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ORIGINAL ARTICLE

Effects of left vagus nerve retraction on post-operative unilateral left-sided laryngeal paralysis following surgical closure of patent ductus arteriosus in dogs

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Objectives: This study was aimed at determining the incidence of left-sided laryngeal paralysis in dogs that underwent patent ductus arteriosus open surgical ligation and at identifying whether left vagus nerve retraction during surgery might be a risk factor for post-operative left-sided laryngeal paralysis development.

Materials and Methods: Medical records for dogs referred to our clinic for surgical patent ductus arteriosus closure between July 2012 and May 2022 were reviewed. The inclusion criteria were echocardiographic diagnosis of left-to-right shunting patent ductus arteriosus, standard surgical ligation of the patent ductus arteriosus, short-term follow-up at 30 days and long-term follow-up for at least 365 days.

Results: Of the 40 dogs included, left vagus nerve retraction was performed during surgical dissection in 25 dogs. All dogs survived the surgery, with full closure of the patent ductus arteriosus in 100% of cases. The overall incidence of post-operative left-sided laryngeal paralysis was 12.5%. Heavier weight was significantly associated with a greater risk of left-sided laryngeal paralysis after surgery (odds ratio = 1.19; P = 0.044). Left vagus nerve retraction during surgery was not significantly associated with left-sided laryngeal paralysis risk (P = 0.996). No dogs required arytenoid lateralisation. In long-term follow-up, 37/40 dogs remained alive at an average of 1874 days after surgery.

Clinical Significance: Endoscopic evaluation of laryngeal function after surgical patent ductus arteriosus ligation is recommended when dogs present with inspiratory stridor, vocal changes, exercise intolerance or regurgitation post-operatively.

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INTRODUCTION

The ductus arteriosus is a normal foetal vessel that connects the systemic and pulmonary circulations, specifically the main pulmonary artery to the descending aorta, and moves venous blood away from the collapsed foetal lungs. Physiologically, the ductus arteriosus closes shortly after birth. Mechanisms that lead to the closure of the ductus arteriosus include the combination of pulmonary pressure changes, increased oxygenation, and decreased prostaglandin E2 levels, redirecting blood flow to establish normal blood circulation after birth (Buchanan, 1999; Buchanan & Patterson, 2003; Dice & Bhatia, 2007; Oliveira et al., 2011).

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In approximately 4.7 of 1000 dogs, the ductus arteriosus fails to close postnatally (Jones & Buchanan, 1981). Shortness of the ductus arteriosus and a hypoplastic and poorly contracting ductus muscle mass can contribute to failure of closure (Buchanan, 1978; Buchanan & Patterson, 2003). Patent ductus arteriosus (PDA) represents the most common congenital heart malformation in dogs, accounting for 25% to 30% of congenital malformations (Buchanan, 1999; Patterson, 1968). It contributes to the development of pulmonary hypertension and volume overload of left-sided cardiac structures, thus potentially leading to congestive heart failure, with a mortality rate of 64% by 1 year of age (Eyster et al., 1976).

Complete attenuation of the blood flow through the ductus arteriosus *via* surgical ligation or transarterial catheterisation and occlusion is the standard treatment for PDA (Gordon & Miller, 2005; Achen et al., 2008; Goodrich et al., 2007; Gordon et al., 2010). Survival rates of 89% to 95% after surgical ligation of PDA support the curative potential of surgical correction (Birchard et al., 1990; Eyster et al., 1976; Van Israël et al., 2003); however, several complications have been associated with the procedure, including death, haemorrhage, lung laceration and chylothorax, with mortality rates of 0% to 7% (Buchanan, 1994; Bussadori et al., 2001; Goodrich et al., 2007; Hunt et al., 2001).

In dogs and cats, the left recurrent laryngeal nerve originates from the left vagus nerve (LVN), circumvents the aortic arch caudal to the ligamentum arteriosum, ascends towards the larynx and terminates as the left caudal laryngeal nerve, which innervates the muscles that abduct the left arytenoid cartilage during inspiration. The proximity of the LVN and its recurrent laryngeal branch to the ductus arteriosus makes it vulnerable to iatrogenic damage during the surgical procedure (Adamovich-Rippe et al., 2013). In human patients, a possible adverse result of such injury in children is left vocal cord paralysis, which is a considerable adverse effect of PDA closure that has been associated with low weight at the time of surgery (Clement et al., 2008; Engeseth et al., 2018; Pereira et al., 2006; Smith et al., 2009). Unilateral left-sided laryngeal paralysis (LLP) following surgical PDA closure has been described in cats in two studies (Adamovich-Rippe et al., 2013; Hutton et al., 2015). The following databases [Medline (Pubmed), MVH Medical Library, Ovid] have been searched with the following keywords: patent ductus arteriosus, dog and laryngeal paralysis on December 3, 2024; the following textbooks have been consulted (Ettinger et al., 2024; Fossum, 2018; Tobias & Johnston, 2017). No reports other than abstracts (Steffey, 2018; Van Israël, 2021) have been found doing these searches.

