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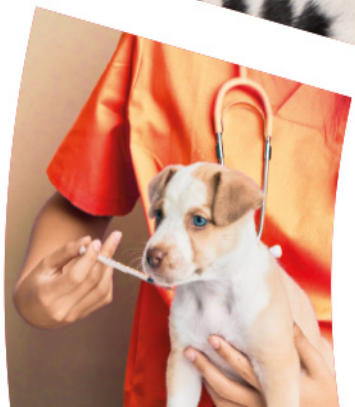

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ORIGINAL ARTICLE

Clinical findings, surgical treatment and long-term outcome of dogs and cats with double aortic arch: four cases (2005–2022)

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Objective: To describe the clinical presentation, diagnostic findings, treatment and long-term outcome following surgery of dogs and cats undergoing surgical treatment for a double aortic arch.

Materials and Methods: Medical records of dogs and cats diagnosed with a double aortic arch between 2005 and 2022 at three small animal referral hospitals were retrospectively reviewed. Long-term outcome was assessed by a clinical examination and/or by contacting the owners or referring veterinarians.

Results: Two dogs and two cats were included. Regurgitation after eating, stunted growth and poor weight gain were the predominant clinical features. All animals had thoracic radiography and oesophagography; a dilation of the cranial thoracic oesophagus cranial to the heart base, was described in all animals. CT angiography confirmed double aortic arch in three of these and the right aortic arch was larger and appeared more well developed compared with the left aortic arch in all based on CT or surgical findings. Surgery was performed via a left fourth intercostal thoracotomy; ligation and transection of the lesser left aortic arch was performed. Follow-up time ranged from 360 to 1563 days. All animals showed a marked improvement during the postoperative period, and all gained weight gradually. Owners' perception of the surgical procedure outcome and quality of life was described as excellent for all animals.

Clinical Significance: Surgical ligation of the lesser aortic arch in dogs and cats with double aortic arch is associated with a favourable prognosis for recovery, resolution of clinical signs, and quality of life with only minor feeding modifications.

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INTRODUCTION

Vascular ring anomalies (VRA) are developmental anomalies of the embryonic aortic arches that encircle and displace both the oesophagus and trachea, by the formation of a complete or partial ring (Vianna & Krahwinkel 2004, Backer *et al.* 2005, Du Plessis *et al.* 2006). Persistent right aortic arch (PRAA) with patent left ductus arteriosus (PDA) or ligamentum arteriosum are two of the most common vascular anomalies of the thoracic aorta in small animals (Buchanan 1968, 2004, Patterson 1968, Ellison 1980, Van Gundy 1989, Henjes *et al.* 2011). Double aortic arch (DAA) is the most common vascular ring anomaly seen in

humans, representing over 50% of complete vascular ring correctional surgery patients (Bonnard *et al.* 2003, Backer *et al.* 2005), but it is rare in small animals with only 12 reports in the veterinary literature so far (Van de Linde-Sipman *et al.* 1973, Aultman *et al.* 1980, Martin *et al.* 1983, Findji & Degueurce, 1999, Yarim *et al.* 1999, Ferrigno *et al.* 2001, Vianna & Krahwinkel 2004, Du Plessis *et al.* 2006, Moonan *et al.* 2007, Skrzypczak *et al.* 2017, Follette *et al.* 2019, Sekhar *et al.* 2021).

In normal embryological development, the right fourth aortic arch regresses, and the left fourth aortic arch with its ligamentum arteriosum, derived from the left sixth aortic arch, persists (Du Plessis *et al.* 2006, Morgan & Bray 2019). Double aortic arch results from the persistence of both left and right fourth aortic arches, resulting in entrapment of the oesophagus and trachea (Martin *et al.* 1983, Van Gundy 1989, Ferrigno *et al.* 2001, Du Plessis *et al.* 2006, Follette *et al.* 2019). Double aortic arch represents a complete vascular ring that is formed laterally by both the right and left aortic arches; ventrally by the heart or the common trunk of the two arches, and dorsally by the "fused" descending aorta (Moonan *et al.* 2007).

