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Aortic Arch Anomalies in Dogs: Prevalence and Classification Using Multidetector Computed Tomographic Angiography

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ABSTRACT

Aortic arch anomalies are significant due to their potential association with vascular ring malformations. Among these, a persistent right aortic arch is the most frequently seen in dogs. However, there is limited published information regarding the distribution and types of these vascular abnormalities. This retrospective study aimed to explore the prevalence and variety of aortic arch anomalies detectable through thoracic CT scans. CT scans from a database collected between 2008 and 2020 were analyzed by two reviewers to determine the frequency and classification of aortic arch anomalies. Additional details such as breed, age, and reason for the examination were extracted from medical records. The study reviewed 213 CT scans. Out of these, 21 dogs (9.9%) presented with a right-sided aortic arch and a left ligamentum arteriosum, resulting in esophageal compression. Further incidental findings included: an aberrant left subclavian artery (76.2%), a persistent ductus arteriosus (4.8%), a left-sided brachiocephalic trunk (14.3%), a bicarotid trunk (81.0%), and a double aortic arch (4.8%). The remaining 192 dogs (90.1%) showed a normal left aortic arch without any esophageal compression. In these cases, incidental findings included an aberrant right subclavian artery (1.6%), a vessel branching into the left caudal lung lobe (1.0%), dilation of the subclavian arteries (1.0%), and a bicarotid trunk (0.5%). In line with earlier studies, an aberrant left subclavian artery was the most commonly observed incidental abnormality in dogs with a persistent right aortic arch. A novel finding in this research was the presence of a left-sided brachiocephalic trunk in 14.3% of dogs with this anomaly, though it did not lead to additional esophageal compression. Similarly, aberrant right subclavian arteries were found without causing esophageal compression.

Keywords: Vascular ring anomaly, Persistent right aortic arch, Persistent ductus arteriosus, Vascular anomaly

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Background

Congenital aortic arch malformations carry clinical significance primarily because they can form vascular rings that entrap the esophagus and trachea [1]. A vascular ring is any developmental anomaly of the great vessels that fully or partially encircles these structures, producing secondary esophageal constriction [1–3]. Dogs with such rings typically regurgitate undigested food shortly after meals [3]. Multidetector computed tomographic angiography with intravenous contrast is currently the gold-standard imaging modality for definitive anatomical diagnosis of these anomalies [4–6].

Among vascular ring anomalies in dogs, persistent right aortic arch remains by far the most prevalent, accounting for approximately 7% of cases in referral populations [7, 8]. Purebred dogs are affected more frequently than mixed-breed individuals, with German Shepherd Dogs showing marked predisposition [7, 8].

Embryologically, the mature thoracic aorta derives from a complex bilateral system that begins with an aortic sac connected to paired dorsal aortae via six pairs of pharyngeal arch arteries [9]. Under normal development:

- arches 1, 2, and 5 regress completely
- arch 3 forms the proximal common carotid arteries while the intervening dorsal aortic segments disappear
- the left 4th arch becomes the definitive aortic arch
- the right 4th arch contributes only to the brachiocephalic trunk
- the right 7th intersegmental artery forms the right subclavian artery
- the 6th arches give rise to the proximal pulmonary arteries and temporary ductus arteriosus (right side obliterates prenatally; left side closes postnatally and persists as the ligamentum arteriosum)
- the right dorsal aorta caudal to the right subclavian artery regresses, allowing the left dorsal aorta to become the descending thoracic aorta [9, 10].

Persistent right aortic arch results when the right 4th arch and right dorsal aorta persist and enlarge instead of their left counterparts [10]. The physiologically retained left ligamentum arteriosum then stretches from the left pulmonary artery to the abnormal right-sided arch, completing a constricting ring around the esophagus (classic Type 1) [9].

Seven distinct vascular ring configurations that can cause varying degrees of esophageal compression are currently recognized in the dog [9, 10] **(Figure 1)**:

- Type 1: persistent right aortic arch + left ligamentum arteriosum
- Type 2: persistent right aortic arch + persistent left subclavian artery
- Type 3: persistent right aortic arch + left ligamentum arteriosum + persistent left subclavian artery
- Type 4: double aortic arch
- Type 5: left aortic arch + persistent right ligamentum arteriosum
- Type 6: left aortic arch + persistent right subclavian artery
- Type 7: left aortic arch + persistent right ligamentum arteriosum + persistent right subclavian artery

Widespread availability of thoracic CT has dramatically increased the detection of aortic arch variants in dogs examined for reasons unrelated to suspected vascular rings, including many that never produce clinical signs. To date, no large single-center series has reported the overall frequency and morphological range of aortic arch anomalies encountered on routine thoracic CT examinations irrespective of clinical indication. The present retrospective study was therefore designed to review all thoracic CT studies performed at our institution over a 13-year period, regardless of the original reason for imaging, in order to document the true prevalence and spectrum of aortic arch anomalies in a general hospital population of dogs.

