

Surgical ligation of patent ductus arteriosus in dogs: Incidence and risk factors for rupture

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Abstract

Objective: To determine the rates of rupture and mortality associated with surgical ligation of patent ductus arteriosus (PDA) in dogs and to identify risk factors for rupture.

Study design: Retrospective cohort.

Animals: Two-hundred and eighty-five dogs with PDA undergoing surgical ligation.

Methods: Information regarding signalment, weight, surgical findings, complications, presence of residual flow, and survival was recorded. Age, weight, and presence of residual flow were compared between cases with and without rupture.

Results: The initial surgical approach was extrapericardial (144), intrapericardial (46), not reported (94), or Jackson-Henderson (1). Rupture of the PDA occurred in 7.0% of dogs (20/285, 13 extrapericardial, 3 intrapericardial, 4 not reported). No difference in age or weight was found between dogs with and without rupture. Overall mortality was 0.4% (1/285). Additional major complications occurred in 1.4% of dogs, all in the nonrupture group. The overall rate of residual flow after ligation was 9.4%. Dogs with rupture were more likely to have residual flow than those without rupture ($P = .012$). If ligation was performed after rupture (rather than hemostasis only), no difference in residual flow rates ($P = .398$) was noted between dogs with rupture and those without.

Conclusion: The rate of rupture with surgical ligation of PDAs was low. No specific risk factors for rupture were identified.

Clinical significance: Successful treatment of PDA rupture is possible, evidenced by the low mortality rate in this population of dogs. Ligation of the PDA after rupture, either in the concurrent or a subsequent procedure, reduces the odds of residual flow.

1 | INTRODUCTION

Patent ductus arteriosus (PDA) is one of the most common congenital heart conditions in dogs.¹ Closure of the

PDA is recommended when left-to-right shunting is present, either via surgical ligation or transarterial methods using occluding devices such as the Amplatzer canine ductal occluder (Infiniti Medical, LLC, Palo Alto, California).

Surgical ligation is recommended over transarterial occlusion when the patient is too small or the shape of the PDA is not amenable to transarterial procedures.^{2,3} Closure of the PDA is recommended to prevent congestive heart failure and improve long-term survival.⁴

Major complications associated with surgical ligation of PDAs are reported to occur in 6% to 15% of dogs and include rupture of the PDA with subsequent hemorrhage, lung trauma, residual flow through the PDA, and cardiac arrest associated with closure of the PDA.^{2,5-7} Specific risk factors for rupture are controversial, with increasing age and weight^{4,5} being reported as significant risk factors in some studies but not others.^{8,9} Major complications associated with transarterial procedures are reported to occur in 0% to 4% of dogs and include hemorrhage from the femoral artery, hemorrhage from perforation of the aorta, embolization of the occlusion device, and cardiac arrest associated with closure of the PDA.^{2,7,10} Reported mortality rates with surgical ligation range from 0% to 6%,^{2,5-7} whereas mortality rates with transarterial procedures range from 0% to 3%.^{2,7,10,11}

Surgical dissection techniques used for PDA ligation include an extrapericardial or intrapericardial technique, or the Jackson-Henderson technique.¹²⁻¹⁴ The Jackson-Henderson technique has been reported to lead to increased rates of residual flow in comparison with an extrapericardial technique,¹⁵ although this was refuted in another study.¹⁶ The Jackson-Henderson technique is useful, particularly after rupture, as it eliminates the need to pass an instrument medial to the PDA, where the muscular wall of the PDA is weakest and rupture is most common.^{12,17}

The objective of this study was to determine the rates of rupture and mortality associated with surgical ligation of PDAs and to identify risk factors for rupture of the PDA during dissection. The hypothesis was that increasing age and weight would increase the risk of rupture based on the authors' clinical experience.

2 | MATERIALS AND METHODS

Medical records at 2 veterinary teaching hospitals (University of Georgia and Texas A&M University) were searched for client-owned dogs undergoing surgical ligation of a left-to-right shunting PDA between January 1, 2008 and December 31, 2019. Dogs that underwent a successful transarterial procedure for closure of the PDA were excluded; dogs that underwent an unsuccessful transarterial procedure and subsequent surgical ligation were included. Dogs in which the surgical procedure was aborted prior to attempted dissection and ligation were excluded.