According to the Ellison classification of aortic arch anomalies, DAA is classified as type 4 VRA (Ellison 1980, Backer *et al.* 2005, Joly *et al.* 2008, Sekhar *et al.* 2021), and is categorised either as right arch dominant with a small or atretic left arch (Ellison 1980, Martin *et al.* 1983, Yarim *et al.* 1999, Ferrigno *et al.* 2001, Buchanan 2004, Moonan *et al.* 2007, Sekhar *et al.* 2021); a left arch dominant with a smaller or atretic right arch (Lawson *et al.* 1957, Vianna & Krahwinkel 2004, Follette *et al.* 2019); or symmetrical (or balanced) arches (Findji & Degueurce, 1999, Du Plessis *et al.* 2006, Skrzypczak *et al.* 2017).

Clinical signs in dogs and cats with VRA, including DAA, are usually seen at the time of weaning with regurgitation being the most frequent sign, secondary to oesophageal narrowing at the heart base and secondary dilation of the oesophagus cranial to the constriction (Yarim *et al.* 1999, Vianna & Krahwinkel 2004). Respiratory signs such as stridor, wheezing, cough and cyanosis may be seen in addition to regurgitation, secondary to either entrapment and constriction of the trachea by the two vessels or aspiration pneumonia (Ellison, 1980, Martin *et al.* 1983).

Comparatively, in human medicine, the most common symptoms with DAA are respiratory (70% to 95%) before 1 month of age, including stridor (57%) recurrent upper respiratory tract infection (27%) and cough (21%); rather than upper gastrointestinal signs (5% to 50%) with dysphagia reported only in 15% of the cases (Backer *et al.* 2005, Humphrey *et al.* 2006, Suh *et al.* 2012).

A presumptive diagnosis of VRA is commonly made on the basis of clinical history, presenting clinical signs, thoracic radiographs and contrast oesophagogram; all of which illustrate oesophageal constriction at the heart base and precardial oesophageal dilation. Persistent right aortic arch may be diagnosed on good quality radiographs (Buchanan 2004), however definitive presurgical confirmation of the vascular ring anatomy is facilitated by CT angiography (CTA), MRI or angiography (Henjes *et al.* 2011).

Non-surgical management is unlikely to provide long-term relief of clinical signs and so surgical intervention is required to resolve the underlying oesophageal obstruction (Morgan & Bray 2019). Early surgical treatment is recommended in the hope that it will minimise the risk of secondary, longstanding compromise to oesophageal function and thus reduce the risk of aspiration pneumonia and chronic oesophageal dysmotility (Vianna & Krahwinkel 2004, Morgan & Bray 2019).

The principle of surgery is to relieve the compression of the oesophagus and/or trachea by transection of the vascular structure or remnant responsible for the constriction, which in the case of DAA requires identification and transection of the "lesser" aortic arch (Moonan *et al.* 2007).

Historically, the prognosis for dogs and cats with DAA was considered poor, however, recent case reports suggested positive outcomes (Vianna & Krahwinkel 2004, Moonan *et al.* 2007, Skrzypczak *et al.* 2017, Follette *et al.* 2019, Sekhar *et al.* 2021). There is currently limited information regarding postsurgical outcomes for these patients. The aim of this study was to describe the clinical presentation, diagnostic findings, treatments and long-term outcomes following surgery of cats and dogs diagnosed with DAA.

MATERIALS AND METHODS

Study design and inclusion criteria

The electronic patient records of the Royal Veterinary College and the authors' personal case logs were searched to identify dogs and cats with a diagnosis of DAA between January 2005 and January 2022. Animals were included if they had a diagnosis of DAA confirmed by diagnostic imaging or at surgery, had a comprehensive medical record and underwent surgical intervention. There was no limit for the follow-up period.

Data extraction

One investigator (MR) independently searched the database of the Royal Veterinary College, using the search engine available in the practice management systems (CRIS™) whereas the other investigators (FC, GC, DB) independently searched their personal surgical case logs or resident case logs at their institutions (from 2005 onwards), searching for the keywords "double aortic arch". The search was conducted between November 2021 and February 2022.

Data retrieved from the medical records included: clinical history, signalment, presenting clinical signs, physical examination findings, preoperative blood test results, preoperative diagnostic imaging findings, surgical and anaesthetic time, surgical treatment, time from surgery to discharge, whether the patient survived to hospital discharge, time and cause of death.