Veterinary and human patients with LLP can develop airway problems, aspiration pneumonia, exercise intolerance, feeding and swallowing difficulties and/or vocal changes (Dedo et al., 1979; Zbar et al., 1996).

The objective of our study was to determine the incidence of post-operative LLP in dogs that underwent open PDA surgical ligation, as well as to identify any associated preoperative risk factors. We also sought to investigate whether retraction of the LVN during surgery might affect the development of post-operative LLP. We hypothesised that LVN retraction would be a risk factor for the development of post-operative LLP.

MATERIALS AND METHODS

Inclusion criteria

Medical records for dogs referred to our clinic for surgical PDA closure between July 2012 and May 2022 were reviewed. The data were collected by a single operator on the clinical software using keywords. Dogs were included in the study if they had a diagnosis of left-to-right shunting PDA confirmed by an echocardiographic examination performed by a diplomate of the European College of Veterinary Internal Medicine, cardiology subspecialty.

Dogs with additional cardiac congenital anomalies with haemodynamic significance and dogs that had incomplete medical records or were lost at follow-up were excluded from the study. Procedural success was defined as patient survival with complete PDA closure confirmed by colour-flow Doppler echocardiography at 30 days after surgery.

Data collection included the following:

- Signalment (age, breed, sex and body weight), history (duration of the condition and previous medical treatments), clinical signs, and physical examination findings
- Preoperative echocardiographic data and continuous electrocardiographic recording
- Surgical procedure technique
- Occurrence of major, potentially life-threatening (*e.g.* severe haemorrhage, respiratory or cardiac arrest and left recurrent laryngeal nerve injury) and minor, non-life-threatening (*e.g.* transient post-operative systemic hypertension, seroma formation and left thoracic limb lameness) complications
- Post-operative echocardiographic findings 30 days after surgery (shunt closure and residual shunting, systolic function and cardiac remodelling)
- Long-term follow-up information was gathered through medical records and/or telephone interviews with owners using a questionnaire. The questionnaire addressed the cause of death (cardiac disease or other), the necessity of lifelong post-operative cardiac treatment and the owners' satisfaction with the dog's quality of life.

Diagnostic techniques

Transthoracic two-dimensional, M-mode, spectral and colour-flow Doppler echocardiography was performed (General Electric Vivid S5 and Vivid E95 with a range of 2.5 to 10 MHz phase-array and matrix probes) with continuous electrocardiogram recording. All echocardiographic examinations were performed by the same board-certified veterinary cardiologist. Dogs were unsedated and gently restrained in right and left lateral recumbency.

All echocardiographic studies were performed in accordance with recommendations for standardised transthoracic imaging planes (Thomas et al., 1993), and Doppler echocardiographic views were oriented to obtain optimal alignment with blood flow (Darke et al., 1993). Systolic function was subjectively assessed according to ejection fraction and fractional shortening. Left atrial and ventricular dilatation (none, mild, moderate or severe) was recorded, and the presence and severity of mitral valve regurgitation were subjectively scored. Ductal flow timing, velocity and shape were recorded in all dogs. Any concurrent cardiac congenital defects, pulmonary hypertension and/or left-sided congestive heart failure (CHF) were also documented.

The recorded electrocardiographic data included heart rate and rhythm. Preoperative administration of cardiac medications such as diuretics (*e.g.* furosemide), angiotensin-converting enzyme inhibitors (*e.g.* benazepril) and inodilators (*e.g.* pimobendan) was also recorded.

Surgical treatment

All surgical procedures were performed by a European College of Veterinary Surgeons (ECVS) diplomate. A standardised general anaesthetic protocol was used for all patients, including premedication with midazolam (0.1 mg/kg intravenously iv) and fentanyl (2.5 µg/kg iv), induction with propofol (1 to 4 mg/kg iv) or alfaxalone (1 to 3 mg/kg iv to effect) and maintenance with a constant rate infusion of fentanyl (5 µg/kg/hour) and isoflurane inhalant. Intercostal nerve blocks were performed by infiltration of bupivacaine (2 mg/kg) from the third to the sixth intercostal space. Cephazolin (20 mg/kg iv) was administered preoperatively and repeated every 90 minutes during surgery.