Data obtained from the medical record included age, sex, breed, weight, whether a transarterial procedure was performed prior to surgery, surgical dissection technique (intrapericardial, extrapericardial, Jackson-Henderson), suture size and material used for ligation, major intraoperative complications, presence of residual flow postoperatively, time of evaluation for residual flow postoperatively, and survival to discharge from the hospital. For dogs with rupture, additional information was collected including location of the rupture, at what point in the procedure rupture occurred, whether the PDA was ligated after rupture or if hemostasis was achieved without ligation, and information on whether a second surgical procedure was attempted for ligation. If rupture occurred and ligation was performed, the dissection technique that was used (extrapericardial, intrapericardial, or Jackson-Henderson) was recorded. Residual flow was determined by evaluation of postoperative echocardiogram reports. Severity of residual flow was subjectively assessed by board-certified cardiologists or cardiology residents under the supervision of a board-certified cardiologist.

The number of dogs treated with surgical ligation and transarterial occlusion were determined for each institution for each year of the study period to allow for investigation of the impact of experience on complication rates.

Descriptive statistics were generated. Normally distributed data are expressed as mean \pm SD and non-normally distributed data are expressed as median (range). Nominal logistic regression was used to compare age and weight between cases with and without rupture. A Fisher's exact test was used to compare residual flow and suture size used for ligation with presence of residual flow between groups (with and without rupture). Only variables in which ≥ 6 dogs were represented were included for analysis. Significance was set at $P < .05$.

3 | RESULTS

Two hundred and eighty-five dogs underwent surgical ligation of a left-to-right shunting PDA and were included in the study. The median age of the dogs was 5.9 months (1-118 months) with 212 females (212/285, 75.1%, 162 intact, 50 spayed) and 73 males (73/285, 25.6%, 59 intact, 14 castrated) included. The most commonly represented breeds included Chihuahua (45/285, 15.8%), mixed-breed dogs (44/285, 15.4%), Maltese (30/285, 10.5%), Pomeranian (24/285, 8.4%), Yorkshire terrier (23/285, 8.1%), dachshund (18/285, 6.3%), German shepherd dog (15/285, 5.3%), and miniature, toy, or teacup poodle (13/285, 4.6%), along with 37 other breeds. The median weight of the dogs was 2.73 kg (0.55-42.8 kg).

Two-hundred and sixty-five dogs (265/285, 93.0%) underwent surgical ligation without rupture of the PDA, and 20 dogs (20/285, 7.0%) experienced rupture of the PDA (Table 1). No difference in age ($P = 0.404$; 6 months, range 1-118 months, without rupture; 7 months, 2-24 months, with rupture) or weight ($P = .551$, 3.00 kg, range 0.55-42.80 kg, without rupture; 3.00 kg, range 0.78-26.00 kg, with rupture) was found between dogs with rupture and those without.

Thirty-three dogs (33/285, 11.6%) had an unsuccessful transarterial procedure prior to proceeding with surgical ligation (30 dogs in the nonrupture group, 3 dogs in the rupture group). All transarterial procedures were planned to use the Amplatzer canine ductal occluder (Infiniti Medical, LLC). The most common reason for lack of success of the transarterial procedure was that the femoral artery was too small for passage of the device. Additional reported complications related to unsuccessful transarterial procedures were occluder dislodgement (4) and puncture of the aorta with a catheter (1). In the dogs with dislodgement, no attempts were made to retrieve or reposition the dislodged occluder. The dog that had puncture of the aorta underwent repair of the aortic defect during its open surgery for PDA ligation.

In the nonrupture group, the surgical approach was described as extrapericardial (131/265, 49.4%), intrapericardial (43/265, 16.2%), Jackson-Henderson (1/265, 0.4%), or not reported (90/265, 34.0%). The suture type used was silk (258/265, 97.4%), PDS (1/265, 0.4%), or not recorded (6/265, 2.3%). Suture size was 2-0 (164/265, 61.9%), 0 (61/265, 23.0%), 3-0 (19/265, 7.2%), 1 (11/265, 4.2%), 2 (2/265, 0.8%), 4-0 (1/265, 0.4%), or not recorded (7/265, 2.6%).