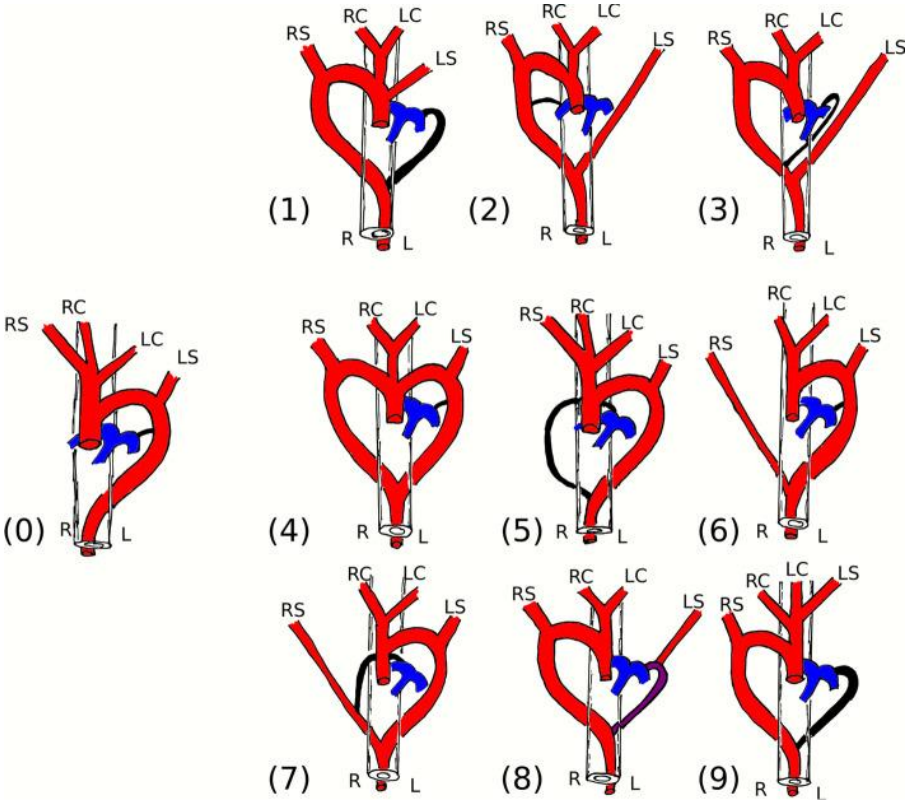

Figure 1. Newly proposed expanded classification of canine vascular ring-forming aortic arch anomalies. Every configuration shown can potentially constrict the esophagus, although Types 2 and 6 rarely produce clinically relevant compression

Schematic key (numbered panels):
(0) Normal left aortic arch configuration
(1) Type 1: right aortic arch + left-sided ligamentum arteriosum
(2) Type 2: right aortic arch + retroesophageal left subclavian artery (without ligamentum)
(3) Type 3: right aortic arch + left ligamentum arteriosum + retroesophageal left subclavian artery
(4) Type 4: double aortic arch
(5) Type 5: left aortic arch + right-sided ligamentum arteriosum
(6) Type 6: left aortic arch + aberrant right subclavian artery (no ligamentum)
(7) Type 7: left aortic arch + right ligamentum arteriosum + aberrant right subclavian artery
(8) Type 8: right aortic arch with left subclavian artery originating directly from a patent ductus arteriosus (novel variant)
(9) Type 9: right aortic arch with a left-positioned brachiocephalic trunk that gives rise to both carotid arteries and the left subclavian artery ("mirror-image" branching; novel variant)
Color coding: blue = pulmonary arterial structures; black = ligamentum arteriosum or patent ductus arteriosus.
Types 1–7 follow the original system published by Ellison G in 1980 [11]. Types 8 and 9 are newly introduced variants identified in the current study population.

Materials and Methods

This was a retrospective descriptive study involving a review of thoracic CT images stored in the Justus Liebig University Clinic database, covering the period from January 2008 to December 2020. Only CT scans that included both pre- and post-contrast images were selected. The study adhered to standard veterinary practices for clinical patients, and no specific animal care or use protocols were required for this retrospective study.
The data extracted for the dogs meeting the inclusion criteria included breed, sex, age at the time of imaging, date of imaging, and the reason for the CT examination.

CT scan methodology

The CT scans were performed while the animals were under general anesthesia. Propofol was used for induction, followed by isoflurane to maintain anesthesia, and mechanical ventilation was employed throughout the procedure. Two different CT machines were used: SOMATOM Emotion (Siemens Healthcare, Erlangen, Germany) and Diamond Select Brilliance (Philips Health Systems, Best, Netherlands), both equipped with 16 detectors. The dogs were positioned in sternal recumbency, and in the majority of cases (201 out of 213), a breath-hold technique was applied. This was achieved by inducing apnea through manual hyperventilation and maintaining a positive pressure between 10 to 20 mm/Hg. A contrast medium (Accupaque™ 300, GE Healthcare) was injected intravenously at a dose of 2 ml/kg body weight, followed by a saline flush. The contrast injection was delayed for 60–90 seconds before scans were performed, capturing the "late venous phase." Additionally, arterial phase images were obtained in 53 cases using bolus tracking. CT parameters included a slice thickness of 1.5 mm, pitch of 0.8, rotation time of 0.6 s, 130 kV, and 160-200 mA.

