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Anatomical anomalies and variations of main thoracic vessels in dogs: a computed tomography study

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KEYWORDS
Persistent left cranial vena cava;
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Abstract *Introduction:* There is scarce information about the prevalence of anomalies and anatomical variations of the main great thoracic vessels in dogs, particularly in dogs without congenital heart disease.
Animals: The study included 878 privately owned dogs.
Material and methods: Computerized tomography (CT) thoracic studies carried out between 2011 and 2014 for a variety of reasons were reviewed. The prevalence of

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Congenital;
Anomalies;
Asymptomatic

anomalies and anatomical variations of the aorta and vena cava, the arterial branches of the aortic arch and the main branches of the intrathoracic veins in dogs with no evidence of congenital heart disease was evaluated. Poor-quality CTs, CTs with thoracic pathology that impaired visualization or those of young dogs with clinical evidence or suspicion of congenital cardiac disease were excluded.
Results: Eight hundred two CT studies were analysed. Eight dogs (1%) showed an anatomic anomaly. The most common anomaly was an aberrant retroesophageal right subclavian artery (n = 7, 0.8%). One dog showed a dilated azygos vein secondary to an interrupted vena cava. Three types of branching of the common carotid arteries were observed: both arteries arising at the same point (type I: n = 506/742; 68.2%), separated (type II: n = 212/742; 28.6%) or from a common trunk (type III: n = 24/742; 3.2%).
Conclusions: Major anatomical variations or anomalies of the main great thoracic vessels in dogs without congenital cardiac disease were rare. An aberrant retroesophageal right subclavian artery was the most common anomaly found. Three slight variations of common carotid artery branching were identified. These findings might be of relevance for surgical or catheterization procedures.
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Abbreviations

ARSA	aberrant right subclavian artery
CdVC	caudal vena cava
CHD	congenital heart disease
CT	computed tomography
PDA	patent ductus arteriosus
PLCVC	persistent left cranial vena cava

Introduction

The main great thoracic vessels in dogs include the ascending aorta, the aortic arch and the descending aorta, the brachiocephalic trunk, subclavian arteries and veins, common carotid arteries, internal thoracic arteries and veins, axillary artery and vein, superficial cervical artery and vein, vertebral arteries and veins, the costocervical trunk, pulmonary arteries and veins, the cranial vena cava and the post-hepatic caudal vena cava and azygos veins [1,2]. These vessels develop during the first few weeks of gestation. Abnormalities during that embryological phase can lead to anomalies or anatomical variations [3].

Arterial and venous vascular anomalies can be classified based on their location within the vascular system as systemic, pulmonary or coronary [4]. According to human literature, the term vascular anomalies comprise vascular malformations and vascular tumours [5]. Patent ductus arteriosus (PDA) represents the most important vascular malformation in veterinary medicine [4]. Vascular anomalies are considered those that may be associated with clinical symptoms, whereas the term anatomical variations is usually reserved for those alterations which do not lead to symptoms. There is, however, a degree of overlap (e.g. anomalies where clinical signs might be extremely rare or only sporadical). Arterial anomalies can be associated with clinical symptoms. For example, dysphagia and regurgitation can be seen in cases of vascular ring anomalies, which are caused in 95% of the cases by a persistent right aortic arch [6]. Aortic arterial anomalies include aortic coarctation [7] interruption of the aorta [8], aneurysms [9] or aortic dissection [10,11]. A failure in the development of the truncus arteriosus can cause aorticopulmonary septal defects [12].

Anatomical variations of the venous vasculature are often considered incidental findings. The most frequently reported is the presence of a persistent left cranial vena cava (PLCVC) [4], which may be detected as an incidental finding during echocardiography [13]. Two configurations of PLCVC are described in dogs, namely complete (where the PLCVC receives blood from veins cranial to the heart) or incomplete PLCVC (where the proximal portion of the PLCVC receives a vein which drains from the left costocervical—vertebral trunk) [14]. It may become significant during certain surgical procedures (e.g. ligation of a PDA or pacemaker implantation) [4]. Congenital heart diseases (CHDs) such as pulmonic stenosis, subaortic stenosis or ventricular septal defects, may occur concurrently with PLCVC [15]. Other anomalies reported include absence of the caudal vena cava (CdVC) and aberrant caudal venous return via a left azygos [16] and, rarely, cranial vena cava aneurysms [17].