Dogs were positioned in right lateral recumbency. The surgical approach involved a left fourth intercostal thoracotomy with an extrapericardial dissection. The standard surgical technique was used, consisting of isolation of the PDA by blunt dissection, without opening of the pericardium, and passage of right-angle forceps behind the ductus in a caudal-to-cranial direction (Fig 1). In the first 25 dogs, the LVN was isolated and retracted using a nylon monofilament (USP 3-0) suture placed around the nerve to gently retract it ventrally (Fig 2), whereas no LVN retraction was performed in the final 15 dogs. After the passage was created around the PDA, a ligature loop was passed from a caudal to cranial direction medial to the PDA. The loop was divided to form two individual strands that were slowly tied around the ductus (Fig 3), beginning with the suture closest to the aorta. The PDA was fully attenuated over 2 minutes whilst monitoring for reflex bradycardia (Branham reflex) (Madruga et al., 2021; Wattanasirichaigoon & Pomposelli, 1997). In all dogs, ligations were performed with silk sutures (USP 2-0, 0 or 1). The thoracotomy was routinely closed. Negative intrapleural pressure was restored by needle thoracocentesis after closure of the muscle layer. Thoracostomy drains were not placed in any cases.

Immediate post-operative thoracic radiographs were taken in all dogs to assess for persistence of iatrogenic pneumothorax and/or pleural effusion. Additional thoracocentesis was performed, if necessary. Post-operative analgesia consisted of methadone (0.2 mg/kg iv, every 4 hours) or fentanyl (constant rate infusion, 2 to 5 µg/kg/hour) (dose and duration were adapted according to the Glasgow pain score), in combination with meloxicam (0.1 mg/kg) once daily, orally, for 3 to 5 days. In some cases, diuretic treatment with furosemide (2 mg/kg iv) was administered twice daily during the first 24 to 48 hours of hospitalisation. In patients where the cardiac treatment with pimobendan was advised preoperatively by the cardiologist, the treatment continued at the recommended dosage until the first cardiological check-up 30 days post-operatively. Post-operative antibiotic therapy was continued with cephalexin (15 to 20 mg/kg) twice daily, orally, for 7 days.

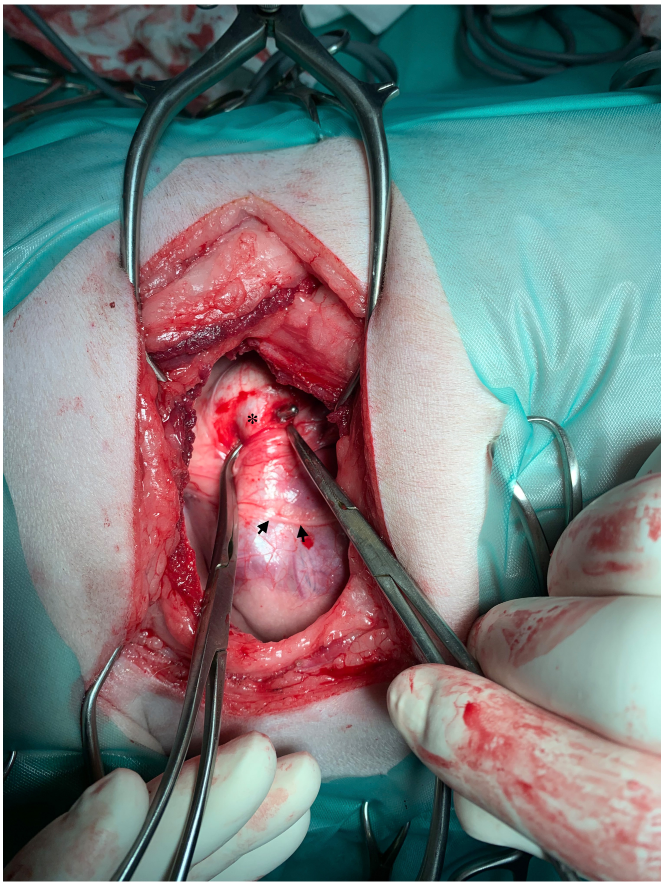

FIG 1. Photographs showing the intraoperative appearance of the left heart base. Pericardial reflection and individualisation of the PDA (*) by a Satinsky Debakey vascular clamp passed from the cranial to the caudal direction. Visualisation of the phrenic nerve (black arrows). PDA Patent ductus arteriosus.

