortality was 2%. Ninety-five percent of dogs experiencing intraoperative hemorrhage survived to discharge. Survival to discharge was 97%. One- and 5-year survival rates were 96.4% and 87%, respectively.

CLINICAL RELEVANCE
Surgical ligation for a left-to-right shunting PDA is recommended due to the good long-term prognosis. Certain preoperative factors such as age, weight, and the presence and degree of mitral valve regurgitation had no detectable association with risks of intraoperative hemorrhage and, therefore, should not preclude surgical treatment for a left-to-right shunting PDA. Future studies are needed to further assess the association between increasing LA:Ao ratio and risk of intraoperative hemorrhage.

A patent ductus arteriosus (PDA) is a congenital heart anomaly characterized by the fetal ductus arteriosus vessel failing to close after birth.[1] The ductus arteriosus functions in utero to bypass the pulmonary system and shunt blood into systemic circulation.[1,2] Following birth, a PDA shunts blood from the aorta into the main pulmonary artery, resulting in a pathologic volume overload of the left atrium and ventricle, as well as the pulmonary system.[1,3] This volume overload can eventually progress to

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left-sided congestive heart failure (CHF) and chronic pulmonary hypertension. In patients in which the pulmonary vascular resistance exceeds that of the systemic vasculature, reverse blood flow of deoxygenated blood from the pulmonary artery through the shunt vessel into the aorta occurs with subsequent differential systemic cyanosis.[1,4] This condition is termed a "reverse PDA" or "right-to-left shunt PDA," and surgical intervention to ligate the shunting vessel is no longer indicated.

Dogs diagnosed with a left-to-right shunting PDA that undergo surgical correction have been shown to have an increased survival rate and better long-term outcome compared to dogs that do not undergo surgical intervention.[3] Surgical intervention includes either ligation of the PDA via a lateral thoracotomy or transvascular device closure. Risks associated with both types of intervention include hemorrhage (most commonly from either the PDA or vascular access vessel), arrhythmias, and cardiac arrest, with the risk of intraoperative hemorrhage reported between 6.25% and 15%.[5–7] Multiple retrospective studies have evaluated preexisting patient factors and their association with intraoperative complications, short-term outcome, and long-term prognosis and have reported a 1-year survival rate of 94%.[3,5–8]

While there is conflicting literature in terms of prognostic variables for dogs undergoing surgical ligation for a PDA, these retrospective studies span over 4 decades. There have been significant improvements in early detection of congenital heart anomalies in dogs, as well as substantial advancements in management for patients experiencing intraoperative complications. To the authors' knowledge, a large cohort study evaluating preoperative patient factors to identify risk factors for intraoperative hemorrhage and other complications, as well as the effect of intraoperative complications on short- and long-term outcomes, has not been published in recent literature. The objectives of this exploratory study were to evaluate the short- and long-term outcomes in a large cohort of dogs diagnosed with and undergoing surgical ligation for a PDA, identify risk factors for intraoperative hemorrhage, and evaluate intra- and postoperative complications, mortality rates, and long-term survival. We hypothesized that there would be a similar survival rate for dogs undergoing surgical ligation of a PDA compared to previous studies. We further hypothesized that the presence of concurrent congenital cardiac disease or acquired cardiac disease as evidenced by the presence of chamber enlargement or abnormal valvular regurgitation would increase the risk of intraoperative hemorrhage due to secondary structural cardiac changes, and intraoperative hemorrhage would occur at a higher rate than previously reported.

Materials and Methods

Data collection

Medical records at 8 veterinary academic institutions (University of Florida, Iowa State University, University of Missouri, University of Georgia, Oklahoma State University, Colorado State University, Cornell University, and North Carolina State University) were reviewed between the months of February and July 2021 for dogs diagnosed with a left-to-right shunting PDA. Five institutions each had a single reviewer, and 3 institutions each had 2 reviewers doing different parts of the search. Surgical operative reports and patient diagnoses were searched using the key words "PDA/patent ductus arteriosus," "PDA ligation," or "PDA surgery." Dogs that underwent surgical ligation between January 2010 and January 2020 were included in the study. Dogs were excluded if surgical ligation was aborted for reasons other than hemorrhage or cardiac arrest, such as diagnosis of a right-to-left shunting PDA or anesthetic complications prior to surgery that necessitated waking the patient up from anesthesia, as including these patients would create a falsely high number of cases that did not experience intraoperative hemorrhage or other complications.