With the exception of PDA and vascular ring anomalies, there are few studies that evaluate the prevalence of different cardiovascular congenital abnormalities in dogs, and the existing studies largely focus on CHD that cause clinical signs, such as heart murmurs, and are confined to referral populations [15,18,19]. A study investigating the genetic inheritance of CHD in dogs, which included vascular abnormalities in 290 animals with CHD, reported PDA in 82/290 (28.3%) as the most common CHD, followed by persistent right aortic arch in 23/290 (7.9%) and PLCVC in 13/290 (4.5%) dogs [20]. Similarly, Tidholm [18] described PDAs in 18/152 (11.1%) dogs diagnosed with a CHD and, more recently, Oliveira et al. [15], identified 237 PDA (20.9%) and nine PLCVC (0.8%) from 1,132 congenital cardiac defects in 976 dogs with CHD.

Computed tomography (CT) scan imaging is a recognized technique for vascular evaluation and is clinically used for this purpose in veterinary medicine [21]. In 1982, Webb et al. [22] used CT for the first time to describe mediastinal venous anomalies in humans, which included PLCVC and anomalies of the left brachiocephalic and azygos veins. Subsequently, many other human medicine publications used CT to describe congenital thoracic vascular anomalies in general [23,24], or more specifically reporting the morphology of the superior vena cava [25] or aortic arch [26]. Others have focussed on investigating the frequency of those anomalies [27], in particular the variations of aortic arch anatomy [28,29].

As the prevalence of thoracic vascular anomalies in asymptomatic dogs without CHD is unknown, the aim of this study was to retrospectively evaluate the presence of anatomical anomalies of the main great thoracic vessels in this group of dogs using thoracic CT.

Animals, materials and methods

In a cross-sectional study data from all canine thoracic CT scans obtained at the Langford Veterinary Services (University of Bristol) from 2011 to 2014 were retrospectively reviewed. A total of 878 dogs were imaged during this period. Age, sex, breed, body weight and the reason for CT were recorded for all dogs. Based on the main clinical problem, the animals were classified into eight different groups: neoplastic, respiratory, neurological, gastrointestinal, surgical, cardiac (acquired), haematological and miscellaneous.

Images were acquired using a Siemens Emotion™ 16-slice multi-slice computed tomography scanner. Images were acquired using a kV of 130, effective mAs was 120 (Care Dose 4D software varies this to body thickness), a pitch of 0.8 with a rotation time of 0.6 s. Images were reconstructed using a B31s (Siemens, Erlangen) algorithm. A detector size of 1.2 mm was used with images reconstructed at 3 mm slice thickness. A commercially available PACS viewer (Osirix™, Pixmeo) was used to reformat the images and 2D sagittal, transversal and dorsal planes were used for evaluation. Contrast and non-contrast studies were included in the study as long as the vascular morphology images were of good quality and clearly defined the lumen, contour and branching of the studied vessels.

Animals with concurrent diseases (e.g. thoracic masses obscuring the thoracic vasculature) that limited the quality of thoracic CT images were excluded. Dogs that had been diagnosed with a CHD or that presented with clinical findings suggestive of CHD (e.g. heart murmurs) were also excluded unless the dog had been evaluated by a cardiologist and CHD had been ruled out. Acquired heart disease was not an exclusion criterion, if the diagnosis (and exclusion of CHD) was confirmed by echocardiographic examination by a cardiologist.

The CTs were reviewed by a trained observer (P.S.-M.), who underwent extensive training by a board-certified specialist in cardiology (D.C.-S.) and a board-certified specialist in diagnostic imaging (C.W.-S.) before the study. All cases were examined following the same standardized protocol, assessing the ascending aorta, the aortic arch and the descending aorta first followed by evaluation of the following branches from the left to right: the left subclavian artery, the brachiocephalic trunk with its arteries the left common carotid, right common carotid and right subclavian artery. Subsequently, the cranial vena cava as well as the post-hepatic segment of the CdVC and the azygos veins were assessed. The superficial internal thoracic, axillary, superficial cervical and vertebral arteries and veins, the costocervical trunk and the pulmonary artery and veins were not specifically evaluated.