Intraoperative and postoperative complications were recorded and information regarding outcomes, reoccurrence of clinical signs, type of diet and subjective quality of life assessment were obtained via clinical records and telephone interviews with owners. Outcomes were defined according with Krebs *et al.* (2014) and categorised as: excellent (no evidence of regurgitation, no relapse of clinical signs and no dietary modification required),

good (continued modification or restriction of food type required, continued regurgitation with a frequency of <1/week), or poor (continue or recurrence regurgitation daily to weekly regardless of diet; death or euthanasia as a direct result of the DAA or as result of surgical complications).

Literature review

To describe the prognosis for dogs and cats with this condition, an online scoping literature search was performed until February 19, 2022 using Medline (Pubmed; http://www.pubmed.gov/), ScienceDirect (https://www.sciencedirect.com) and Google Scholar (https://scholar.google.com) databases with the following keywords: "double aortic arch". All the reports describing DAA in dogs and cats were included. No restrictions on language, publications status or publications year were applied.

RESULTS

Case presentation

Two dogs and two cats met the inclusion criteria (Table 1). The first clinical signs of disease were reported after weaning (at approximately 8 weeks of age) in all animals. Regurgitation after eating was the main clinical sign along with failure to grow and/or gain weight although all animals were reported to have an adequate appetite. All the clinical signs are reported in Table 1. Physical examination was considered unremarkable in all the animals. Complete blood count and serum biochemistry were performed in three animals and mild anaemia was confirmed in case 1, but results in cases 2 and 3 were unremarkable.

Whilst all animals had thoracic radiographs and oesophagography, only three cases had CTA. Thoracic radiography and oesophagography revealed a dilated cranial thoracic oesophagus, which terminated at the level of the heart base (Fig. 1). CTA showed the ascending aorta from the heart base split into two divisions encircling the trachea and oesophagus causing narrowing of the oesophageal lumen (Fig. 2). Again, the cranial thoracic oesophagus was markedly dilated but appeared normal caudal to the descending aorta, in all animals. Narrowing of the tracheal lumen was described in one cat (case 3), but the trachea was considered to be unaffected by the DAA in the other two animals. In all three animals that underwent CTA, the right aortic arch (RAA) was larger and appeared more well developed compared with the left aortic arch (LAA). Echocardiography was performed in both dogs and did not show any abnormalities.

Surgery was performed via a left fourth intercostal thoracotomy. Surgical time ranged from 65 to 80 minutes and anaesthetic time ranged from 120 to 180 minutes.

The surgical technique was similar for all animals: the left aortic arch was isolated, with a tourniquet placed around it. The left aortic arch (intended for division) was temporarily occluded to ensure that blood pressure and heart rate were unaffected. In case 3, systolic arterial blood pressure was measured from both the thoracic and pelvic limbs during left aortic arch occlusion; and only a small change was recorded. Non-invasive, systolic oscillometric blood pressure was 90 mmHg on both limbs; after temporary occlusion remained at 90 mmHg on the thoracic limb and increased to 98 mmHg on the pelvic limb. The "lesser" left aortic arch was divided between two ligatures at each end (Fig. 3). The ligatures consisted of a combination of encircling sutures and transfixed suture and a combination of silk, nylon or polypropylene. Further dissection to the level of the oesophagus was performed to ensure that no obvious fibrous bands were causing constriction. In both cats (cases 3 and 4), the left ligamentum arteriosum was also ligated and transected. In cases 3 and 4, orogastric intubation was performed to confirm the release of the oesophagus. Focal dilation of the oesophagus at the level of the vascular constriction was performed in cases 1 and 2 using an endoscopic balloon and a Foley urinary catheter, respectively. Thoracostomy tubes were placed in all cases and removed within 48 hours after surgery. Surgery was uncomplicated in three cases; mild intraoperative haemorrhage occurred in case 2 during ligation of the aortic arch that necessitated placement of a second encircling ligature. All four animals survived the surgical procedure. During the postoperative period, three animals suffered a complication event. Case 1 had an episode of hypersalivation 2 weeks after surgery and a course of omeprazole was administered. Case 3 showed hypersalivation, retching and regurgitation during the first 24 hours after surgery, which resolved spontaneously. Case 4 was reported to have a single episode of regurgitation 48 hours after surgery. Hospitalisation ranged from 2 to 4 days and all four animals survived to discharge. During the postoperative period, the animals were managed with omeprazole and "postural feeding" starting with small frequent meals of liquid food and gradually decreasing the frequency and altering the consistency of the food to reduce the water content. Follow-up time was 360 and 868 days for the two dogs and 387 and 1563 days for the two cats. All animals showed a marked improvement during the postoperative period, and they all gained weight. Case 1 was euthanased during the follow-up period at 868 days for reasons unrelated to the DAA. At the last follow-up, this dog was being fed wet food from a height with no report of regurgitation. Case 2 and 4 were fed normal commercial wet and dry food with no regurgitation reported. Case 3 was fed wet food and small dry biscuits; however, regurgitation was occasionally reported when the cat was fed any large-sized dry biscuits. According with Krebs *et al.* (2014), the owners' perception of the surgical procedure outcome and quality of life during the last follow-up was described as excellent in cases 2 and 4 and as good in case 3.