Data recorded included patient signalment (age, breed, and sex), any reported noncardiac-related comorbidities, presence and duration of clinical signs related to cardiac disease (exercise intolerance, dyspnea, coughing, and lethargy), presence of other cardiac abnormalities, history of CHF, physical examination parameters at presentation (weight, murmur timing and grade, and presence and description of arrhythmias), and echocardiogram and ECG data recorded from written reports. Acute clinical signs were defined as signs present for < 7 days. Chronic clinical signs were defined as signs present for > 7 days. Intraoperative information including dissection method around the PDA, occurrence of intraoperative hemorrhage and location of bleed, anesthetic complications, need for blood transfusion(s), ligation method of the PDA, and intraoperative death and cause was recorded. Intraoperative hemorrhage was defined as > 5% blood loss and/or acute hemorrhage from the PDA vessel that was deemed life-threatening by the surgeon. Intraoperative complications were divided into 4 categories: anesthetic-related complications, cardiopulmonary arrest, arrhythmias, and prolonged anesthetic recovery as noted in the anesthesia record. Immediate postoperative complications, recheck cardiac auscultation, ECG and echocardiogram data, number of days hospitalized, survival to discharge, and medications sent home were recorded. Two-week recheck information (survival to incision check, presence of a heart murmur and/or other cardiac disease, data from echocardiogram and ECG reports if performed or available, and other complications) and long-term follow-up information (recheck echocardiogram and ECG reports, presence of persistent congenital or acquired cardiac disease, need for long-term cardiac medications, date and cause of death, and other cardiac-related complications such as development of arrhythmias or presence of persistent changes secondary to the PDA) were recorded. Survival time for each patient was recorded and defined as the number of days between surgery and date of death or date of last follow-up.

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Cardiopulmonary assessment

Three-view thoracic radiographs reviewed by a board-certified radiologist were included in this study. Data recorded included evidence of cardiac silhouette enlargement along with left atrial and left ventricular enlargement, evidence of pulmonary vessel overload based on enlargement of the pulmonary arteries and veins, presence of a bulge at the main pulmonary artery and/or aortic arch, and evidence of pulmonary edema consistent with left-sided CHF. Echocardiograms reviewed by a board-certified cardiologist were included in this study. Data recorded included the following: LA:Ao ratio as reported in a 2-D right parasternal short-axis view, with results divided into 3 categories based on degree of left atrial enlargement (≤ 1.54, 1.55 to 2.4, and ≥ 2.5)[3,9–11]; left atrial size as reported in a 2-D right parasternal view; the left ventricular size in diastole and systole, as reported in M-mode; the reported PDA description was used to divide patients into 5 groups (types 1, 2, 3a, 3b, and 4) as classified by Houghton et al[12] based on the size of the PDA; murmur auscultation and presence of a palpable thrill; degree of left-sided cardiomegaly; presence and severity of mitral valve regurgitation (MR); evidence of left-sided CHF; presence and severity of pulmonary hypertension; and presence of any ECG abnormalities. ECGs written by a board-certified cardiologist were included in this study, and data recorded included the presence and description of any arrhythmias and presence of any other abnormalities within the individual wave components. Postoperatively, the same values on thoracic radiographs, echocardiograms, and ECGs were recorded when available. If residual PDA flow was noted on echocardiogram, it was classified as trivial, mild, moderate, or severe as previously described by Achen et al.[13]

Statistical analysis

A univariate logistic regression model was utilized to evaluate preoperative and perioperative patient factors and the predictive risk of intraoperative hemorrhage, perioperative mortality, and short- and long-term survival. Acute versus chronic duration of clinical signs were treated as continuous variables. A Fisher exact test was used to determine the association between preoperative and perioperative patient factors and intraoperative hemorrhage. A univariate analysis of intraoperative complications and their impact on short- and long-term survival was evaluated. A multivariable logistic regression model was performed to evaluate whether a combination of preoperative and perioperative patient factors impacted the predictive risk of intraoperative hemorrhage. A 1-way χ^2 test was used to determine statistical significance with a P value < .05 considered statistically significant.

Results

History and physical exam

Four hundred twenty-one dogs were evaluated for surgical ligation of a left-to-right shunting PDA. Four dogs were excluded, with 3 dogs having anesthetic complications prior to the start of surgery necessitating abortion of the procedure and 1 dog being diagnosed with a right-to-left shunting PDA at the time of surgery. A total of 417 client-owned dogs were included in this study. A total of 60 dog breeds were represented, with Chihuahuas (12%), Maltese (9%), Pomeranians (7%), and German Shepherd Dogs (6%) overrepresented. The majority of dogs were intact females **(Table 1)**.