The anatomy was determined on the axial images. All vessels were tracked in three different planes: dorsal, sagittal and transversal until classification into definitive category was reached. Any doubtful case for the trained observer was temporarily categorized as unclassified.

The anatomy of the common carotid arteries was further classified into three categories according to their vascular branching (Fig. 1):

- Type I: both common carotid arteries arise from the same point;
- Type II: both common carotid arteries arise separately;

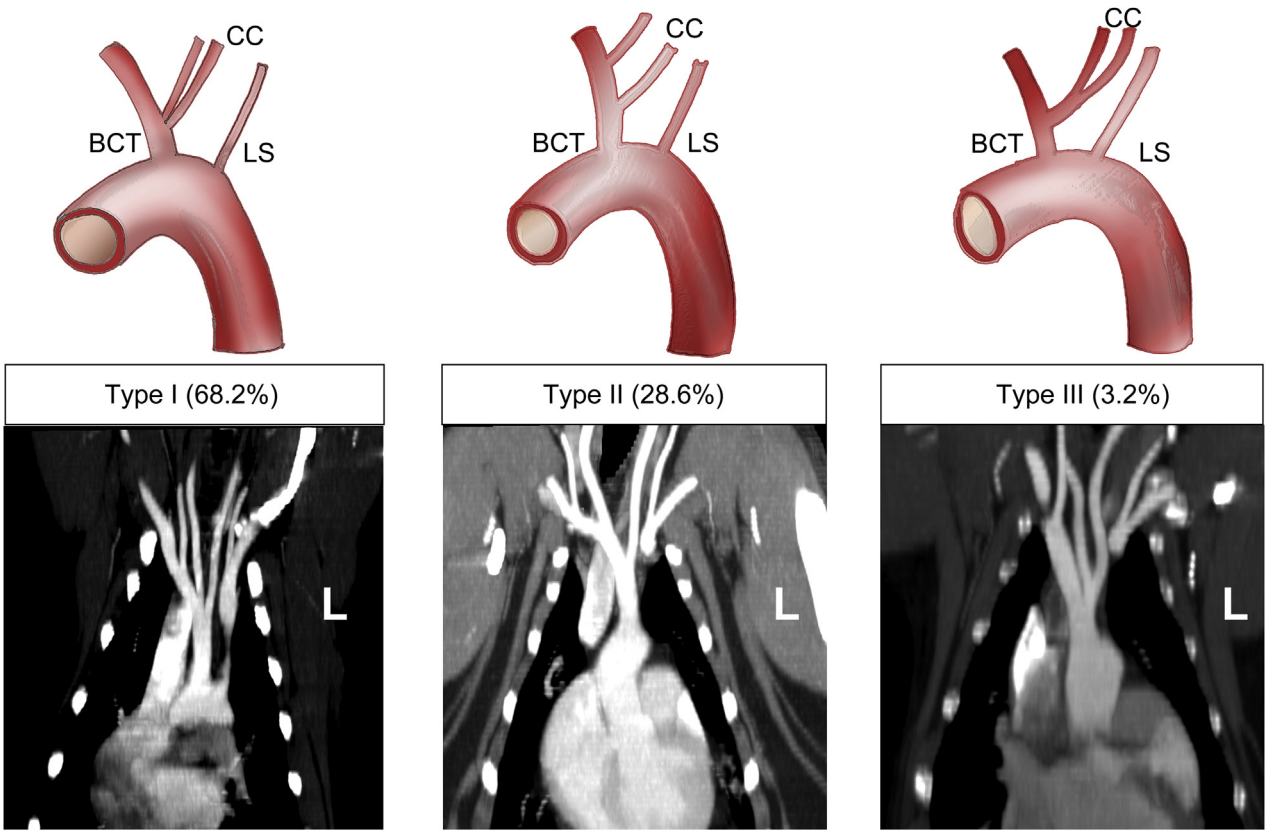

Fig 1 Classification of the common carotid arteries. Schematic pictures of type I, type II and type III common carotid arteries in relation with their contrast enhanced CT image on a sagittal plane below. BCT: brachiocephalic trunk; CC: common carotid arteries, LS: left subclavian artery.