For the rupture group, the initial surgical approach was described as extrapericardial (13/20, 65.0%), intrapericardial (3/20, 15.0%), or not reported (4/20, 20.0%). All 20 dogs in the rupture group survived the surgical procedure. For 13 dogs in the rupture group, ligation was pursued and accomplished in the same surgical procedure. Ligation was continued using the original technique (intrapericardial, extrapericardial, or not reported) in 9/13 dogs (69.2%) or the procedure was converted to the Jackson-Henderson technique in 4/13 dogs (30.8%). These ligations were achieved using silk (13/13, 100.0%) with a suture size of 2-0 (10/13, 76.9%) or 0 (3/13, 23.1%). One dog underwent partial transection with oversew of the PDA in the same surgical procedure. In 6 dogs, ligation was not pursued in the same surgical procedure; instead, hemostasis without ligation was accomplished by a combination of digital pressure (3), vascular clips (3), topical hemostatic agent use (2), and suture of a visible defect in the PDA (1), with 2 dogs having no information reported on hemostatic

techniques and the remaining 4 dogs having more than 1 method applied (Table 1). No difference in surgical dissection technique (extrapericardial versus intrapericardial) was detected between dogs with and without rupture of the PDA ($P = .741$), nor was a difference detected between suture size used for ligation and rupture of the PDA ($P = .497$). For the 6 dogs in which hemostasis was achieved without ligation, 3 were reoperated to ligate the PDA at 1, 2, and 53 days following the initial procedure, 2 dogs were recommended to have a second operation but were never returned, and 1 dog was euthanized postoperatively due to hemothorax.

Information about residual flow after ligation was available for 243 dogs (243/265, 91.7%) in the nonrupture group and 16 dogs (16/20, 80.0%) in the rupture group based on postoperative echocardiogram (Figure 1). For the 243 dogs without rupture, no evidence of residual flow was appreciated in 225 dogs (225/243, 92.6%) at a median of 1 day postoperatively (0-696 days). In 18 dogs (18/243, 7.4%), residual flow was noted initially, but at last follow-up residual flow had resolved spontaneously. Twenty-one dogs (21/243, 8.6%) had residual flow at last follow-up (median 27 days, range 0-1098 days postoperatively). Three dogs underwent a second surgical procedure to ligate the PDA to resolve residual flow; these dogs had grades of mild, severe, and not reported for their initial residual flow. Sixteen dogs in the rupture group had an echocardiogram for evaluation of residual flow at a median of 1.5 days (1-525 days) postoperatively (Table 1). Dogs with ruptures were more likely to have residual flow than dogs without rupture ($P < .002$, OR 8.2, 95% CI 2.8-24.3; 21/243 dogs without rupture had residual flow, 7/16 dogs with rupture had residual flow). In dogs where rupture occurred but successful ligation was ultimately performed despite rupture (excluding hemostasis only cases), the risk of residual flow was not different from dogs that underwent surgical ligation without rupture ($P = .074$, 21/243 dogs without rupture had residual flow, 3/11 dogs with rupture and subsequent ligation had residual flow). The overall rate of residual flow with ligation regardless of rupture was 9.4% (24/254). No association between suture size and presence of residual flow was found ($P = .108$).

Major intraoperative complications other than hemorrhage occurred in 4 dogs in the nonrupture group (4/285, 1.4%) leading to a total major intraoperative complication rate of 8.4% (24/285). These other complications were inadvertent ligation of the main pulmonary artery (1) or a branch of the main pulmonary artery (1), cardiopulmonary arrest with successful resuscitation (1), and difficulty with dissection of the PDA via an extrapericardial approach due to fibrosis requiring reoperation the following day via an intrapericardial approach (1). No

TABLE 1 Details of rupture in 20 dogs with rupture of the PDA during attempted surgical ligation