Table 1—Signalment and preoperative cardiac history of dogs undergoing surgical ligation of left-to-right shunting patent ductus arteriosus.

Parameter	Value
Age (mo)	*10.3
Weight (kg)	*5.1
Female	73.9%
Intact	^83.4%
Spayed	^16.6%
Male	26.1%
Intact	^81.7%
Neutered	^18.3%
Breed	
Chihuahua	12%
Maltese	9%
Pomeranian	7%
German Shepherd Dog	6%
Clinical signs	
Yes	42%
Acute	^17.9%
Chronic	^82.1%
History Lt-CHF	10%
Lt-CHF at presentation	14%

Unless otherwise specified, values represent the percentage out of total number of dogs in the study (n = 417). Acute clinical signs were defined as signs present for < 7 days. Chronic clinical signs were defined as signs present for > 7 days.

Lt-CHF = Left-sided congestive heart failure.

*Values reported as median. ^Values reported as percentage out of total number of dogs in a specific parameter.

The median age was 10.3 months (range, 1 to 108 months; IQR, 5 months), and the median weight was 5.1 kg (range, 0.3 to 53.7 kg; IQR, 2.75 kg). A total of 179 (42%) dogs presented with clinical signs of a PDA, including lethargy, collapse, exercise intolerance, tachypnea, and coughing. There was no association between age at the time of surgery and survival to discharge (P = .7), 1-year survival (P = .5), or 5-year survival (P = .3).

Fifty-nine (14%) dogs had recorded comorbidities, with the most common being cryptorchidism (5/59 [8.5%]), intestinal parasites (5/59 [8.5%]), or presence of an umbilical hernia (4/59 [6.8%]). Reported cardiac comorbidities included pulmonic stenosis (3/59 [5.1%]), pulmonary hypertension, (2/59 [3.4%]), subaortic stenosis (2/59 [3.4%]), atrial septal defect (1/59 [1.7%]), the presence of a second pulmonary artery (1/59 [1.7%]), second-degree atrioventricular (AV) block (1/59 [1.7%]), mitral valve stenosis (1/59 [1.7%]), and mitral valve dysplasia (1/59 [1.7%]). Sixty (14.4%) dogs had a history of a previous surgical procedure, with 15 of those being cardiac-related surgeries. Previous cardiac surgeries included previous Amplatz canine duct

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occluder (ACDO) placement attempts in 14 dogs and balloon valvuloplasty for pulmonic stenosis in 1 dog; 1 dog underwent ACDO placement attempt and surgical ligation under the same anesthetic period, and 1 dog underwent ACDO removal and surgical ligation under the same anesthetic period. There was no association between previous cardiac surgery and occurrence of intraoperative hemorrhage or other intraoperative complications.

Of the 417 dogs, 42 (10%) had a history of left-sided CHF and 59 (14%) had evidence of left-sided CHF at the time of presentation. Eighty-six (21%) dogs were receiving cardiac medications at the time of presentation, with furosemide and pimobendan being the most common medications. Multiple logistic regression models were used to evaluate age and weight with a history of heart failure or the presence of heart failure at presentation and the risk of intraoperative hemorrhage. There was a significant association of intraoperative hemorrhage in patients with evidence of heart failure at presentation, regardless of weight (P = .04) or age (P = .04). There was not a significant association of intraoperative hemorrhage in patients that had a history of heart failure, regardless of weight (P = .17) or age (P = .12).

Of the 417 dogs, 413 had a recorded heart murmur on presentation. The most common type of murmur was a continuous grade 5/6 heart murmur. Three out of the 417 (0.7%) dogs had only a systolic murmur. Two separate murmurs were auscultated in 19 (4.6%) dogs, all of which had a continuous murmur and left apical systolic murmur concurrently.

Cardiopulmonary assessment

Thoracic radiographs were performed in 221 (53%) dogs; 210 (95%) of those dogs had evidence of cardiomegaly per the written radiology report. An echocardiogram was performed in 407 (98%) dogs; the remaining 10 dogs were suspected to have a PDA on the basis of the presence of a continuous heart murmur and bounding femoral pulses. The LA:Ao measurement was recorded in 314 (75%) dogs. Results were divided into 3 categories based on measurement; 165 (53%) had an LA:Ao ratio < 1.5, 138 (44%) had an LA:Ao ratio of 1.55 to 2.4, and 11 (3%) had an LA:Ao ratio of > 2.5.