Follow-up and complications

In six out of 40 dogs (15%), possible iatrogenic damage to the left recurrent laryngeal nerve was suspected 30 days after surgery because of the development of clinical signs suggesting laryngeal paralysis. Five of six dogs underwent endoscopic examination of the respiratory tract under general anaesthesia. Endoscopic procedures were performed with a videoendoscope (Olympus bronchoscope 5.5 mm). Dogs were premedicated with an intramuscular injection of acetylpromazine (0.03 to 0.04 mg/kg) and butorphanol (0.3 mg/kg); anaesthesia was induced with propofol (1 to 6 mg/kg, iv) and maintained with propofol boluses as required. Doxapram (0.2 to 2 mg/kg, iv) was administered in

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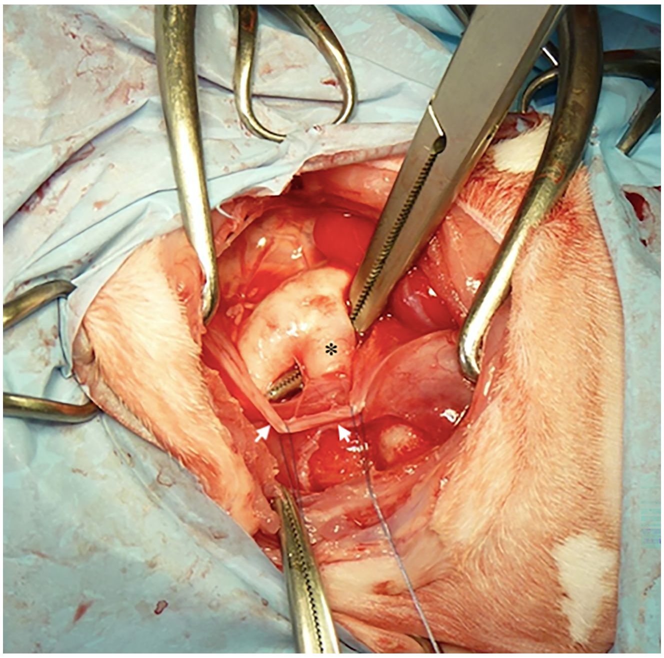

FIG 2. Photographs showing the intraoperative appearance of the PDA. The left vagus nerve (white arrows) is retracted ventrally by two monofilament non-absorbable sutures. The PDA (*) is gently dissected with a pair of right-angle forceps. PDA Patent ductus arteriosus.

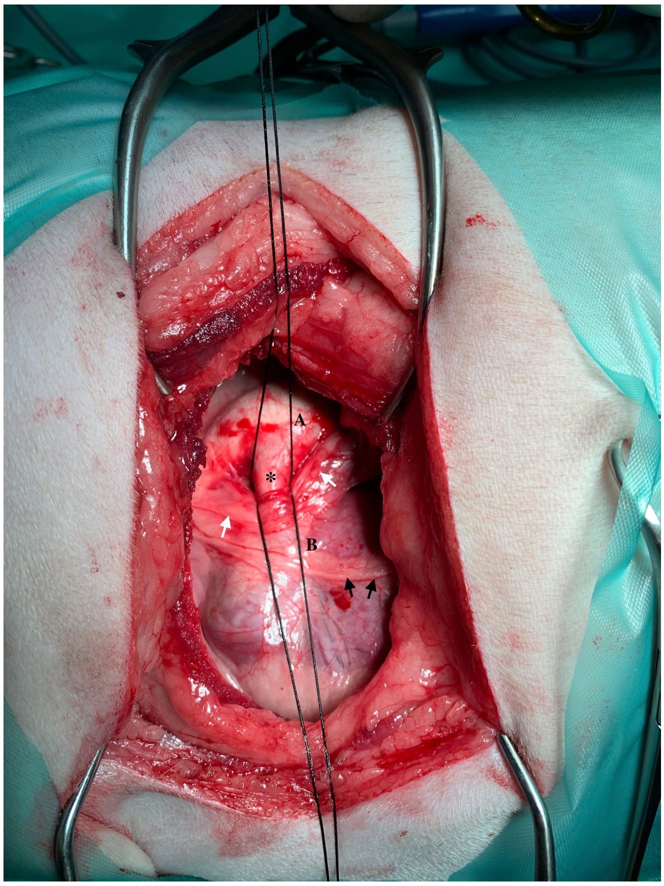

FIG 3. Photographs showing the intraoperative appearance of the left heart base. The PDA is denoted by an asterisk (*), the vagus nerve by a white arrow and the phrenic nerve by black arrows. (A) and (B) represent the two silk sutures positioned dorsally and ventrally around the PDA. PDA Patent ductus arteriosus.

two dogs to stimulate laryngeal function during the endoscopic examination.

Diagnosis of LLP was confirmed by direct laryngoscopy; additional blood tests to evaluate thyroid function and acetylcholine receptor antibodies were performed to exclude other potential causes responsible for laryngeal paralysis.