- Type III: both common carotid arteries arise from a common trunk (known as bicarotid trunk).

Dogs, in which concurrent structures (such as localized cranial lung masses) precluded the visualization of the common carotid artery anatomy, were classified as not-assessable. Similarly if the images of this particular area were affected by artefacts (motion or atypical neck position limiting visualization) then these studies were classified as not assessable. In cases where the remainder of the study was diagnostic, these dogs were included in the assessment of the remaining thoracic structures.

Unclassified images were reviewed by three board-certified specialists in cardiology (D.C.-S., K.B., S.F.) and a board-certified specialist in diagnostic imaging (C.W.-S.); a consensus was reached for a final classification. If a consensus could not be reached, the case was included in the non-assessable group.

Descriptive statistics were performed. The Kolmogorov—Smirnov test was used to assess normality of quantitative variables. Age and weight were not normally distributed and results are reported as median and interquartile range. Animals were grouped into weight groups ($<$15 kg, 15—30 kg, $>$30 kg) and brachycephalic versus non-brachycephalic breeds. Comparison between sex, weight groups and brachycephalic breeds with the presence of vascular anomalies and the types of carotid branching pattern were assessed by Chi-squared analysis of contingency tables. Significance was considered at $p<0.05$. To determine significant frequencies, calculation of the standardized adjusted residuals was performed, that corresponds to a Z-value, so values greater than 1.96 indicates that observed frequencies are greater than expected and lower than -1.96 indicates that observed frequencies lower than expected. Data processing and statistical analysis were carried out using Microsoft Excel 2013 and IBM SPSS 22.0 for Windows.

Results

Of the 878 canine thoracic CT studies retrieved from the PACS viewer, 76 were excluded, because

of inadequate image quality (58/76, 76%), mass effect (12/76, 16%) concurrent CHD (5/76, 7%), and one was a post-mortem study (1/76, 1%). A total of 802 CT scans were, therefore, reviewed. In 504 cases contrast studies were available (62.8%). The study population consisted of 441 male (55%) and 361 female (45%) dogs with a median age of 8 years (interquartile range: 5–10 years) and a median weight of 24 kg (interquartile range: 14–31 kg). The population included a wide variety of breeds. The most common dogs included were Labrador retrievers, followed by Springer spaniels, Golden retrievers and Cocker spaniel (Table 1). Of these dogs, 97 (12%) were brachycephalic breeds. Separating dogs into weight groups showed that 210 dogs weighed less than 15 kg (26.21%), 338 dogs weighed 15–30 kg (42.1%) and 254 dogs more than 30 kg (31.7%).

Presenting reasons for CT were: neoplastic (n = 259, 29.5%), respiratory (n = 209, 23.9%), neurological (n = 126, 14.4%), gastrointestinal (n = 57, 6.5%), surgical (n = 67, 7.7%), cardiac (acquired) (n = 16, 1.8%), haematological (n = 55, 6.3%) and miscellaneous (n = 87, 9.9%).

Eight vascular abnormalities were found. Seven dogs had an aberrant right subclavian artery (ARSA) (Fig. 2A and B), and one had a dilated azygos vein secondary to an interrupted CdVC (Fig. 3). The seven ARSA cases included six breeds: two Golden retrievers and one Boxer, Kesshond, Scottish terrier, German shepherd and crossbreed dog each. Four of these were male neutered; three were female spayed. In all ARSA cases, the right subclavian artery branched directly from the aortic arch and passed dorsally to the oesophagus, forming an incomplete vascular ring around the oesophagus. No association was identified between the presence of ARSA and sex, brachycephalic breed or weight groups. A PLCVC was not detected in any of the study dogs. Type I carotid artery branching was the most common form seen in 506 dogs (63.1%). Type II

Table 1 Number of dogs and breeds included in the study.