There was evidence of MR in 205 (65%) dogs based on echocardiogram. Based on echocardiogram reports, the MR was further classified as trace in 61 (30%) dogs, mild in 115 (56%), moderate in 26 (13%), and severe in 3 (1%). There was no association between the presence or degree of MR and survival to discharge (P = .3) or the 1-year survival rate (P = .7).

In total, 400 patients were able to be classified according to Houghton et al[12] as a PDA type 1 (n = 57), type 2 (136), type 3a (43), type 3b (157), or type 4 (7) based on available records, with the majority of patients classified as type 3b and thereby indicating the presence of a palpable thrill, MR, and marked left cardiomegaly with no evidence of left-sided CHF.

Overall, 37 dogs (37/417 [8.9%]) had evidence of electrocardiographic abnormalities on preoperative ECG, with the most common abnormalities being tall R waves (10/37) and ventricular premature complexes (VPCs; 10/37). Other abnormalities included first-degree AV block (n = 2), secondary degree AV block (5), atrial fibrillation (4), ventricular bigeminy (2), and accelerated idioventricular rhythm (1).

Intraoperative data

The dissection method of the PDA was classified as either a standard cranial to caudal or caudal to cranial approach (98%) or as the Jackson-Henderson approach (2%). Of the cases in which the Jackson-Henderson approach was used, 64% started with a standard approach to the PDA and then converted to the Jackson-Henderson approach when bleeding from the PDA was observed. The ligation method was reported in 395 dogs, with silk suture being most common (92%), followed by suture and hemoclips (2%), hemoclips alone (2.5%), suture other than silk alone (3%), or umbilical tape (0.5%).

Intraoperative complications were recorded in 182 patients (43.6%). Of the dogs experiencing complications, 146 dogs (80.2%) had anesthetic-related complications, including hypothermia, bradycardia, and hypotension. Other complications included the following: 4 (2.2%) dogs suffered cardiopulmonary arrest, 27 (14.8%) dogs had arrhythmias, and 4 (2.2%) dogs had a prolonged anesthetic recovery.

Out of the 417 patients undergoing surgery, intraoperative hemorrhage occurred in 45 (11%) patients and 20 (5%) dogs required a blood transfusion during surgery **(Figure 1)**. Reported methods for achieving hemostasis included placement of hemoclips (22%), conversion to a Jackson-Henderson approach (16%), and use of Gelfoam in 1 patient. Of the 45 patients experiencing hemorrhage, 5 were euthanized or died due to persistent bleeding. Of the 40 surviving patients, the procedure was aborted in 7 patients; the PDA was ligated in the remaining 33 patients. The site of hemorrhage was described as along the medial aspect of the PDA (49%), from the cranial aspect of the PDA (2%), from the caudal aspect of the PDA

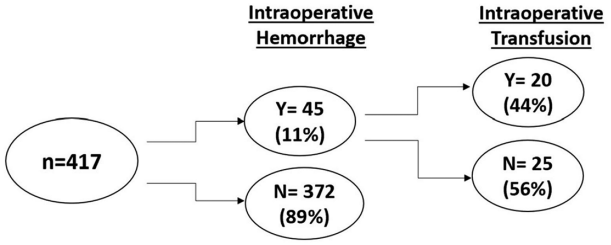

Figure 1—Occurrence of intraoperative hemorrhage and blood transfusions in dogs undergoing surgical ligation of left-to-right shunting patent ductus arteriosus (PDA). For the 417 dogs undergoing surgery for ligation of a left-to-right shunting PDA, occurrence of intraoperative hemorrhage was recorded. The total number and percentage of dogs experiencing intraoperative hemorrhage is shown in the above flow chart. Of the 45 dogs experiencing intraoperative hemorrhage, the total number and percentage of those receiving an intraoperative blood transfusion is shown above. Y = Yes. N = No.

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(4%), from the lateral aspect of the PDA (2%), originating from a great vessel (7%), originating from a superficial intercostal vessel (18%), or unknown (18%). Based on this exploratory study, there was no association between age at the time of surgery and risk of intraoperative hemorrhage (P = .7) or between weight and risk of intraoperative hemorrhage (P = .96). The type of PDA and risk of intraoperative hemorrhage did not have any association (P = .28) as based on a Fisher exact test. Similarly, the type of PDA and location of intraoperative hemorrhage did not have any association (P = .7) based on a Fisher exact test. There was no association between the presence or degree of MR and intraoperative hemorrhage (P = .3). The association between increasing LA:Ao ratio and risk of intraoperative hemorrhage was also not significant with a P value of .08.