Statistical analysis

Statistical analysis was performed in R 4.3.0. Shapiro–Wilk tests were conducted to assess whether numeric variables were normally distributed. Age and weight were compared between groups with Wilcoxon rank sum tests. The effect of the surgical method on laryngeal paralysis risk was tested with a logistic regression model. Possible contributing factors (age, sex, weight and preoperative CHF) were tested in univariate regressions and added to the full model if a trend ($P<0.2$) was identified. Non-significant variables and interactions were then removed stepwise to yield the final model.

RESULTS

Signalment and clinical findings

Of the 62 dogs that underwent surgical treatment of a PDA between July 2012 and May 2022 in our clinic, 40 met the inclusion criteria. The breeds most commonly represented were Keeshond ($n=5$), Chihuahua ($n=4$), Welsh Corgi Pembroke ($n=4$), Border Collie ($n=4$) and Maltese ($n=3$). Twenty-four dogs (60%) were female and 16 (40%) were male. The median age of dogs that underwent surgery with LVN retraction was 5 (2 to 29) months, and their median weight was 5.6 (1.6 to 57.7) kg, while for dogs in which a retraction of LVN was not performed, the median age was 4 (2 to 19) months and median weight was 2.6 (0.7 to 30) kg.

Fourteen dogs (35%) were asymptomatic at presentation and were referred to a specialty centre for echocardiographic evaluation of heart murmurs identified by the referring primary care veterinarian during clinical examinations for unrelated reasons. Twenty-six (65%) dogs were clinically affected with signs, including exercise intolerance ($n=8$, 31%), cough ($n=7$, 28%), retarded growth ($n=4$, 15%), polyuria–polydipsia ($n=2$, 8%) and auricular myoclonus ($n=1$, 4%).

During physical examination, expiratory dyspnoea ($n=3$, 7.5%) and harsh lung sounds on auscultation ($n=1$, 2%) were reported. A basilar continuous heart murmur was detected in all 40 dogs, and the murmurs were classified as grade 6/6 in five cases (12.5%), grade 5/6 in 12 cases (30%), grade 4/6 in 22 cases (55%) and grade 3/6 in only one case (2.5%).

Diagnostic findings

A definitive diagnosis of left-to-right shunting PDA was made in all 40 dogs *via* Doppler echocardiography at a mean of 10 days

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Video 1. Laryngeal endoscopic video showing unilateral LLP. LLP Left-sided laryngeal paralysis.

(0 to 49 days) prior to surgery. Left atrial and/or ventricular dilatation was detected in all dogs and was defined as mild in seven dogs (18%), moderate in 16 dogs (40%) and severe in 17 dogs (42%). Dilation of the right side of the heart was not observed in any cases. Mitral valve regurgitation was absent in five dogs (12%), mild in 16 dogs (40%), moderate in 15 dogs (38%) and severe in four dogs (10%). Systolic function was diminished in nine dogs (22%), five dogs (12%) had mild pulmonary hypertension and 17 dogs (42%) had a diagnosis of left-sided CHF. One case (2.5%) had changes compatible with mitral valve endocarditis (thrombus of 5 to 6 mm on the atrial side of the parietal mitral valve causing a mild inflow obstruction).

Electrocardiographic results were available in all 40 cases (100%). Abnormalities on electrocardiography were detected in three dogs (7.5%), including ventricular extrasystoles, supraventricular extrasystoles and atrial fibrillation.

Twenty-eight (70%) of the 40 dogs received cardiac medications prior to surgery: nine dogs (32%) received furosemide alone (1 to 3 mg/kg, PO, q 24 h, q 12 h or q 8 h); ten dogs (36%) received pimobendan alone (0.2 to 0.36 mg/kg, PO, q 12 h); five dogs (18%) received a combination of furosemide and pimobendan; one dog (4%) received benazepril hydrochloride (0.17 mg/kg, PO, q 12 h) and pimobendan (0.17 mg/kg, PO, q 12 h); and three dogs (11%) received furosemide (1 to 3 mg/kg, PO, q 12 h) in combination with a broad spectrum antibiotic (amoxicillin–clavulanic acid, cephalosporin or metronidazole) due to concomitant pathologies not associated with the PDA.

Surgical treatment and complications

Twenty-five dogs (62%) undergoing surgery between July 2012 and December 2019 had LVN retraction during surgical dissection of the PDA, whereas the LVN was not retracted in 15 dogs (38%) operated from January 2020 to May 2022. The groups had similar sex and age, whereas the median weight was significantly lower in dogs in which LVN retraction was not performed (P = 0.042).

All surgical procedures were performed by the same ECVS diplomate, who successfully closed all PDAs. The surgical procedure was consistent with a standard surgical ligation with an open approach *via* left thoracotomy at the fourth intercostal space (Monnet & Tobias, 2017).