Number (%)	Breeds
116 (14.5%)	Labrador retriever
55 (6.9%)	Springer spaniel
40 (5%)	Golden retriever
37 (4.6%)	Cocker spaniel
69 (8.6%)	Crossbreeds
31 (3.9%)	German shepherd
31 (3.9%)	Jack Russell terrier
27 (3.6%)	Border collie
22 (2.7%)	West Highland white terrier
21 (2.6%)	Staffordshire terrier
18 (2.2%)	Lurcher
17 (2.1%)	Whippet
16 (2%)	Greyhound
13 (1.6%)	Weimaraner
12 (1.5%)	English bull terrier, flat-coated retriever, Rottweiler, Miniature schnauzer
11 (1.4%)	Pointer
9 (1.1%)	Yorkshire terrier
8 (1%)	Dachshund, Irish setter
7 (0.9%)	Cavalier King Charles spaniel, bullmastiff
5 (0.6%)	Basset hound, Bichon frise, Dogue de Bordeaux, Hungarian vizsla, Siberian husky, Bernese mountain dog, Rhodesian Ridgeback
4 (0.5%)	Beagle, Border terrier, Dalmatian, Labradoodle, Patterdale, poodle, pug, Scottish terrier, Shih Tzu, Tibetan terrier
3 (0.4%)	Alaskan malamute, Cairn terrier, Chihuahua, Welsh corgi, deerhound, Doberman, Great Dane, Irish wolfhound, Petit basset Griffon Vendeen, Irish setter
2 (0.2%)	Airedale, Akita Inu, English bulldog, cockapoo, Fox terrier, Irish Water spaniel, Italian Spinone, Lhasa Apso, Maltese, Newfoundland, saluki, Shar-Pei, Sprocker spaniel
1 (0.1%)	Borzoi, Boston terrier, Chow Chow, Curly-coated retriever, Eurasier, Finnish spitz, Grand Griffon Vendeen, Irish terrier, Keeshond, Leonberger, Lowchen, Manchester terrier, Norfolk terrier, Norwegian elkhound, Old English sheepdog, otterhound, papillon, Parton Russell terrier, Pekingese, Polish Lowland sheepdog, Pyrenean mountain dog, Rough collie, Giant schnauzer, Shetland sheepdog, Spanish Breton, Spanish water dog