Cases reported in the literaturesys

A total of 12 other case reports were identified in the literature search for a total of 10 dogs and two cats. Signalment, presenting clinical signs, diagnostic imaging findings, surgical intervention, complications and outcomes are reported in Table 2.

Two cats and two dogs died or were euthanased without any surgical intervention. Of the eight dogs that underwent surgical ligation and division of one of the aortic arches, three died due to complications. A 10-week-old puppy (unreported breed) developed left ventricular hypertension that evolved to cardiac congestive insufficiency and pulmonary oedema 30 minutes after surgery. A 7-week-old German shepherd dog developed

Table 1. Descriptive analysis of two dogs and two cats with double aortic arch (DAA)

Case	Species	Breed	Gender	Age (weeks)	BW (kg)	BCS	Presenting clinical signs	Diagnostic methods	Surgical time (anaesthetic time) (minutes)	Surgical approach	Complications (intraoperative)	Complications (postoperative)	Diet	Outcome (days)
1	Canine	PRT	ME	10	1.7	4	Regurgitation, weight loss, lethargy, retching, respiratory noise after eating	Radiographs CTA Echocardiography	80 (140)	L fourth ICT LAA ligation: 2 encircling ligatures (3.0 silk)	-	Hypersalivation	Wet food	Euthanased – unrelated (868)
2	Canine	JRT	ME	96	5	3	Regurgitation, stunted growth	Radiographs CTA Echocardiography	72 (120)	L fourth ICT LAA ligation 2 encircling ligatures (2.0 silk + 2.0 nylon)	Mild bleeding	-	Wet/dry food	Excellent (360)
3	Feline	DSH	FE	20	2.2	3	Regurgitation, stunted growth, weight loss	Oesophagogram, CTA	80 (180)	L fourth ICT LAA ligation: 1 encircling ligature (5.0 Prolene) + 1 transfixant ligature (6.0 Prolene) LLA ligation (5.0 Prolene)	Regurgitation	Hypersalivation, retching, regurgitation	Wet food, small dry biscuits	Excellent (387)
4	Feline	DSH	FE	9	0.56	3	Regurgitation, lethargy, pyrexia, lethargy, respiratory noise after eating	Oesophagogram	65 (150)	L fourth ICT LAA ligation: 1 encircling ligature (5.0 Prolene) + 1 transfixant ligature (6.0 Prolene) LLA ligation (5.0 Prolene)	-	Occasional regurgitation	Any	Excellent (1563)

BW bodyweight, BCS body condition score, CTA computed tomographic angiography, PRT Parson Russel terrier, ME male entire, L left, ICT intercostal thoracotomy, LAA left aortic arch, LLA left ligamentum arteriosum, JRT Jack Russel terrier, DSH domestic shorthair, FE female entire

aspiration pneumonia 3 days after surgery. A 7-week-old beagle showed a marked postoperative deterioration following incorrect identification of the VRA. Among the remaining five dogs, a good outcome was reported in all with a follow-up ranging from 4 days to 4 years. No particular dietary requirements were reported in these animals.

FIG. 1. Left lateral oesophagogram of a 2-year-old male entire Jack Russel terrier (case 2) presented with a history of regurgitation. Note the marked distension of the oesophagus cranial to the sixth intercostal space (arrow)

DISCUSSION

In the case series reported here, cats and dogs with DAA underwent ligation and transection of the lesser aortic arch and had an excellent outcome and quality of life with only minor dietary/feeding modifications.

According to recent literature and the cases reported here, regurgitation remains the most prevalent clinical feature of dogs and cats with DAA and respiratory signs were more commonly associated with aspiration pneumonia rather than tracheal compression (Follette *et al*. 2019, Morgan & Bray 2019).