No intraoperative complications were recorded. All dogs survived the surgery and were discharged from the hospital at a mean of 3.5 (1 to 5) days after surgery. In the immediate post-operative period, in two dogs (5%) a grade 2/6 systolic apical murmur was audible; one of these dogs was diagnosed with mitral endocarditis preoperatively. One dog (2.5%) had persistent atrial fibrillation post-operatively, and two dogs (5%) had persistent pulmonary oedema. One dog (2.5%) had systolic arterial hypertension (190 to 200 mmHg) in the first 24 h after surgery, and treatment was initiated with intravenous pimobendan (0.2 mg/kg, q 12 h) in combination with benazepril hydrochloride/spironolactone (0.25/2 mg/kg, PO, q 24 h) and amlodipine (0.5 mg/kg, PO, q 12 h). The dog was stabilised and was discharged 4 days after surgery.

Outcomes

Follow-up information from clinical examination and echocardiography was obtained for all dogs by the same cardiologist 30 days after surgery. All the owners were very satisfied with their dog's quality of life after surgery.

The PDA was closed in 39 dogs (98%). One dog had minimal residual shunting, but the PDA was completely closed by 60 days post-operatively. Cardiac remodelling was considered satisfactory in 29 dogs (73%). Diminished contractility persisted in four dogs (10%).

At 30 days' follow-up, clinical signs consistent with LLP were reported in six dogs (15%), including at least one of the following: voice anomalies (n = 4), exercise intolerance (n = 4), regurgitation (n = 3) and difficulties in swallowing water (n = 1). Laryngeal auscultation revealed increased laryngeal sounds in all dogs. No stridor had been observed at rest but was induced by exercise in all dogs. In all six dogs, LVN retraction was performed during surgery. Thoracic radiograph findings were within normal limits for all dogs.

Five of six dogs (83%) underwent further investigation by respiratory endoscopy under general anaesthesia, with two dogs requiring a doxapram challenge to confirm the diagnosis. In all five dogs, unilateral LLP was confirmed (Video 1). Other endoscopic anomalies included bronchitis (n = 1), grade 1 tracheal collapse (n = 1) and mild right-sided bronchoconstriction (n = 1). Bronchoalveolar lavage (BAL) with aerobic–anaerobic culture and mycoplasma PCR detection was performed on the dog exhibiting macroscopic signs of bronchitis. The BAL results were within normal limits, and the PCR test was negative. Blood tests assessing thyroid function (total T4) were conducted for all dogs, yielding values within the physiological range. Additionally, acetylcholine receptor antibodies were measured in three dogs (50%) and found to be within normal limits.

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Long-term follow-up *via* telephone interviews of the owners was obtained for all dogs at least 365 days after surgery, with a mean follow-up time of 1931 (365 to 4130) days. Of them, 19 dogs (47%) had a long-term clinical and echocardiographic follow-up with the same board-certified cardiologist, with a mean follow-up time of 1012 (91 to 3216) days. Thirty-seven dogs (92%) were still alive at the time of manuscript preparation (mean follow-up time of 1874 days; range 365 to 4130 days). Two dogs (5%) died for reasons unrelated to cardiac disease at 2192 and 3216 days after surgery. One dog (2.5%) died due to progression of cardiac disease at 2508 days after surgery.

Details of the LLP cases

The dogs with an endoscopic diagnosis of post-operative LLP included two Border Collies, one Newfoundland, one Australian Shepherd, and one Akita Inu. Two were female and three were male. The mean age was 12 months (2 to 29), and the mean body weight was 24.2 kg (5 to 57.7 kg). The five dogs continued their follow-up in the long term, with a mean follow-up time of 1755 days (180–3216 days). Three dogs remained alive at the time of manuscript preparation (mean telephone follow-up time of 2717 days; range 2269 to 3158 days). One dog was euthanased 2505 days post-operatively because of protein-losing nephropathy, and another dog was euthanased at 3216 days because of mandibular osteosarcoma. No dogs developed aspiration pneumonia. Moreover, no dogs required surgical management of the laryngeal paralysis, as they had good quality of life with conservative management (harness use and exercise restriction during warm weather).

In the population studied here, greater body weight was significantly associated with an elevated risk of unilateral LLP after surgery (odds ratio = 1.19; $P = 0.044$). LVN retraction during surgery was not significantly associated with the risk of LLP post-operatively ($P = 0.996$). Age, sex and preoperative CHF were not significantly associated with LLP risk or selected for the final model (all univariate $P < 0.2$).

DISCUSSION

Left-sided vocal cord paralysis (LVCP) is a well-recognised complication of PDA closure in premature infants, with an overall incidence as high as 11.5% (Davis et al., 1988; Pereira et al., 2006; Russell et al., 1998); therefore, surgical techniques in human medicine are continually being refined to avoid this condition (Pereira et al., 2006). In feline patients undergoing open surgical ligation of the PDA, LLP is a documented complication (Hutton et al., 2015), which is analogous to left vocal fold paralysis in human patients.