Dog	Rupture location	Rupture timing	Ultimate Ligation method	Hemostasis techniques	Death	Reoperation	Residual flow	Comments
1	Caudal	Dissection	Hemostasis only	Digital pressure, vascular clips	N	N	Y – reduced	
2	Medial	Dissection	Standard	Digital pressure	N	N	Y – NR	
3	NR	NR	Standard	NR	N	N	Y – moderate	
4	Caudal	Dissection	Transect, oversew	Hemostatic clamps	N	N	Y – reduced	Transarterial occluder placed 730 days postoperatively
5	NR	NR	Hemostasis only	NR	N	Y – 1 day, no complications	Y – mild	
6	NR	Dissection	JH	NR	N	N	Y – mild	Residual flow resolved at 135 days postoperatively
7	Caudal, cranial	Dissection	Hemostasis only	Digital pressure, gel foam, hemostatic clamps, vascular clips	N	N	Y – reduced	Attempted conversion to JH intraoperatively but a second rupture occurred, mild to moderate residual flow at 525 days postoperatively
8	NR	NR	Hemostasis only	NR	N	Y – 2 days, rupture of PDA, successful ligation	N	60 days later had continuous flow, suspect recanalization
9	NR	Suture passage	Standard	Tightening suture	N	N	NE	
10	Cranial	Dissection	Hemostasis only	Vascular clips, suture of visible defect	Y	N	NE	Attempted conversion to JH intraoperatively but hemorrhage occurred again, euthanized 1 hour postoperatively due to continued hemothorax
11	Caudal	Dissection	Hemostasis only	Digital pressure, gel foam	N	Y – 53 days, JH, no complications	NE	
12	Caudal, medial	Dissection	JH	Removal of forceps	N	N	N	
13	Cranial	Passing forcep	Standard	Digital pressure, rehemorrhaged when passing suture, tying suture resolved hemorrhage, vascular clips	N	N	N	
14	NR	NR	Standard	NR	N	N	N	
15	NR	Tying suture	Standard	Hemostatic clamp	N	N	N	
16	NR	NR	Standard	Aortic clamp	N	N	N	
17	Cranial	Dissection	JH	Digital pressure	N	N	N	
18	NR	NR	Standard	Digital pressure	N	N	N	
19	Middle	NR	Standard	Hemostatic clamp	N	N	N	
20	Caudal	Dissection	JH	Digital pressure	N	N	NE	

Abbreviations: JH, Jackson-Henderson; N, no; NE, not examined; NR, not reported; PDA, patent ductus arteriosus; Y, yes.

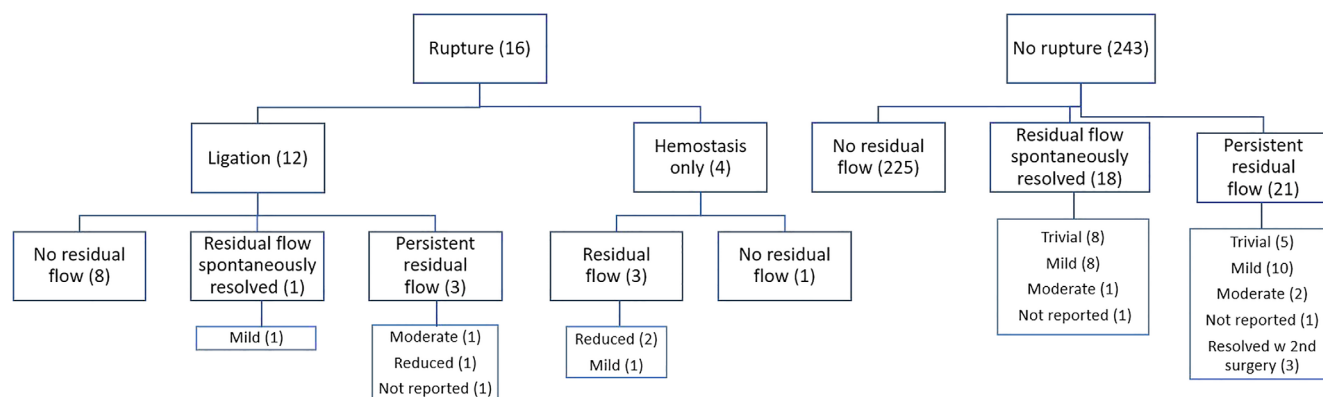


FIGURE 1 Incidence of residual flow for 259 dogs undergoing surgical ligation of a PDA with follow-up echocardiographic evaluation for residual flow

additional intraoperative complications were reported in the rupture group.

Overall mortality was 0.4% (1/285), with no dogs in the nonrupture group dying prior to hospital discharge (0/265, 0.0%) and 1 dog (1/20, 5.0%) in the rupture group dying prior to hospital discharge. This dog was euthanized 1 hour postoperatively due to persistent hemothorax despite hemostasis being achieved intraoperatively.

Over the study period, one institution performed a total of 52 transarterial procedures compared to 190 surgical ligation procedures (mean 9.3 ± 2.8 surgical procedures per year; transarterial procedures were not commonly offered until 2012 at this institution) while the second institution performed a total of 111 transarterial procedures and 175 surgical procedures (mean 14.6 ± 3.4 surgical procedures per year; transarterial procedures were performed regularly at this institution for the entire study period).

4 | DISCUSSION

Rupture of the PDA during surgical ligation occurred in 7.0% of dogs in this study. Previously reported rates of rupture with surgical ligation via an extrapericardial dissection technique range from 0.0% to 15.4%.^{2,4–8,15,16} When evaluating the combined raw data from these previous reports, the overall hemorrhage rate was 6.8% (41/607 dogs), which is consistent with the results of the 285 dogs in the present report.