In this study, CTA was performed in three animals, and it was extremely helpful in achieving a definitive diagnosis of DAA, to determine the dominant aortic arch and to assist in surgical planning. In these cases, CTA showed a dominant RAA with a lesser LAA, which is considered the most common conformation in small animals and is similar to human patients with DAA (Backer *et al*. 2005; Sekhar *et al*. 2021).

Based on CTA findings and the presence of a less developed LAA, a left fourth intercostal thoracotomy approach was chosen for all the animals reported here. Case 4 had an oesophagogram suggesting a VRA. A PRAA with a left ligamentum arteriosum was suspected and a DAA was diagnosed intraoperatively. When the exact anatomy of a VRA is unknown, before surgery, a left intercostal thoracotomy is advised on the basis that 95% of VRA in small animals are a PRAA with a left ductus or ligamentum

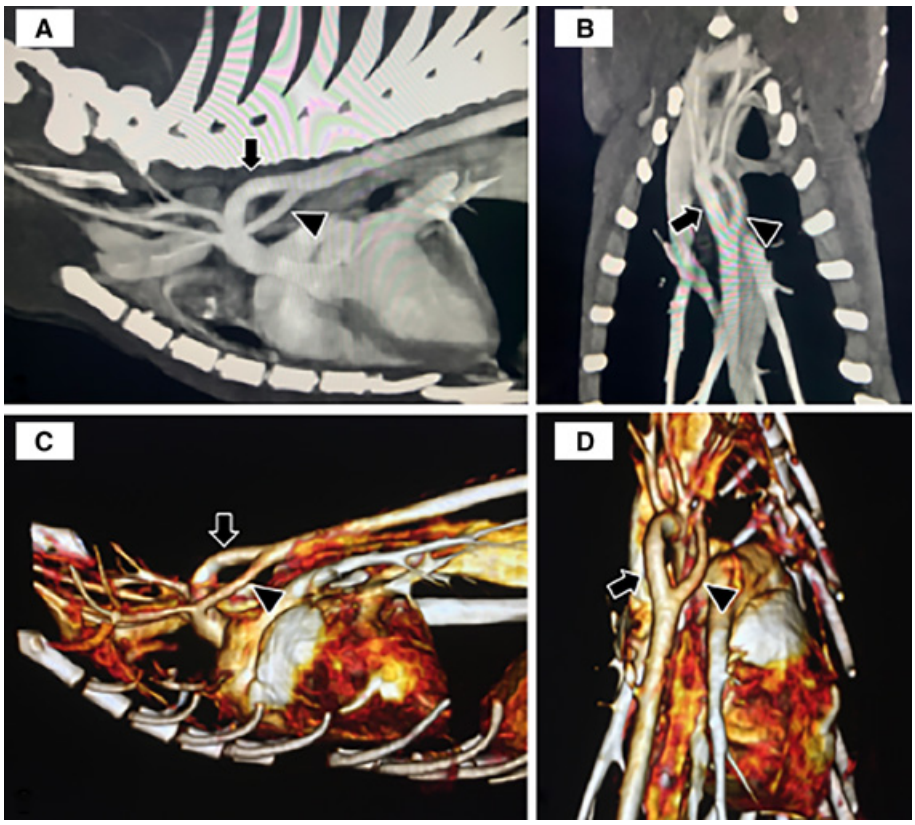

FIG. 2. CTA multiplanar reconstruction and volume rendering images in sagittal (A, C) and dorsal (B, D) planes of the thorax showing a DAA in a 2-year-old male entire Jack Russel terrier (case 2). Note the larger and well-developed right aortic arch (arrow) compared with the smaller left aortic arch (arrowhead)