Image review procedure

The image datasets were reviewed by two radiologists: a first-year ECVDI resident (C.S.) and an ECVDI board-certified radiologist (S.S.). Evaluation was conducted using DICOM-viewing software (Horos v. 3.3.6), and the reviewers were free to adjust the image orientation, window width, and level according to their preferences. They also had the option to generate 3D reconstructions. The focus was on identifying abnormalities in the aortic arch and brachiocephalic trunk. Any structural irregularities, including the presence of a right aortic arch, abnormal subclavian arteries, PDA, and the anatomy of the brachiocephalic trunk, were carefully noted. In cases with a right aortic arch, the dogs were categorized according to previously defined types [9, 10], or if no match was found, the origins and course of any abnormal vessels were recorded. The diameter of these vessels was subjectively assessed, and any expansion in size beyond their origin was classified as a dilation.

Study Results

Out of the 213 dogs included, 53 had both arterial and venous phase scans available, while the remaining dogs only had venous phase images. Of these, 21 dogs presented clinical signs suggestive of a vascular ring anomaly, such as regurgitation after eating, while the other 192 dogs underwent CT for unrelated conditions, including exercise intolerance, spontaneous pneumothorax, lung diseases, and metastatic screening. These dogs did not exhibit clinical symptoms indicative of a vascular ring anomaly. The results are categorized as follows:

Dogs with clinical symptoms of vascular ring anomaly

Of the 21 dogs showing clinical signs, there were 15 females and 6 males. These included 9 Labrador Retrievers, 4 German Shepherds, 2 mixed-breed dogs, and 1 each of the following: French Bulldog, Gos d'Atura Català, Husky, Jack Russell Terrier, Border Collie, and Australian Shepherd. The average age was 2 months, ranging from 6 weeks to 4 months. All 21 dogs were found to have a right aortic arch on CT, with secondary compression of the esophagus caused by the left ligamentum arteriosum. This finding was confirmed surgically in each case.

Among these 21 dogs, 16 were diagnosed with Type 3 vascular ring anomaly (persistent right aortic arch, persistent left ligamentum arteriosum, and aberrant left subclavian artery). Two of these 16 dogs also showed the aberrant left subclavian artery branching from the PDA, confirmed via CT **(Figure 2)**. Both underwent surgery to close the PDA and dissect the left subclavian artery. One dog was identified as having a Type 4 anomaly (double aortic arch). Three other dogs did not fit any of the previously described types. These dogs displayed a right aortic arch along with a left-sided brachiocephalic trunk, which included both carotid arteries and the left subclavian artery, while the right subclavian artery branched separately from the aorta **(Figure 3)**. In these three cases, the esophageal compression was caused by the right aortic arch and the left ligamentum arteriosum.

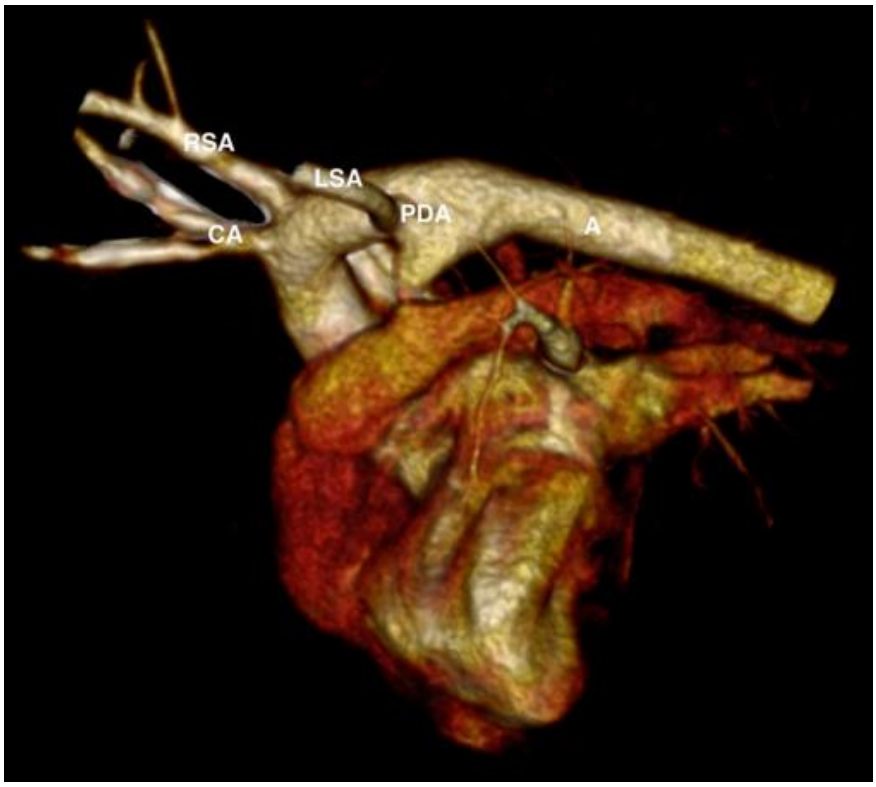

Figure 2. 3D CT rendering showing an abnormal left subclavian artery (LSA) originating from the patent ductus arteriosus (PDA). Legend: A = Aorta, RSA = Right Subclavian Artery, CA = Carotid Arteries