Increasing age has been previously reported to be a risk factor for rupture,⁵ but other studies have not confirmed this.^{8,9} Age was suspected to be a possible risk factor based on author experience. Older dogs may have larger hearts due to being larger in size at an older age and due to chamber enlargement due to the PDA,

sometimes complicating the dissection of the PDA. Further, older dogs may have more remodeling and scar tissue in the area due to chronic changes from altered blood flow, which could lead to alteration of the vessel structure, more difficult dissection, and increased risk of rupture. However, age was not confirmed as a risk factor for rupture in the dogs of the current report, thus this hypothesis was rejected. Increasing weight has been associated with increased risk of intraoperative death and decreased long-term survival,^{4,5} but has not been evaluated as a risk factor in more recent studies evaluating rupture with surgical ligation,^{2,5–7} but one reason increased weight could be concerning for increased risk of rupture is that the PDA itself will likely be larger. This would lead to a greater surface area on the medial aspect of the PDA, where rupture is most common due to the weakness of the vessel wall in this area.¹² Additionally, with a larger PDA, larger instruments are required to span the width of the PDA when passing suture. In the authors' experience, these larger instruments lead to less precise dissection due to sheer size, which may increase the risk of rupture. It is also possible that certain large breeds of dogs are predisposed to certain morphologies of PDAs that make them more susceptible to rupture. Despite these theories, weight was not associated with risk of rupture in the present study; thus this hypothesis was rejected.

The overall mortality rate for this population was 0.4%, lower than previously reported mortality rates for surgical ligation and transarterial occlusion.^{2,6,7,10,11} Only 1 dog in this population died and this dog was in the rupture group. Although hemostasis was achieved intraoperatively, the dog developed persistent hemothorax within 1 hour of surgery and euthanasia was elected. Although the risk of rupture is low, when it occurs, hemorrhage can be severe and immediate action is required. Surgeons should be familiar with hemorrhage control

procedures and have the necessary tools available in the event of rupture. Digital pressure, hemostatic clamps, hemostatic agents, and suture or vascular clips can all be used to control hemorrhage in the event of rupture. This low mortality rate is encouraging; despite massive hemorrhage, hemorrhage control and survival is possible with proper preparation, including blood typing, access to blood products, access to hemostatic materials, and knowledge of their application.

The majority of PDAs that ruptured could be ligated with either an extrapericardial, Jackson-Henderson, or intrapericardial dissection technique. The Jackson-Henderson technique is a useful technique for PDA ligation.¹³ It is not frequently used as a first-line treatment due to some studies reporting higher rates of residual flow compared to the standard technique,¹⁵ although this was refuted in another study.¹⁶ Despite this, surgeons should be knowledgeable about this technique, particularly for cases in which rupture occurs on the medial aspect of the PDA, as this technique eliminates the need for passing forceps medial to the PDA. Similarly, the intrapericardial technique allows surgeons a slightly different location for dissection, possibly avoiding disruption of the previous rupture site when reoperating on a dog for PDA ligation after rupture.¹⁴ This technique was also useful for 1 dog in the nonrupture group in this study. After initial extrapericardial dissection, fibrosis was encountered and the intrapericardial technique was performed the following day, which allowed for avoidance of the fibrous tissue and successful ligation. This technique could be considered in the same operative event if the extrapericardial technique is found to be difficult.

Only 6 dogs had control of hemostasis without specific attempts at ligating the PDA. In some cases, achieving hemostasis can result in partial, if not complete occlusion of the PDA and this occurred in 1 dog of the current report. This likely occurs during attempts to control hemorrhage with suture or vascular clips that cause partial reduction of the vessel lumen. In time, thrombus formation may assist in further reducing blood flow through the PDA. When these cases were included in the analysis, the risk of residual flow was higher with the occurrence of rupture, indicating that attempts at hemostasis without ligation of the PDA are likely to result in residual flow. When cases where only hemostasis was achieved without further attempts at ligating the PDA were excluded, the risk of residual flow was no different from that of dogs without rupture. Interestingly, several dogs had hemorrhage during passing or tying of the suture, which was controlled by proceeding with tightening of the suture. However, for cases in which hemorrhage occurs during dissection and prior to suture passage, surgeons should weigh the risk of repeated

rupture with continued dissection versus the risk of significant residual flow.