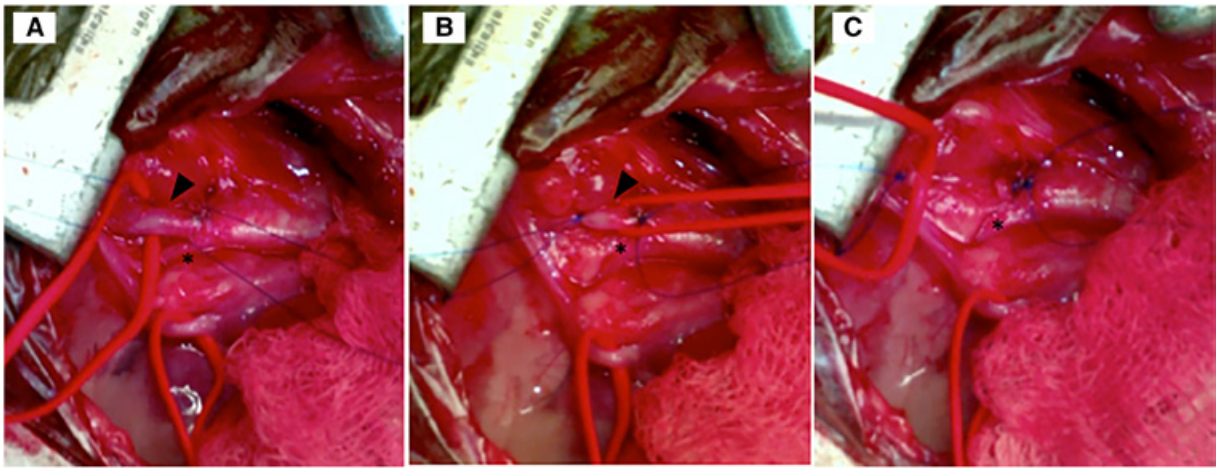

FIG. 3. Intraoperative view during dissection (A), ligation (B) and transection (C) of the left aortic arch (arrowhead) in a 5-month-old female entire domestic shorthair (case 3) with double aortic arch. Note the vessel ends sutured with Prolene. Note the left ligamentum arteriousum (*)

arteriosum (Buchanan 2004). However, a deep understanding of the vascular ring anatomy is essential to have a positive outcome for the patient if it falls into the 5% that have a different configuration (Buchanan 2004).

For the surgical management of DAA, ligation and transection of the smaller patent aortic arch is required, and the side of the thoracotomy should be ipsilateral to this to provide better visibility for ligation and transection (Aultman *et al*. 1980, Martin *et al*. 1983, Du Plessis *et al*. 2006, Morgan & Bray 2019).

To demonstrate that an animal can tolerate ligation and transection of one of the aortic arches, the aortic arch can be temporarily occluded and haemodynamic parameters including heart rate, blood pressure and quality of the femoral pulse can be observed. Aultman *et al*. (1980) suggested that the arch producing the strongest femoral pulse should be retained whenever possible. It has also been advocated that echocardiographic assessment of the aortic pressures through each aortic arch may allow objective identification of a pressure difference between the two vessels (Morgan & Bray 2019).

Ligation and resection of one aortic arch, even if small, may reduce the functional volume of the aorta. According to Poiseuille's law, the resistance to flow would increase inversely proportional to the power of four of the change in aortic diameter, potentially leading to an increase in pressure in the preceding vasculature and left ventricle (Ferrigno *et al*. 2001, Vianna & Krahwinkel 2004, Morgan & Bray 2019). An alternative surgical approach has been proposed, involving anastomosis of one of the aortic arches after initial transection, allowing the oesophagus and trachea to be free of constriction (Fingeroth 1993). The risk of reduced functional aortic volume can simultaneously be eliminated, thus the haemodynamic of the aorta and the pulmonary vasculature should not be compromised (Du Plessis *et al*. 2006). This has not yet been performed in small animals.

In addition, Aultman *et al*. (1980) reported that correcting a DAA is more complicated if both arches are of near equal diameter as the ligation of one arch would produce hypertension with increased afterload and work on the left ventricle, pulmonary hypertension, cardiac insufficiency and ultimately death. For surgical management of symmetric aortic arches, intraoperative assessment via occlusion and palpation of the femoral artery can allow subjective evaluation of the more patent vessel (Aultman *et al*. 1980, Du Plessis *et al*. 2006, Morgan & Bray 2019). The vessel that provides the stronger femoral pulse when occluded is the vessel to be resected (Aultman *et al*. 1980, Du Plessis *et al*. 2006, Morgan & Bray 2019).

In the veterinary literature, only three animals with suspected or confirmed symmetrical DAA have been reported: a 4-week-old German shepherd dog was euthanased after diagnosis (Findji & Degueurce, 1999); an 8-week-old beagle was euthanased due to acute deterioration after an exploratory thoracotomy and an incorrect diagnosis (Du Plessis *et al*. 2006); a 10-week-old Czechoslovakian wolfdog is the only case that survived ligation of one of the arches; a 10% decrease in heart rate and a 15% drop in blood pressure were observed during occlusion but no further haemodynamic consequences were reported (Skrzypczak *et al*. 2017).