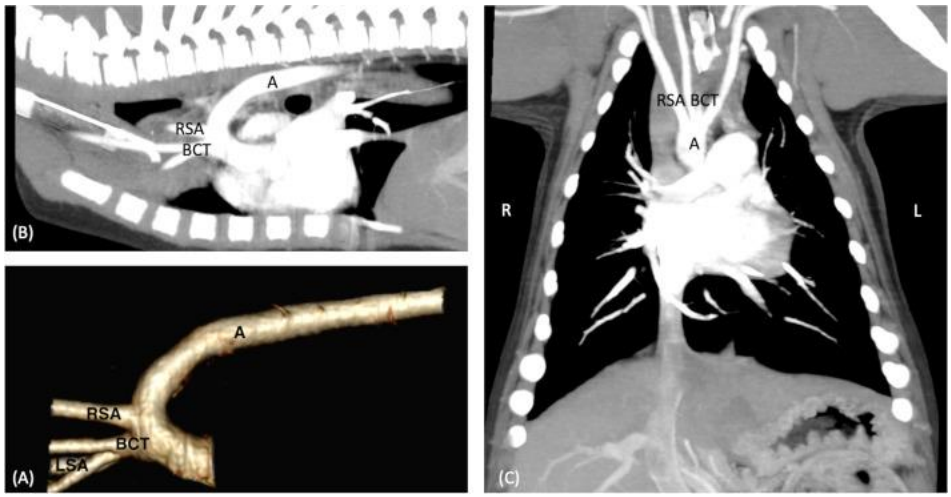

Figure 3. CT image depicting a left-sided brachiocephalic trunk (BCT) that consists of both carotid arteries (CA) and the left subclavian artery (LSA). The right subclavian artery (RSA) branches independently from the aorta. (A) 3D volume-rendered image, (B) Sagittal MIP, (C) Dorsal MIP. Legend: A = Aorta

Among the 21 dogs with a right aortic arch, none exhibited a normal brachiocephalic trunk. Instead, several dogs displayed abnormal vascular branching patterns, as summarized in **Table 1**.

Table 1. Summary of Arterial Branching Anomalies in Dogs with Right Aortic Arch

Anomaly (in dogs with persistent right aortic arch, n = 21)	Percentage (%)	Number of dogs
Normal (right-sided) brachiocephalic trunk	0.0	0
Bicarotid trunk	81.0	17
Aberrant left subclavian artery (classic Type 3)	76.2	16
Left-sided brachiocephalic trunk (containing both carotid arteries + left subclavian artery)	14.3	3
Double aortic arch (Type 4)	4.8	1

Aberrant left subclavian artery arising directly from patent ductus arteriosus	9.5	2
Patent ductus arteriosus visible	14.3	3
Right subclavian artery originating as a separate branch from the right aortic arch	100	21

Esophageal compression, caused by the left ligamentum arteriosum, was observed in all of these cases.

Dogs without vascular ring anomaly symptoms

The other 192 dogs, which had CT scans for reasons unrelated to vascular ring anomalies, included 47 females, 42 spayed females, 58 males, and 45 neutered males, with a mean age of 6.4 years (range: 2 months to 16 years). Among them, 155 were purebred, and 37 were mixed-breed. Of these, 184 dogs had normal aortic arches and brachiocephalic trunks, with no signs of esophageal compression. However, 8 dogs displayed changes in the branching patterns or diameter of the aorta or brachiocephalic trunk, which are detailed in **Table 2**. Six of these cases were considered incidental, with no clinical significance. These findings included: an aberrant right subclavian artery without esophageal compression, focal dilation of the subclavian arteries, and a bicarotid trunk.