Major intraoperative complications other than hemorrhage occurred in 1.4% of dogs in the present study. Two dogs had inadvertent ligation of the main pulmonary artery or a branch of the main pulmonary artery. Knowledge of anatomy of this area is imperative to avoid complications of this nature. The vagus nerve generally courses directly over the PDA and the fremitus from turbulent blood flow can be palpated to help identify the vessel.¹² The recurrent laryngeal nerve also can be an indication of the location of the PDA as it branches off of the vagus nerve and travels around the PDA, although this nerve may not be visible in all dogs. Another dog had cardiopulmonary arrest after PDA ligation, which has been reported previously.¹⁰ This was likely associated with the Branham reflex; bradycardia that develops as the aorta experiences a sudden increase in pressure with ligation.¹² Slow ligation of the PDA over 2-3 minutes has been proposed to reduce the risk of the Branham reflex occurring.^{6,15} The time over which sutures were tied was not reported in most cases in this study but this complication was reported in only 1 dog in the present report and resuscitation efforts were successful.

Residual flow occurred in 9.4% of dogs that underwent PDA ligation with or without rupture. This compares favorably to previous reports, which showed a 21% (4/19) to 49% (18/37) rate of residual flow with standard ligation and a 36% (5/14) to 53% (8/17) rate of residual flow with the Jackson-Henderson technique.^{15,16} A more recent study reported a 9.7% (6/62) residual flow rate, which is comparable to the residual flow rate in the dogs of the present study. One group reported a residual flow rate as low as 6.0% (2/33) but limited reporting to include only dogs with clinically significant flow. Although trivial or even mild flow may be considered acceptable after PDA ligation and may be likely to resolve over time; moderate or severe residual flow may indicate insufficient tightening of the suture. It is important to ligate the vessel sufficiently to eliminate all blood flow although, subjectively, some surgeons express concern about suture tearing through the vessel during ligation leading to rupture and hemorrhage.¹² Only 1 dog in the present study had rupture during tying the suture (2-0 silk). During knot tying, the suture broke. The surgeon suspected that the resultant hand jerk tore the PDA, although other unrecorded factors may have contributed to rupture. Ultimately, ligation of the remaining intact suture strand led to resolution of hemorrhage in this dog. Suture size used in this study ranged from 4-0 to 2, with the most common suture size used being 2-0. Subjectively, smaller suture may be more likely to tear through the vessel while larger suture may be more difficult to tighten fully, although no

association between suture size and the presence of residual flow was found.

One limitation of this study is that surgeon experience could not be determined from the records. Both hospitals report the surgical team in the operative report but the primary surgeon (faculty member or resident) could not be discerned from the records. In one study, rupture occurred in 4 of 64 dogs, all of which were being primarily operated on by a resident at the time of rupture.⁶ Surgeon experience was not associated with rupture in another study.⁸ It is possible that surgeon experience with surgical PDA ligation may have decreased with the adoption of transarterial procedures; however, both hospitals that provided cases for this study routinely perform surgical PDA ligations with no substantial alterations in case numbers over the course of this study. Another factor in which evaluation of surgeon experience would be intriguing is the presence of residual flow after ligation. It is possible that inexperienced surgeons may be less likely to tightly secure the ligation due to perceived concern of rupture if the suture tears through the vessel.

Other limitations of this study include its retrospective nature. Information specific to the location and timing of rupture were not available for every dog. The morphology of PDAs was not often recorded in the record, making comparison of rupture based on morphologic classification impossible. Residual flow was recorded as reported in the record but in some cases standard classifications of severe, moderate, mild, trivial were not used and use of these classifications was subjective in nature.

The risk of rupture during surgical ligation of PDAs was low at 7.0% with an overall mortality rate of 0.4%. No specific risk factors for rupture were identified. Surgeons should be cautious during PDA ligation and should be prepared to treat rupture and hemorrhage if it occurs. The odds of residual flow are higher if only hemostasis and not ligation is achieved following rupture. Successful treatment of PDA rupture is possible, evidenced by the low mortality rate in this population of dogs.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

AUTHOR CONTRIBUTIONS

Grimes JA, DVM, MS, DACVS-SA: Substantial contributions to study conception and design and the acquisition, analysis, and interpretation of data for the work, drafting the work and revising it critically for important intellectual content, final approval of the version to be

published, accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Thieman Mankin KM, DVM, MS, DACVS-SA: Substantial contributions to study conception and design and the acquisition, analysis, and interpretation of data for the work, drafting the work and revising it critically for important intellectual content, final approval of the version to be published, accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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