The overall intraoperative mortality rate was 2.2% (9/417), with 4 of the 9 (44%) dogs dying from cardiac arrest and 5 (56%) dogs dying or being euthanized due to uncontrollable hemorrhage.

Postoperative data

Ten out of the 20 (50%) dogs receiving an intraoperative blood transfusion required an additional blood transfusion following surgery. Eighty-four (21%) of the surviving 408 dogs had a recorded persistent heart murmur following surgery. Five dogs had a murmur recorded after surgery that went away prior to discharge.

Postoperative echocardiograms were performed on 129 dogs prior to discharge. Eighty-nine dogs showed complete attenuation of their PDA with no flow. Eight dogs had no flow through the PDA but had persistent MR. Twenty-two dogs had mild flow present through their PDA, and 4 dogs had mild flow through their PDA and evidence of MR.

Postoperative ECG findings were reported for 46 dogs, with 8 (17.4%) having a postoperative arrhythmia. Recorded arrhythmias included atrial fibrillation in 7 dogs (15.2%), and persistent second-degree AV block in 1 dog that was noted preoperatively (2.2%). There was no association between the need for a blood transfusion, presence of a persistent heart murmur postoperatively, or presence of a persistent arrhythmia postoperatively with survival to discharge or long-term survival.

Three dogs suffered from cardiopulmonary arrest postoperatively, and only 1 dog was able to be successfully resuscitated. Other postoperative complications included hemothorax (n = 2; 0.4%) with 1 dog requiring an autotransfusion for the hemothorax, pneumothorax (1; 0.2%), a chylothorax (1; 0.2%), pulmonary edema secondary to CHF (1; 0.2%), noncardiogenic pulmonary edema and supraventricular tachycardia (1; 0.2%), atrial fibrillation (1; 0.2%), and transient Horner syndrome (1; 0.2%). The average hospitalization time for dogs surviving surgery was 2 days (range, 1 to 8 days).

Survival to discharge, 2-week survival, 1-year survival, and 5-year survival were determined on the basis of available records and phone calls to the client. Of the 417 dogs undergoing surgery, 405 (97%) survived to discharge. Sixty-two dogs were discharged on cardiac medications including pimobendan, furosemide, atenolol, sildenafil, and/or enalapril.

Following discharge, 100 dogs were lost to follow-up, 302 (99.5%) dogs survived to the 2-week recheck visit, and 1 (0.5%) dog died prior to the 2-week recheck, with the cause of death suspected to be due to an underlying arrhythmia. At the 2-week recheck, 12 (4%) dogs had documented cardiac disease as based on echocardiogram findings or thoracic radiograph findings, including subaortic stenosis in 2 dogs, left-sided cardiomegaly in 9 dogs, pulmonary hypertension in 1 dog, and pulmonary stenosis in 1 dog; 3 (1%) dogs had a documented arrhythmia; and 28 (9.3%) dogs had a persistent heart murmur.

One-year follow-up was available for 221 dogs, with 213 (96%) alive at 1 year and 8 (4%) deceased at 1 year postoperatively. Five-year follow-up was available for 101 dogs, with 88 (87%) alive and 13 (13%) deceased. Long term, 81 (36.7%) dogs had recorded heart disease based on follow-up echocardiograms, 58 (26.2%) dogs had a recorded heart murmur, 33 (14.9%) dogs had recorded arrhythmias, and 31 (14%) dogs required cardiac medication. Of the 31 dogs requiring long-term cardiac medication, 20 dogs received a single medication (pimobendan, 6/20; enalapril, 9/20; benazepril, 1/20; diltiazem, 1/20; and atenolol, 3/20). Two dogs received both pimobendan and furosemide, and 1 dog received sotalol and mexiletine. Eight of the 31 dogs receiving long-term cardiac medications were on 3 or more medications. Of the 81 dogs with recorded heart disease, 50 dogs had evidence of persistent changes secondary to the PDA and 31 dogs had evidence of other cardiac disease. For dogs that survived to discharge but did not survive to the 1-year or 5-year time points, the cause of death was cardiac related in 38%, noncardiac related in 38%, and unknown in 24%.