Table 2. Frequency and Types of Aortic and Brachiocephalic Trunk Abnormalities in Dogs with Left Aortic Arch

Aortic arch and brachiocephalic trunk anomalies observed in dogs with normal left aortic arch (n = 192)	Percentage (%)	Number of dogs
Aberrant right subclavian artery	1.6	3
Aberrant vessel arising from the descending aorta and terminating in the left caudal lung lobe	1.0	2
Focal dilatation of the left subclavian artery	0.5	1
Bicarotid trunk originating from the brachiocephalic trunk	0.5	1
Focal dilatation of the right subclavian artery (Figure 5)	0.5	1

Two dogs, one 2-month-old male Flat-Coated Retriever and one 6-month-old male Shetland Sheepdog, presented with exercise intolerance. CT imaging revealed an abnormal vessel in both dogs, originating from the aorta at the fourth thoracic vertebral level, as shown in Figure 4. This vessel coursed caudally and ventrally, draining into the left caudal lung lobe, establishing a systemic-to-pulmonary shunt. Both dogs also had a persistent ductus arteriosus. The Flat-Coated Retriever had a hypoplastic left pulmonary artery and reduced left lung volume compared to the right side, though both pulmonary arteries were present. In the Shetland Sheepdog, the PDA was successfully closed via catheter embolization, and the dog was lost to follow-up.

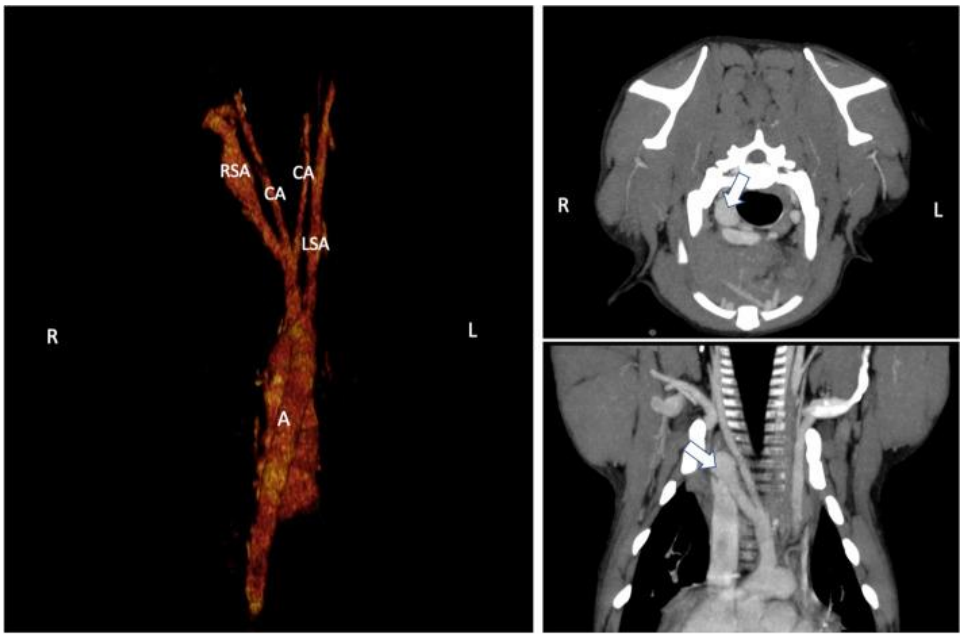

Figure 5. 3D CT rendering illustrating mild dilation of the right subclavian artery. (B) Transverse image, (C) Dorsal image showing the dilation, with arrows pointing to the affected area. Legend: A = Aorta, RSA = Right Subclavian Artery, LSA = Left Subclavian Artery, CA = Carotid Arteries