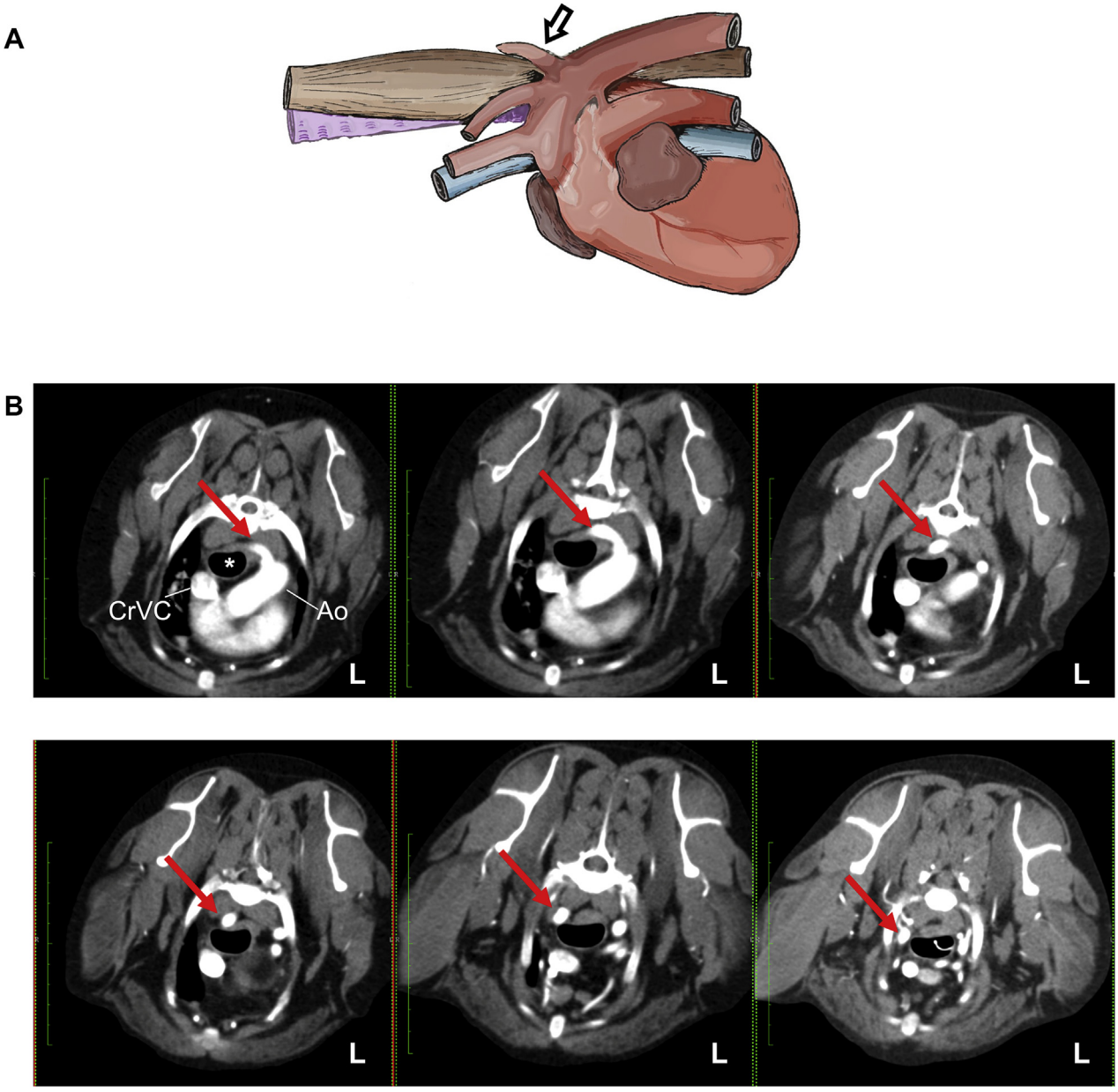

Fig 2 (A) Schematic picture of the aberrant right subclavian artery. The right subclavian artery (arrow) branches from the aortic arch and passes dorsally to the oesophagus forming an incomplete vascular ring around the oesophagus. (B) Contrast enhanced CT image series showing the path of the aberrant right subclavian artery (arrows). CrCV: cranial vena cava. Ao: aorta. The trachea is marked with an asterisk (*).

was identified in 212 dogs (26.4%) and type III in 24 dogs (3%) (Fig. 1). In 60 dogs (7.5%), categorization was not possible. The percentages after excluding these cases were as follows: type I (68.2%), type II (28.6%) and type III (3.2%). The type of carotid artery branching pattern was not associated with brachycephalic breed; however, an association with sex was observed ($p<0.001$), in which type II was more common in female dogs, whereas type I and III were more common in males (Table 2) Furthermore, an association between the weight and type of carotids was found ($p<0.001$), with type III being overrepresented in animals over 30 kg (16/24) and type II underrepresented in this category. It was also found that animals less than 15 kg had more frequently type II and less commonly type I carotid anatomy. In middle-weight dogs (15—30 kg), type III appeared to be less frequent than expected (Table 3).

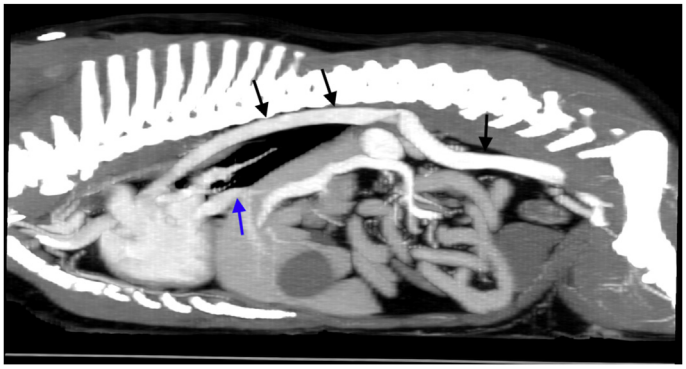

Fig 3 Interrupted caudal vena cava (blue arrow) with an azygos (black arrow) continuation and secondary azygos dilation, observed in one dog (2-D image postcontrast, sagittal plane showing the interrupted caudal vena cava).