Discussion

In this study, the majority of dogs undergoing surgical intervention for a left-to-right shunting PDA were female (73.9%) small-breed dogs < 1 year of age, which is consistent with previous reports.[3,8,14] Two hundred five (65%) dogs had evidence of MR at presentation; however, there was no correlation between presence or degree of MR and an increased risk of intraoperative hemorrhage, thereby rejecting our hypothesis. Intraoperative hemorrhage did occur at the higher end of the previously reported range[5,6,8] in this study (10.8%), with intraoperative hemorrhage from the PDA vessel occurring in 6.3% of patients. Based on available data, our hypothesis that intraoperative hemorrhage would occur at a higher rate could not be rejected due to our reported rate falling within the previously reported ranges. The occurrence of intraoperative hemorrhage was not correlated to survival. The short- and long-term survival rates in this study were similar to previous reports,[3,7] thereby supporting our hypothesis.

Multiple studies have investigated preexisting patient factors and their association with intraoperative complications, short-term outcome, and long-term prognosis in dogs with a left-to-right shunting PDA.[1–3,5,7,8,14] A study by Bureau et al[7] reported that preexisting factors such as age, weight, and right atrial dilation were negative prognostic indicators for survival; however, a later report[8] in 2007 showed that there was no correlation between age and patient size in terms of successful treatment. Our

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study found that there is no correlation between age or weight of the patient and occurrence of intraoperative hemorrhage, which supported the conclusions reported in the 2007 study.[8]

A review[15] of 100 cases in 1976 found that dogs diagnosed with atrial fibrillation and MR had a 50% mortality rate within 1 month of surgery. The mortality rate for dogs with MR was improved to 94% at 1 year in a 2005 review[7] of 52 cases, which is similar to findings in our study. While 50% of patients in our study had some degree of MR, there was no association between the presence or severity of MR and an increased risk of intraoperative hemorrhage. Additionally, there was no correlation between the presence or severity of MR at the time of surgery and short- or long-term survival, including the cases with documented severe MR. A study[8] in 2007 investigated the long-term outcome for dogs undergoing either surgical ligation or transarterial catheter occlusion for treatment of a PDA and found that the presence of left-sided CHF preoperatively was associated with a higher mortality rate postoperatively. In our study, 10% of dogs had a history of left-sided CHF and 14% had evidence of left-sided CHF at presentation, with neither having an impact on short- or long-term outcome. However, there was an association between the presence of left-sided CHF at presentation and intraoperative hemorrhage. It is possible that the presence of left-sided CHF and associated volume overload is secondary to a larger-diameter PDA. The PDA may be friable due to lower levels of collagen and higher levels of elastin and are therefore at a higher risk of tearing during dissection.[16] It is important to note that the aforementioned studies and our current study had a low number of overall adverse events, which impacted the power in detecting associations between patient factors and intraoperative hemorrhage. However, significant advancements have been made in the detection, monitoring, and medical management of CHF, which likely contribute to the improvement in survival and outcome for patients undergoing ligation of a PDA with concurrent left-sided CHF.

In 2014, Saunders et al[3] reviewed 520 cases to determine the long-term outcome of dogs diagnosed with a left-to-right shunting PDA and determined that LA:Ao ratio was correlated to perioperative mortality with the predicted risk of perioperative death increasing from 2% with a normal LA:Ao ratio, up to 20% if the LA:Ao ratio was ≥ 2.5. While not statistically significant, our study did show that the association between the LA:Ao ratio and risk of intraoperative hemorrhage may be clinically significant. Of the dogs with known LA:Ao ratios that experienced intraoperative hemorrhage, 60% had an abnormal LA:Ao ratio. This association could help explain the previously reported increased risk of perioperative death, as it is feasible that a dilated left atrium could result in a more difficult dissection due to the proximity of the left atrium to the pulmonary artery and potential alteration of normal anatomic orientation with left atrial enlargement. The majority of hemorrhage associated with PDA dissection occurred medial to the shunt vessel, so it is possible that the origin of the bleed was actually from a perforated large atrium instead of the medial wall of the PDA. Additionally, as mentioned above, an enlarged left atrium may indicate more severe volume overload secondary to a larger PDA diameter, thereby resulting in a larger shunt fraction and more friable PDA vessel, increasing the risk of intraoperative hemorrhage and mortality.[16] The LA:Ao ratio was unknown in 25% of cases and there was not a standardized method of measuring this ratio, so it is possible that additional data points may have allowed this association to be statistically significant.