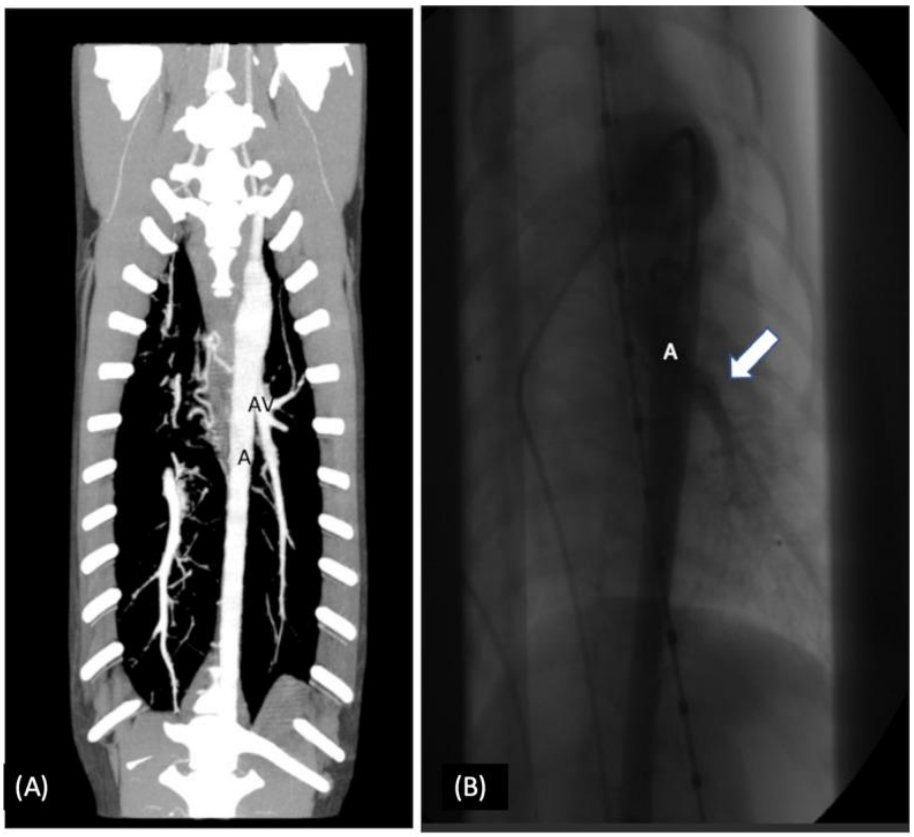

Figure 4. CT reconstruction of an abnormal arterial vessel (AV) originating from the left aorta (A) and draining into the left caudal lung lobe. (A) Dorsal MIP view, (C) Angiography, highlighting the AV with arrows. The contrast enhancement shows the injection site into the aorta

Discussion

This is the first study to systematically assess variations in the aortic arch detectable by thoracic CT in a canine population, comparing these findings to previously recognized types. In this study, 9.9% of dogs showed a persistent right aortic arch, which aligns with past research [7, 8]. However, unlike other studies, German Shepherds were not the predominant breed in our cohort [6, 7], with Labrador Retrievers being the most commonly affected breed, representing 42.9% of cases. This suggests a higher representation of Labrador Retrievers in our hospital's population.

In addition to the seven established types of vascular ring anomalies described in prior studies [9], two further types were referenced in a previous review [3]. One of these types, first noted in a 1979 surgical case, involved an abnormal vessel branching from the aorta near the left subclavian artery, passing medially and draining into the brachiocephalic artery [11]. This case is more likely an aberrant right subclavian artery rather than a full vascular ring anomaly. The second type, characterized by incomplete esophageal compression caused by an unusual branching pattern of the right intercostal artery, was also described surgically [12]. These two anomalies are better categorized as aberrant vascular structures rather than traditional vascular ring anomalies, so they are excluded from the current classification.

The most frequent anomaly found was Type 3 (persistent right aortic arch with left ligamentum arteriosum and left subclavian artery), affecting 76.2% of the dogs with a right aortic arch. In contrast, Type 1, which was previously considered the most common [9], was not observed. Type 1 is less likely to occur as it involves the regression of the left fourth aortic arch, which is a rare developmental process [1]. Previous studies have found aberrant left subclavian arteries in 33-60% of dogs with right aortic arches, which may not always be detected in surgeries, suggesting CT might offer more accurate detection [4, 13].

Anomalies such as Type 6 (normal left aortic arch with right subclavian artery) were detected incidentally in three dogs undergoing CT for reasons unrelated to vascular anomalies. The right subclavian artery abnormality is caused by abnormal regression of the right dorsal aorta [14], and while it's common in humans (0.5-2% prevalence), its

clinical relevance in dogs remains unclear. In this study, an aberrant right subclavian artery was detected in only 1.4% of dogs and did not cause clinical symptoms. Additionally, two dogs showed mild dilation of the subclavian artery, which is not considered clinically significant and differs from Kommerell's diverticulum, a condition associated with subclavian artery dilatation in humans [4, 15, 16].

One novel finding in this study was the left-sided brachiocephalic trunk, observed in three dogs with a right aortic arch. This trunk included both carotid arteries and the left subclavian artery, mirroring the typical brachiocephalic trunk on the opposite side. To the authors' knowledge, this type has not been previously reported in dogs. In human medicine, this condition is known as a right aortic arch with mirror-image branching and is one of the more common forms of right-sided aortic arch anomalies [1]. In this study, this left-sided brachiocephalic trunk was identified in 14.3% of dogs with a right aortic arch, suggesting that this type should be added to the current classification **(Figure 1)**.

In two canines diagnosed with a persistent right aortic arch, the left subclavian artery originated directly from a patent ductus arteriosus. This specific vascular configuration has been documented in only two prior canine cases, confirming its rarity [17, 18]. The anomaly arises from regression of the left fourth aortic arch both cranial and caudal to the origin of the left subclavian artery [1]. Similar to earlier reports, this variant has not been formally classified and warrants inclusion in the expanded classification system proposed herein (Figure 1). Surgically, both affected dogs underwent ligation and transection of the aberrant left subclavian artery. In human patients, proximal subclavian artery occlusion or stenosis can induce retrograde flow via the vertebral artery, producing subclavian steal syndrome characterized by vertigo, syncope, and upper-limb claudication [19]. Neither dog exhibited clinical evidence of subclavian steal syndrome postoperatively. Nonetheless, surgeons should remain cognizant of this potential complication, and reimplantation of the subclavian artery onto the left carotid artery may be considered to preserve antegrade flow. Beyond ductal origin, three additional anomalous patterns of the left subclavian artery have been reported: isolated course, hypoplasia, and lateral aortic origin [18]. Within the present cohort, one dog displayed mild stenosis of an aberrant left subclavian artery immediately distal to its aortic origin, consistent with previously described subclavian hypoplasia; however, compensatory hypertrophy of left intercostal arteries was not observed.