In animals reported here, variations in heart rate and blood pressure were not observed following temporary occlusion of the smaller aortic arch, therefore complete ligation and transection of the aortic arch was deemed feasible. In case 3, blood pressure on both thoracic and pelvic limbs was also measured before transection with a variation of less than 10% between them. No further consequences were reported.

The prognosis reported for cats and dogs undergoing correction of VRA varies. The definitive association between preoperative factors and postoperative regurgitation has not been made, but the extent of oesophageal dilation cranial to the ligamentous constriction is thought to have an important influence on postoperative prognosis (Krebs *et al*. 2014, Morgan & Bray 2019). It is presumed that the severity of oesophageal dilation is directly proportional to the likelihood of irreversible secondary oesophageal dysfunction and that this should influence the overall outcome following surgery. However, this relationship has not been confirmed clinically (Rallis *et al*. 2000, Morgan & Bray 2019). In some instances, relieving the constriction of the oesophagus is curative, and the cranial oesophageal dilation regresses with time

Table 2. Descriptive analysis of the previous DAA case reports

Case	Species, breed	Age	Clinical signs	Diagnostics	Diagnostic findings	DAA type	Surgery	Complications	Diet	Follow-up -outcome
Sekhar *et al*. (2021)	Canine, Labrador	8m	Vomiting, regurgitation, hyporexia	Radiographs, endoscopy, CT angiography	Dilation cranial oesophagus, DAA	Right dominant arch	L fourth ICT LAA + LLA ligation	-	Normal diet	4y, good
Follette *et al*. (2019)	Canine, Crossbreed	10m	Exercise intolerance, wheezing	Radiographs, oesophagogram, CT	Dilation cranial oesophagus, aspiration pneumonia. luminal narrowing of the trachea, DAA	Left dominant arch	R fourth ICT, RAA ligation	Bradycardia due to fentanyl overdose. Two episodes of regurgitation	Normal diet	3.5w
Skrzypczak *et al*. (2017)	Canine, Czechoslovakian wolfdog	10w	Regurgitation, wheezing after meals, malnutrition, dehydration	Radiographs, oesophagogram oesophagoscopy	Dilation cranial oesophagus	Symmetric AA	L fourth ICT + LAA + LLA ligation	-	Normal diet	12m
Moonan *et al*. (2007)	Canine, GSD	7w	Noisy breathing, regurgitation	Radiographs, oesophagogram	Dilation cranial oesophagus	Right dominant arch + PDA	L fourth ICT, LAA + PDA ligation	-	-	4 days. No issues reported
Du Plessis *et al*. (2006)	Canine, beagle	8w	Regurgitation, dyspnoea, aspiration pneumonia	Contrast oesophagogram		Symmetrical aortic arch	L fourth ICT, LLA ligation	Incorrect VRA identification		24h – dead (deterioration)
Vianna & Krahwinkel (2004)	Canine, crossbreed	3m	Regurgitation	Radiographs, oesophagogram		Left dominant arch	L fourth ICT, RAA ligation		Normal diet	6m, good
Ferrigno *et al*. (2001)	Canine, unreported	10w	Regurgitation	Radiographs, oesophagogram		Right dominant arch	L fifth ICT, LLA ligation	L ventricular hypertension, CHF, pulmonary oedema		30 min, dead
Findji & Degueurce, (1999)	Canine, GSD	4w	Vomiting, stunted growth, dehydration	Radiographs	Aspiration pneumonia	Symmetrical aortic arch	-	-		Dead (unknown reason)
Martin *et al*. (1983)	Canine, GSD	8w	Persistent vomiting	Radiographs, oesophagogram	Dilation cranial oesophagus	-	-	-		Euthanased
Aultman *et al*. (1980)	Canine, GSD	7w	Regurgitation	Radiographs, oesophagogram	Dilation cranial oesophagus	Left dominant arch	L fifth ICT RAA + LLA ligation	Aspiration pneumonia		3 days, dead
Yarim *et al*. (1999)	Feline, Siamese	8w	Regurgitation, cachectic, dehydration, stridor, dysphagia	Radiographs	Constriction at the base of the heart and opposite the fifth intercostal space	Right dominant arch	-	-		Necropsy
Van de Linde-Sipman *et al*. (1973)	Feline, DSH	9m	Vomiting	-	-	Right dominant arch	-	-		Acute dyspnoea, dead

DAA double aortic arch, m month, L left, ICT intercostal thoracotomy, LAA left aortic arch, y, years, R, right, RAA right aortic arch, w week, AA aortic arch, PDA patent ductus arteriosus, LLA left ligamentum arteriosus, GSD German shepherd dog, VRA vascular ring anomaly, h hour, CHF cardiac heart failure, min minute, DSH domestic shorthair

(Muldoon *et al*. 1997). However, in other instances, regurgitation can persist (Muldoon *et al*. 1997).