Previous reports have cited the risk of intraoperative hemorrhage to be anywhere from 6.25% to 15%; however, reports of intraoperative hemorrhage impacting overall mortality vary. In a study[6] of 64 cases, the risk of intraoperative hemorrhage was reported to be 6.25%, and the mortality risk increased significantly from 42% to 100% with intraoperative hemorrhage. A second study[7] looking at 52 cases between 1995 and 2003 reported that 8 of 52 (15%) cases experienced intraoperative bleeding, with all cases surviving to discharge. A more recent study[5] that evaluated 285 dogs undergoing surgical ligation between 2008 and 2019 found an overall hemorrhage rate of 6.8%, with all cases surviving surgery. Intraoperative hemorrhage occurred at the higher end of the previously reported rates at 10.8% in our study. However, the intraoperative mortality risk for dogs experiencing intraoperative hemorrhage was only 11%, which is lower than previously reported.[15,17] Of dogs in this study that experienced intraoperative hemorrhage that survived surgery, 95% survived to discharge. The increased survival rate for dogs experiencing intraoperative hemorrhage is likely attributable to recent advancements that have been made in anesthetic monitoring and protocols, as well as increased availability of blood products in specialty hospitals.

Intraoperative mortality rates have been reported as anywhere from 0% to 8%. Eyster et al[15] reported an 8% intraoperative mortality rate in a review of 100 cases, and a review[8] of 201 cases in 2003 reported a 7% intraoperative mortality rate. This 2003 review also showed that intraoperative complications negatively affected long-term survival.[8] Other retrospective studies have reported intraoperative mortality rates of 0% to 2% in procedures performed by experienced surgeons, defined as surgeons that have performed a minimum of 100 PDA ligation procedures.[3] Results from our study were consistent with an intraoperative mortality rate of 2.2%, with half (56%) of the intraoperative deaths due to uncontrollable hemorrhage and subsequent euthanasia. The low intraoperative mortality rate was likely attributable to the improvements in anesthetic monitoring and ability to successfully treat most intraoperative complications.

Our study reported 1- and 5-year survival rates of 96.4% and 87.1%, respectively, with the 1-year survival rate in this study being similar to those previously reported.[7] The 1-year survival rate in our study was consistent with more recent studies and greatly improved from the 1976 review, in which the 1-year survival rate for all dogs undergoing surgery was only 34%.[15] This improvement in survival over the last several decades is likely due to the significant advancements made in both detecting and treating underlying heart conditions. Screening for congenital heart defects has improved, likely resulting in dogs presenting for congenital heart disease earlier in life with less time for significant cardiac remodeling to occur. Additionally, monitoring and

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treatment for cardiac disease has made substantial advancements in both the perioperative and postoperative periods, resulting in better long-term outcomes for patients undergoing surgery for a PDA.

The main limitation of this study was its retrospective nature and lack of long-term follow-up for patients. Data collected relied on accurate recordings of patient history and physical examination, perioperative complications, and details provided in operative reports. The work-up for each patient was not standardized, so certain diagnostics were not performed preoperatively in every patient. Echocardiogram reports were not available for every patient, so incomplete recordings of an LA:Ao ratio may have contributed to a type II error regarding the significance between an increasing LA:Ao ratio and risk of intraoperative hemorrhage. The method of measuring the LA:Ao ratio may not have been consistent across reports as well, so measurements may differ if a single measurement method was used. Additionally, echocardiogram reports did not routinely report objective information regarding the PDA, such as internal ductal diameter, degree of ductal tapering, or presence of ductal narrowing. Therefore, the PDA classification scheme used in this study relied on a subjective description of the shunt vessel. Finally, there is not a standardized classification scheme for reporting severity of MR as trace, mild, moderate, or severe; therefore, classification of MR is subjective between cardiologists. Operative reports were evaluated to determine whether a surgery resident or board-certified surgeon performed the dissection to see if there was any correlation between surgeon experience and intraoperative hemorrhage; however, this was unable to be accurately determined on the basis of available information. Similarly, different methods of achieving hemostasis during intraoperative hemorrhage were not mentioned in all operative reports. Postoperative recheck diagnostics were not consistently performed in every patient, and physical examination findings such as change in heart murmur were not recorded for every patient. The lack of long-term follow-up for patients was also a limitation in evaluating for associations between perioperative patient factors and complications and their effect on long-term outcome.

In conclusion, surgical ligation for a left-to-right shunting PDA results in low mortality rates and excellent survival rates. Surgical ligation for a left-to-right shunting PDA is thus recommended due to the good long-term prognosis. To the authors' knowledge, this was the largest retrospective study evaluating dogs undergoing surgical ligation of a left-to-right shunting PDA. This study showed that the immediate and long-term survival rates for dogs experiencing intraoperative hemorrhage are improved compared to previous studies, and certain preoperative factors (ie, age, weight, and presence of concurrent heart disease) do not have any association with risks of intraoperative complications and therefore should not preclude surgical treatment in a patient with a left-to-right shunting PDA. While not statistically significant, the presence of an increased LA:Ao ratio may be associated with an increased risk of hemorrhage. This could be the result of an increased shunt fraction secondary to volume overload, increased difficulty of dissection around the PDA, a more friable PDA vessel, or a combination of these factors. Future prospective studies controlling for the method of LA:Ao measurement and evaluating the potential association between an increased LA:Ao ratio and intraoperative hemorrhage are warranted to investigate this finding.