Two additional dogs with a left-sided aortic arch exhibited a solitary aberrant vessel arising from the descending aorta, coursing caudally, and terminating within the left caudal lung lobe. Systemic-to-pulmonary arterial shunts have been reported in several canine case studies [20–25]. Most veterinary descriptions characterize these shunts as hypertrophic, tortuous bronchoesophageal arteries [20–23]. Such hyperplasia may be congenital or acquired secondary to chronic hypoxia or reduced pulmonary arterial flow [23, 26]. In contrast, the two cases reported here showed no bronchoesophageal artery hyperplasia and demonstrated only a single, straight shunt vessel originating directly from the descending aorta. Both pulmonary arteries were identifiable, although mild left pulmonary artery hypoplasia was noted in one individual. No direct communication between the anomalous vessel and the pulmonary arterial tree was observed [27]. No evidence supported an acquired etiology, and apart from the patent ductus arteriosus, no concurrent congenital cardiac defects were identified. In human embryology, persistence of the fifth aortic arch may produce systemic-to-pulmonary connections [1, 28, 29]. Normally, the fifth arches are transient structures located between the fourth and sixth arches that regress early in development [1, 29]. Given that the anomalous vessels described here originated caudal to the ductus arteriosus (a remnant of the sixth arch), persistence of the fifth arch appears improbable. Consequently, the embryological origin remains uncertain, with an aberrant intercostal artery being the most plausible explanation. Although aberrant pulmonary arterial supply from the aorta has been documented in humans [27], comparable canine cases have not been published to date. The vessels observed most likely represent either aberrant nutritive pulmonary vasculature or an accessory pulmonary artery. Occlusion of the vessel in one case produced no clinical sequelae, suggesting limited functional significance.

Study limitations include its retrospective design. Dedicated arterial-phase CT angiography was not performed in every patient, as thoracic imaging was frequently conducted for indications unrelated to suspected vascular pathology. Nevertheless, late-phase contrast enhancement provided adequate visualization of the aortic arch. The modest number of dogs with persistent right aortic arch precluded meaningful epidemiological analysis of malformation distribution. Referral bias toward cardiac cases at the authors' institution may have enriched the population with cardiovascular anomalies.

Conclusions

This investigation documents the spectrum and prevalence of aortic arch anomalies identified by thoracic CT in a canine population. The results highlight the need for refined subclassification of persistent right aortic arch, with at least two previously unrecognized variants identified, yielding a minimum of nine distinct forms in dogs. An expanded classification framework is therefore proposed. Additionally, an aberrant right subclavian artery in dogs with a left aortic arch may constitute an incidental, clinically silent finding. Prospective studies involving larger cohorts are required to validate these observations.

Abbreviations

CT=Computed tomography
PDA=Persistent ductus arteriosus

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Conflict of Interest: None

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Ethics Statement: As a retrospective study, all data sets were acquired from clinical patients using standard veterinary practice, and no animal care and use protocol was required. All patient owners provided written informed consent prior to enrolment in the study.

References

1. Hanneman K, Newman B, Chan F. Congenital variants and anomalies of the aortic arch. Radiographics. 2016;37(1):32–51. doi:10.1148/rg.2017160033
2. Gould SW, Rigsby CK, Donnelly LF, McCulloch M, Pizarro C, Epelman M. Useful signs for the assessment of vascular rings on cross-sectional imaging. Pediatr Radiol. 2015;45(13):2004–16. doi:10.1007/s00247-015-3424-7
3. Morgan KRS, Bray JP. Current diagnostic tests, surgical treatments, and prognostic indicators for vascular ring anomalies in dogs. J Am Vet Med Assoc. 2019;254(6):728–33. doi:10.2460/javma.254.6.728
4. Henjes CR, Nolte I, Wefstaedt P. Multidetector-row computed tomography of thoracic aortic anomalies in dogs and cats: Patent ductus arteriosus and vascular rings. BMC Vet Res. 2011;7(1):57. doi:10.1186/1746-6148-7-57
5. Joly H, D'Anjou M, Huneault L. Imaging diagnosis—CT angiography of a rare vascular ring anomaly in dog. Vet Radiol Ultrasound. 2008;49(1):42–6. doi:10.1111/j.1740-8261.2007.00315.x
6. Pownder S, Scrivani PV. Non-selective computed tomography angiography of a vascular ring anomaly in a dog. J Vet Cardiol. 2008;10(2):125–8. doi:10.1016/j.jvc.2008.09.003
7. Patterson DF. Canine congenital heart disease: Epidemiology and etiological hypotheses. J Small Anim Pract. 1971;12(5):263–87. doi:10.1111/j.1748-5827.1971.tb06231.x
8. Patterson DF. Epidemiologic and genetic studies of congenital heart disease in the dog. Circ Res. 1968;23(2):171–202. doi:10.1161/01.RES.23.2.171
9. Helphrey ML. Vascular ring anomalies in the dog. Vet Clin North Am Small Anim Pract. 1979;9(2):207–18. doi:10.1016/S0195-5616(79)50030-8
10. Ellison G. Vascular ring anomalies in the dog and cat. Compend Contin Educ Pract Vet. 1980;2:693–705.
11. Holmberg DL, Presnell KR. Vascular ring anomalies: Case report and brief review. Can Vet J. 1979;20(3):78–81.
12. Bellenger CR, Warren DF. Esophageal constriction due to aberrant vessels in dogs. Mod Vet Pract. 1970;71:51–3.
13. Buchanan JW. Tracheal signs and associated vascular anomalies in dogs with persistent right aortic arch. J Vet Intern Med. 2004;18(4):510–4. doi:10.1111/j.1939-1676.2004.tb02576.x
14. de Kleer VS. An anomalous origin of the right subclavian artery in the dog. Br Vet J. 1971;127(2):76–82. doi:10.1016/S0007-1935(17)37733-3