Historically, a poor prognosis has been reported for animals with DAA (Van de Linde-Sipman *et al*. 1973, Aultman *et al*. 1980, Martin *et al*. 1983, Findji & Degueurce, 1999, Yarim *et al*. 1999, Du Plessis *et al*. 2006); however, all those reports described dogs and cats that died or were euthanased before any surgical intervention. When considering the prognosis for DAA, the dog described by Du Plessis *et al*. (2006) should also be excluded as the VRA was incorrectly identified during surgery and the dog deteriorated and died in the postoperative period. If the 11 remaining animals (four cases described here and seven previously reported) diagnosed with DAA that underwent surgical intervention were considered, the outcome appears to be good overall, with only two dogs failing to survive to discharge following surgery (Aultman *et al*. 1980, Ferrigno *et al*. 2001).

Before the animals reported here, only two cats with DAA had been reported (Table 2); both of which either died or were euthanased with the DAA subsequently discovered during necropsy (Van de Linde-Siman *et al*. 1973, Yarim *et al*. 1999). Based on the literature search, the two cats reported here are the first two cats with DAA to undergo surgical division of the smaller aortic arch and survived long-term.

In the study reported here, all the animals had an uneventful recovery followed by a gradual improvement in clinical signs after surgery. Unfortunately, case 1 was euthanased for reasons unrelated to the DAA, but the last follow-up showed marked physical improvement and no regurgitation. This dog was being fed wet food from a height and gradually continued to gain weight. For the remaining three animals, two (one dog and one cat) were fed a normal commercial diet without feeding modifications and did not regurgitate and one cat tolerated wet or small size dry food well, however, showed occasional regurgitation when presented with large size dry food.

For animals with PRAA undergoing surgical correction, Krebs *et al*. (2014) reported a mortality rate to hospital discharge of 8%, increasing to, 18% within 2 months after surgery. Most owners of surviving dogs reported a good or excellent long-term outcome, with 30% having complete resolution of clinical signs or no need for dietary/feeding modifications (excellent outcome) and 57% having persistent mild clinical signs (regurgitation frequency less than once per week) or requiring dietary medical management (good outcome) (Krebs *et al*. 2014). According to Krebs *et al*. (2014), among the nine animals reported that survived to discharge, seven (cases 2, case 4 and five cases previously reported) had an "excellent" outcome on the basis of the complete resolution of clinical signs and freedom from special dietary management. Two animals (cases 1 and 3) had a "good" outcome on the basis of the need for minor dietary modification to reduce/eliminate regurgitation. Overall, a good long-term outcome and resolution of clinical signs can be expected after surgical management of dogs and cats with DAA (Vianna & Krahwinkel 2004, Moonan *et al*. 2007, Skrzypczak *et al*. 2017, Follette *et al*. 2019, Sekhar *et al*. 2021).

In conclusion, dogs and cats with DAA had non-specific clinical signs compatible with VRAs. Advanced diagnostic imaging is strongly recommended in surgical planning. Dogs and cats with DAA undergoing surgical division of the smaller aortic arch can have a favourable prognosis for recovery, resolution of clinical signs, and quality of life.

Conflict of interest

None of the authors of this article has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

Author contributions

Matteo Rossanese: Conceptualization (lead); data curation (lead); methodology (lead); project administration (lead); validation (lead); writing – original draft (lead). **Filippo Cinti:** Conceptualization (equal); data curation (equal); resources (equal); validation (equal); writing – review and editing (equal). **Guillaume P. A. Chanoit:** Conceptualization (equal); data curation (equal); resources (equal); validation (equal); writing – review and editing (equal). **Dan James Brockman:** Conceptualization (equal); data curation (equal); resources (equal); validation (equal); writing – review and editing (equal).

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