Table 2 Distribution of carotid types in female and male dogs.

Sex	n	Type I	Type II	Type III
Female	361	207 (63.9%)^{L} [−2.2]	112 (34.6%)^{H} [3.2]	5 (1.5%)^{L} [−2.3]
Male	441	299 (71.5%)^{H} [2.2]	100 (23.9%)^{L} [−3.2]	19 (4.5%)^{H} [3.3]
Total	802	506 (68.2%)	212 (28.6%)	24 (3.2%)

[ ]: adjusted standardized residuals; H: observed proportion significantly higher than expected based on standardized adjusted residuals ($p<0.050$); L: observed proportion significantly lower than expected based on standardized adjusted residuals ($p<0.050$).

Table 3 Distribution of carotid types in different weight groups excluding the non-assessable cases.

Weight	n	Type I	Type II	Type III
<15 kg	210	116 (62.0%)^{L} [−2.1]	67(38.5%)^{H} [2.5]	4 (2.1%) [−1.0]
15—30 kg	338	220 (70.7%) [1.3]	87 (28.0%) [−0.3]	4 (1.3%)^{L} [−2.5]
>30 kg	254	170 (69.7%) [0.6]	58 (23.8%)^{L} [−2.0]	16 (6.6%)^{H} [3.6]
Total	802	506 (68.2%)	212 (28.6%)	24 (3.2%)

[ ]: adjusted standardized residuals; H: observed proportion significantly higher than expected based on standardized adjusted residuals ($p<0.050$); L: observed proportion significantly lower than expected based on standardized adjusted residuals ($p<0.050$).

Discussion

This study reports a low incidence of major anatomical anomalies or variations of the main great thoracic vessels in a large population of dogs without CHD. An ARSA was the principal anomaly detected. Three different frequent anatomical slight variations of common carotid artery branching pattern were observed, with both carotids arising from the same site being the most common (type I).

The prevalence of congenital thoracic vascular anomalies in this population was approximately 1%, which is similar to that reported in human medicine. In humans without CHD, the prevalence of thoracic arterial anomalies has been reported at 1.5%, with venous anomalies at only 0.7% [27].

An ARSA was the most common anomaly in this study with a prevalence of 0.8%; here, the right subclavian artery arises directly from the aortic arch and passes dorsal to the oesophagus, sometimes called a 'retro-oesophageal right subclavian artery'. This forms an incomplete vascular ring anomaly, where the oesophagus was mildly compressed between the vessel dorsally and the trachea ventrally, but it is not enough to cause clinical signs such as obstruction or dysphagia (Fig. 2A and B). An almost identical prevalence (3/275; 1.1%) was reported in a review of necropsy findings in 275 dogs [30]. In humans as in dogs, ARSA is the most common congenital anomaly of the aortic arch, with a reported incidence between 0.5% and 2%. This anomaly is mainly considered an incidental finding [27,29]. However, in rare cases, clinical signs such as dysphagia, which is referred as *dysphagia lusoria*, can occur [27,29]. Interestingly, there is a single case report of ARSA being associated with regurgitation in an adult dog [31].

The other incidental anomaly found in our study was an interrupted CdVC with azygos continuation and secondary azygos dilation observed in one dog (Fig. 3). This anomaly is well described in dogs. It seems more common in female dogs [32], as was the case in our study. Although it is considered an incidental finding, complications associated with thrombosis can occur [32]. Furthermore, an

association of interrupted CdVC and portosystemic shunts has been reported [33]. However, neither finding was present in the dogs within our population.