We designed this study to evaluate the possible development of unilateral LLP after LVN retraction during surgical procedures in dogs. Based on the literature search, this is the first study focused on identifying LLP incidence following PDA ligation in dogs. In this retrospective study, 25 dogs underwent surgical ligation with LVN retraction and 15 dogs did not receive LVN retraction. The percentage of females (60%) was similar to that in other reports (67% to 78%) (Bellenger et al., 1996; Bureau et al., 2005; Hunt et al., 2001; Stanley et al., 2003); the median age (7.5 months) and median weight (8.1 kg) were also comparable to those in other reports (4 to 13 months, 4.1 to 10 kg) (Bellenger et al., 1996; Bureau et al., 2005; Hunt et al., 2001; Stanley et al., 2003). Complete surgical ligation of the PDA was achieved in 100% of cases in this study, similar to other studies (95% to 98%: Bellenger et al., 1996; Hunt et al., 2001; Van Israël et al., 2002).

The most common complication and cause of death in dogs undergoing surgical ligation of PDA is haemorrhage from the ductus, with a reported incidence of 0% to 10.8% (Hogan et al., 2004; McNamara et al., 2023; Saunders et al., 2004; Van Israël et al., 2002) and a fatality rate of 2% to 79% (Birchard et al., 1990; McNamara et al., 2023). The mortality rate was 0% in this study, which is in line with rates in other reports. Other previously reported major complications include inadvertent damage to the left cranial lung lobe during thoracotomy, respiratory insufficiency requiring ventilatory support, mesenteric torsion and chylothorax (Birchard et al., 1990; Goodrich et al., 2007), none of which occurred in our study.

Left thoracic limb lameness, suture reaction, seroma formation, atrial or ventricular fibrillation and transient haemoptysis have been reported as minor complications in previous studies (Birchard et al., 1990, Goodrich et al., 2007). Wound complications were not evaluated in our study because the first follow-up at 15 days after surgery was conducted by the referring veterinarian for all dogs, and information regarding wound infection and/or seroma was lacking. Two dogs (5%) had left thoracic limb lameness and one dog (2%) had atrial fibrillation in our study; other minor complications described in prior reports were not identified in our population.

In our study, five dogs (12.5%) developed post-operative LLP. 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 described in 1% of dogs in one report of 98 cases (Van Israël et al., 2002) and has also been described in two abstracts (Steffey, 2018; Van Israël, 2021); additionally, this complication has also been described in 11% of cats in a report of 28 cases (Hutton et al., 2015). In a study of 86 neonatal human patients, iatrogenic laryngeal paralysis after PDA ligation was diagnosed in 16% (Smith et al., 2009).

Contrary to our hypothesis, we found no significant difference in the incidence of post-operative LLP regardless of whether LVN retraction was performed during surgery ($P = 0.996$). However, a randomised controlled study is necessary to compare complication rates for these two methods.

LLP has been suggested to be more likely to occur in feline patients, which often have smaller body size at the time of attenuation and have a more limited surgical field (Hutton et al., 2015). This finding is concordant with the human medicine literature indicating that extremely low birth weight (<1000 g) is a risk factor for iatrogenic LVCP secondary to PDA ligation, with an incidence as high as 40% to 76% (Clement et al., 2008; Malcolm et al., 2008). In our study, this tendency was not observed, and greater weight of the dogs was significantly associated with a higher risk of post-operative LLP (odds ratio = 1.19; $P = 0.044$).

We believe that heavier dogs necessitate better surgical exposure, requiring a wider surgical dissection because of the diameter of the PDA; therefore, a longer duration of retraction could potentially lead to axonotmesis or neurotmesis of LVN, responsible for the LLP. Although LVN retraction did not appear to affect post-operative LLP risk, the limited number of dogs in this study might have been insufficient to detect a subtle to moderate effect of the surgical technique on this complication.

No dogs affected by LLP in our study were breeds predisposed to congenital autosomal recessive or hereditary laryngeal paralysis (Monnet & Tobias, 2017; Ridyard et al., 2000; van Venker-Haagen et al., 1981). Although Newfoundlands are known to be predisposed to acquired laryngeal paralysis (MacPhail, 2020; Stanley et al., 2010), the Newfoundland in this study that developed LLP was iatrogenic due to the acute post-operative onset of clinical signs and the absence of preoperative signs in this patient; moreover, no other signs of progressive neuropathy were reported during long-term follow-up.