15. Donnelly LF, Fleck RJ, Pacharn P, Ziegler MA, Fricke BL, Cotton RT. Aberrant subclavian arteries. AJR Am J Roentgenol. 2002;178(5):1269–74. doi:10.2214/ajr.178.5.1781269
16. Cinà CS, Arena GO, Bruin G, Clase CM. Kommerell's diverticulum and aneurysmal right-sided aortic arch: A case report and review of the literature. J Vasc Surg. 2000;32(6):1208–14. doi:10.1067/mva.2000.108012
17. Saunders AB, Winter RL, Griffin JF, Mankin KMT, Miller MW. Surgical management of an aberrant left subclavian artery originating from a left patent ductus arteriosus in a dog with a right aortic arch and abnormal branching. J Vet Cardiol. 2013;15(2):153–9. doi:10.1016/j.jvc.2013.02.004
18. Scansen B, Townsend K, McLoughlin M. Variants of anomalous left subclavian artery anatomy in dogs with persistent right aortic arch. 2014.
19. Smith J, Koury H, Hafner C, Welling R. Subclavian steal syndrome: A review of 59 consecutive cases. J Cardiovasc Surg. 1994;35(1):11–14.
20. Yamane T, Awazu T, Fujii Y, Watanabe T, Muto M, Okutsu M, et al. Aberrant branch of the bronchoesophageal artery resembling patent ductus arteriosus in a dog. J Vet Med Sci. 2001;63(7):819–22. doi:10.1292/jvms.63.819
21. Fujii Y, Aoki T, Takano H, Ishikawa R, Wakao Y. Arteriovenous shunts resembling patent ductus arteriosus in dogs: 3 cases. J Vet Cardiol. 2009;11(2):147–51. doi:10.1016/j.jvc.2009.04.005
22. Culshaw GJ, Wagner T, Fuentes VL, Schwarz T, Yool DA, French AT, et al. Identification and surgical ligation of aortopulmonic vascular malformation causing left heart volume overload in 4 dogs. J Vet Intern Med. 2013;27(3):583–7. doi:10.1111/jvim.12081
23. Ledda G, Caldin M, Mezzalira G, Bertolini G. Multidetector-row computed tomography patterns of bronchoesophageal artery hypertrophy and systemic-to-pulmonary fistula in dogs. Vet Radiol Ultrasound. 2015;56(4):347–58. doi:10.1111/vru.12247
24. Scollan K, Salinardi B, Bulmer BJ, Sisson DD. Anomalous left-to-right shunting communication between the ascending aorta and right pulmonary artery in a dog. J Vet Cardiol. 2011;13(2):147–52. doi:10.1016/j.jvc.2011.01.003
25. Markovic LE, Kellihan HB, Roldán-Alzate A, Drees R, Bjorling DE, Francois CJ. Advanced multimodality imaging of an anomalous vessel between the ascending aorta and main pulmonary artery in a dog. J Vet Cardiol. 2014;16(1):59–65. doi:10.1016/j.jvc.2013.12.002
26. Roux AL, Granger LA, Reynolds C, Gaschen L. Computed tomography features of bronchial and non-bronchial collateral arterial circulation development in a dog diagnosed with multiple chronic pulmonary thrombi. J Vet Cardiol. 2013;15(4):283–7. doi:10.1016/j.jvc.2013.08.002
27. Fong LV, Anderson RH, Siewers RD, Trento A, Park SC. Anomalous origin of one pulmonary artery from the ascending aorta: A review of echocardiographic, catheter, and morphological features. Br Heart J. 1989;62(5):389. doi:10.1136/hrt.62.5.389
28. Khan S, Nihill MR. Clinical presentation of persistent fifth aortic arch: 3 new cases. Tex Heart Inst J. 2006;33(3):361–4.
29. Gerlis LM, Dickinson DF, Wilson N, Gibbs JL. Persistent fifth aortic arch: A report of two new cases and a review of the literature. Int J Cardiol. 1987;16(2):185–92. doi:10.1016/0167-5273(87)90250-6