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References

1. Broaddus K, Tillson M. Patent ductus arteriosus in dogs. *Compend Contin Educ Vet*. 2010;32(9):E3.
2. Bascuñán A, Thieman Mankin KM, Saunders AB, et al. Patent ductus arteriosus in cats (*Felis catus)*: 50 cases (2000-2015). *J Vet Cardiol*. 2017;19(1):35–43.
3. Saunders AB, Gordon SG, Boggess MM, Miller MW. Long-term outcome in dogs with patent ductus arteriosus: 520 cases (1994-2009). *J Vet Intern Med*. 2014;28(2):401–410.
4. Greet V, Bode EF, Dukes-McEwan J, Oliveira P, Connolly DJ, Sargent J. Clinical features and outcome of dogs and cats with bidirectional and continuous right-to-left shunting patent ductus arteriosus. *J Vet Intern Med*. 2021;35(2):780–788.
5. Grimes JA, Thieman Mankin KM. Surgical ligation of patent ductus arteriosus in dogs: incidence and risk factors for rupture. *Vet Surg*. 2022;51(4):592–599.
6. Hunt GB, Simpson DJ, Beck JA, et al. Intraoperative hemorrhage during patent ductus arteriosus ligation in dogs. *Vet Surg*. 2001;30(1):58–63.
7. Bureau S, Monnet E, Orton EC. Evaluation of survival rate and prognostic indicators for surgical treatment of left-to-right patent ductus arteriosus in dogs: 52 cases (1995-2003). *J Am Vet Med Assoc*. 2005;227(11):1794–1799.
8. Goodrich KR, Kyles AE, Kass PH, Campbell F. Retrospective comparison of surgical ligation and transarterial catheter occlusion for treatment of patent ductus arteriosus in two hundred and four dogs (1993-2003). *Vet Surg*. 2007;36(1):43–49.
9. Hansson K, Häggström J, Kvart C, Lord P. Left atrial to aortic root indices using two-dimensional and M-mode echocardiography in cavalier King Charles Spaniels with and without left atrial enlargement. *Vet Radiol Ultrasound*. 2002;43(6):568–575.
10. Marchesotti F, Vezzosi T, Tognetti R, et al. Left atrial anteroposterior diameter in dogs: reference interval, allometric scaling, and agreement with the left atrial-to-aortic root ratio. *J Vet Med Sci*. 2019;81(11):1655–1662.
11. Singh MK, Kittleson MD, Kass PH, Griffiths LG. Occlusion devices and approaches in canine patent ductus arteriosus: comparison of outcomes. *J Vet Intern Med*. 2012;26(1):85–92.
12. Houghton HE, Ware WA. Patent ductus arteriosus in dogs. *Iowa State Univ Vet*. 1996;58(2):13.
13. Achen SE, Miller MW, Gordon SG, Saunders AB, Roland RM, Drourr LT. Transarterial ductal occlusion with the Amplatzer vascular plug in 31 dogs. *J Vet Intern Med*. 2008;22(6):1348–1352.
14. Van Israël N, French AT, Dukes-McEwan J, Corcoran BM. Review of left-to-right shunting patent ductus arteriosus and short term outcome in 98 dogs. *J Small Anim Pract*. 2002;43(9):395–400.
15. Eyster GE, Eyster JT, Cords GB, Johnston J. Patent ductus arteriosus in the dog: characteristics of occurrence and results of surgery in one hundred consecutive cases. *J Am Vet Med Assoc*. 1976;168(5):435–438.
16. Cocciolone AJ, Hawes JZ, Staiculescu MC, Johnson EO, Murshed M, Wagenseil JE. Elastin, arterial mechanics, and cardiovascular disease. *Am J Physiol Heart Circ Physiol*. 2018;315(2):H189–H205.
17. Birchard SJ, Bonagura JD, Fingland RB. Results of ligation of patent ductus arteriosus in dogs: 201 cases (1969-1988). *J Am Vet Med Assoc*. 1990;196(12):2011–2013.

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