A report in human medicine has suggested that preterm infants, particularly those with a gestational age of less than 28 weeks, are more likely to develop permanent LVCP (Truong et al., 2007). In small veterinary patients, surgical ligation of PDA is generally performed at the age of 8 weeks and preferably before 16 weeks (Goodrich et al., 2007). In this study, surgery was performed at a median of 7.5 weeks, but age was not significantly associated with post-operative LLP risk.

The incidence of unilateral LLP in this study was higher than previously reported after surgical PDA closure in dogs but was in line with the incidence of the same condition in other species. This finding may be due to the 30-day post-operative clinical follow-up performed by a board-certified cardiologist who had previously described this surgical complication in an earlier abstract (Van Israël, 2021) and was therefore more aware of the issue, which may have contributed to improved detection rates.

Clinical signs of LVCP in infants include stridor, weak cry and aspiration (De Jong et al., 2000; Pereira et al., 2006; Zbar et al., 1996); however, as many as 14% of infants are asymptomatic when LVCP is diagnosed (Smith et al., 2009). Dogs with unilateral laryngeal paralysis (mostly left sided) tend to display clinical signs only during strenuous activities (*i.e.* working dogs) (Monnet & Tobias, 2017). Failure to abduct the arytenoid cartilage during inspiration increases the resistance to airflow, and turbulence through the rima glottidis leads to typical inspiratory stridor (Stanley et al., 2010; van Venker-Haagen et al., 1981). Dysphonia is caused by an inability to tense the vocal cords; consequently, the dog's voice changes to a weak, hoarse bark (Parnell, 2010). Partial obstruction of the upper airways by the paralysed arytenoids leads to exercise intolerance (Burbidge, 1995; Parnell, 2010). Severe airway obstruction may result in respiratory distress, cyanosis and collapse. Dogs may also show dysphagia (MacPhail, 2020). In our study, the clinical signs observed 30 days post-closure included voice changes, exercise intolerance and regurgitation, but no inspiratory distress or stridor was detected at rest.

At the time of LLP diagnosis, the clinical signs of laryngeal dysfunction were not considered to be sufficiently severe to warrant surgical intervention. Dogs are not often severely clinically affected until they have bilateral laryngeal paresis or paralysis; therefore, dogs with unilateral laryngeal dysfunction are typically not considered surgical candidates (MacPhail, 2020). In all patients, the left arytenoid cartilage remained paralysed throughout the long-term follow-up, suggesting that the lesions were irreversible. Nonetheless, the laryngeal paralysis did not progress and remained unilateral during the follow-up period. The owners did not observe any worsening of clinical signs and/or respiratory distress during long-term follow-up. If surgical correction were necessary, the prognosis would have been considered good, given the traumatic aetiology of the lesion (Kitshoff et al., 2013), in contrast to acquired laryngeal paralysis as a part of a general peripheral neuropathy.

This study has several limitations, mainly its retrospective design. Secondly, this study was non-randomised, and different treatment effects might have been obtained from a randomised controlled trial. Moreover, the study groups were small, and a potential risk of type I error existed in the statistical analysis. The lack of preoperative assessment of laryngeal function might have altered the post-operative incidence rates of LLP, given that other potential idiopathic or neurological causes of LLP have been reported in dogs (Kitshoff et al., 2013; MacPhail, 2020), although no preoperative abnormalities in arytenoid motion were noted at anaesthetic induction in any patient. Finally, the identification of this complication was contingent on the development of symptoms in the post-operative period, and only symptomatic patients were evaluated.

In conclusion, unilateral LLP is a potential complication after PDA surgical ligation. Despite the lack of significant differences observed in this specific patient cohort, we suggest performing careful LVN retraction, particularly in heavier dogs, to avoid potential LLP development. Post-operative assessment of laryngeal mobility is recommended for any patient with voice anomalies, altered respiratory function or regurgitation with a history of PDA attenuation.

Author contributions

S. Manzoni: Conceptualization (lead); data curation (lead); investigation (lead); project administration (lead); supervision (equal); validation (equal); visualization (equal); writing – original draft (lead); writing – review and editing (lead). **N. Van Israël:** Conceptualization (lead); data curation (supporting); investigation (supporting); project administration (lead); resources (equal); supervision (supporting); validation (lead); visualization (lead); writing – original draft (supporting); writing – review and editing (supporting). **M. Santos:** Data curation (supporting); formal analysis (supporting); supervision (equal); validation (equal); visualization (equal); writing – original draft (equal). **A. Bongartz:** Conceptualization (supporting); data curation (supporting); project administration (supporting); supervision (supporting); validation (supporting); visualization (supporting); writing – review and editing (lead).

Conflict of interest

No conflicts of interest are declared by the authors.

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Data availability statement

The datasets generated and/or analyzed during the current study are available from the corresponding author upon request. All relevant data supporting the findings of this study are included within the article.

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