In human medicine, PLCVC is considered the most common thoracic venous anomaly, with a general prevalence of 0.3% in patients without CHD [34]. A large paediatric study, reported a prevalence of 2.9% in a population of children with CHD versus a prevalence of 0.56% [35] in children without CHD. In veterinary medicine, there is just one recent study investigating the imaging characteristics of PLCVC diagnosed as an incidental finding. This study included a similar number of dogs (n = 979) as our study, and PLCVC was found in 2.6% of them [36]. Interestingly, PLCVC was not observed in our population. The most likely explanation for this discrepancy is the difference of the studied populations, which highlights the caution required when extrapolating results of such studies to the general population. The study by Choi et al. (2016) [36] encompasses dogs from South Korea with a high proportion of small breed dogs among the breeds studied. Nearly 80% of cases with PLCVC in the mentioned study are Shih-Tzus or Pekingese [36]. In our study, only four Shih Tzus and one Pekingese were present, and the percentage of dogs under 10 kg and 5 kg was 13.1% and 2.1%, respectively; the main dog breeds were large breeds, with Labrador retriever (14.5%), English springer spaniel (7%) and Golden retriever (5%) being the most common.

For the purposes of this study, the branching pattern of the common carotid arteries was reviewed and classified into three different anatomical variations. Previously, limited information about the anatomy of the carotid vessel origin in dogs has been published. It is described that the common carotid arteries in dogs typically arise from the brachiocephalic trunk, approximately 10 mm apart (varying from 1 mm to 15 mm). A 'bicarotid trunk' (truncus bicaroticus) has also been reported, where both common carotid arteries arise from a common vessel [1]. In this population, the majority of dogs had type I (68.2%), with type II accounting for 28.6% and type III detected in 3.2% of dogs. Sixty animals (7.5%) could not be classified owing to inadequate imaging quality. A large human study described up to seven different aortic arch branching patterns [29], and an association between the branching pattern of the arterial vessels and human race was observed [29]. In our study, no association of type and different breed morphotype (brachycephalic versus non-brachycephalic breeds) was found. However, we detected a correlation with sex and weight. More female dogs had a type II, whereas male dogs had a higher proportion of type I and III. Albeit statistically significant, these differences are small and unlikely of clinical significance. An association was also found with weight, which showed that dogs less than 15 kg had more commonly a type II and less type I than expected; in middle-weight dogs (15—30 kg), type III was underrepresented, and dogs more than 30 kg had more often type III carotids. This may present breed-associated prevalences; however, owing to the wide range of breeds, further associations could not be investigated. These differences were also small and of dubious clinical significance. In humans, 29% of people with ARSA also had a common carotid trunk [29]. In our study, three of the seven dogs with ARSA had a common carotid trunk. This may suggest an association of these two anomalies in dogs, similar to humans, but further investigations of a larger population of dogs would be required to confirm this.

Limitations of this study include the absence of a uniform protocol for image acquisition and the lack of contrast studies in 298 cases included. The aim of the study was to describe morphological anomalies of the vasculature, and non-contrast images were considered adequate to obtain accurate information in many cases. We were very strict regarding image quality and cases with inadequate image quality were excluded from the study. Furthermore, unclear cases were reviewed by a panel of specialists and doubtful cases were excluded from the analysis.

Other limitations of this study include its retrospective nature and that no comparison of CT findings with post-mortem investigations was performed in any of the cases. Several cases exhibited thoracic pathology (e.g. mediastinal masses) that precluded complete assessment of the thorax and anomalies might have been missed. In addition, as the study was performed in a referral hospital population, the results may not represent the general dog population. Furthermore, although strict scrutiny was carried out, echocardiography was not obtained in all cases and CHD cannot be fully excluded in all patients.

Conclusions

Major thoracic anomalies and anatomical variations of the aorta and vena cava, the arterial branches of the aortic arch and the main branches of the intrathoracic veins in dogs without CHD were rare (1%). An ARSA was most common with a

total prevalence of 0.8% within the population. No cases of PLCVC were identified. Three frequent slight variations of carotid bifurcation were detected; most commonly, both carotid arteries originated from the same point. The results obtained are of relevance for descriptive imaging or anatomical studies, and provide valuable information for interventional cardiologists, radiologists, diagnostic imagers and soft tissue surgeons.

Conflicts of Interest Statement

The authors do not have any conflicts of interest to disclose.

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