






ORIGINAL ARTICLE

Computed Tomographic Assessment of the Main Abdominal Vessels in Dogs

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ABSTRACT

Computed tomographic (CT) characterisation of abdominal vessels is poorly studied. The objectives of this retrospective study were to assess during growth, by CT angiography, the evolution of the aorta (Ao), caudal vena cava (CVC), portal vein (PV), length of the second lumbar vertebra (L2) and different ratios between these structures; and to determine the influence of weight and age on the vessels' sizes and ratios. The first group included six beagles scanned every month from 4 to 12 months old, then every 3 months up to 24 months old. The second group included 26 dogs of different breeds and weights that were considered haemodynamically normal. These dogs were divided into three weight intervals: < 10, 10–30 and > 30 kg. The measurements were repeated three times by three operators. The diameter of the Ao, CVC and PV, the aortic length and the L2 length increased up to 7 months. Similarly, the different ratios, such as CVC/Ao, VP/Ao, Ao/L2 and CVC/L2, were variable up to 7 months old and became stable after 7 months. The diameter of the Ao, CVC and PV, the previously cited ratios and L2 length were variable between weight intervals but stable within one interval. The adult vascular standards and ratios published in the literature should not be used in medium-size dogs younger than 7 months old. As variability is observed between the weight intervals, measurements should be used with care in very small or very large dogs.

1 | Introduction

The aorta (Ao), the portal vein (PV) and the caudal vena cava (CVC) are well described in small animal textbooks (Barone 2021; Culp et al. 2015; Evans and De Lahunta 2012; Lehmkuhl et al. 1997; Schwarz and Johnson 2008). These major abdominal vessels are commonly assessed by ultrasonography and can be used for different ratios (D'Anjou and Penninck 2015; Mattoon, Sellon, and Berry 2020; Sartor, Maprim, and Takahira 2010). For example, the diameter of the CVC and its ratio with the Ao are often used to assess volaemia (Cambournac et al. 2018; Darnis et al. 2018; Holland et al. 2020; Kwak et al. 2018). Recently, the diameter of the CVC was also used to estimate volaemia before and after blood donation

(Herreria-Bustillo, Fitzgerald, and Humm 2019), or to control the response to fluid administration (Rabozzi et al. 2020). The major abdominal vessels, including the PV/Ao ratio, are frequently assessed to diagnose congenital or acquired portosystemic shunts by ultrasonography (D'Anjou et al. 2004).

However, computed tomographic (CT) characterisation of normal abdominal vessels is poorly described. Two recent studies have focused on the evaluation of the CVC diameter/circumference. One study evaluates the variability in diameter of the CVC under low blood pressure (Hanazono et al. 2022), and the second describes the trajectory of the CVC during growth in medium- and large-breed dogs (Reeves et al. 2023).

The vertebral length is frequently used in abdominal radiography to calculate different ratios, and in particular to assess renal size (Lobacz et al. 2012), abnormal dilation of small intestine (Graham, Lord, and Harrison 1998) or liver size (Choi et al. 2013). To the authors' knowledge, the evaluation of vertebral length by computed tomography during growth and its correlation with the patient weight intervals has never been published.

The aims of this study were firstly to assess during the growth, the evolution of the diameter of the Ao, CVC and the PV, the length of the Ao and the length of the second lumbar vertebra (L2) and the ratios between those measurements in a small cohort of beagles; and secondly, to determine the influence of weight intervals on the vessels' size and ratios in a cohort of adult dogs of different breeds.

2 | Materials and Methods

2.1 | Animals

This retrospective study was conducted at the University of Liege and included dogs that underwent an abdominal CT angiography examination for research or diagnostic purposes unrelated to the study. Dogs with any congenital vascular malformation or pathology interfering with the main abdominal vessels were excluded.

Two different groups of dogs were defined. The first group (age group) was a cohort of beagle dogs included in a research project unrelated to this study (experimental procedures were approved by the Ethical Committee of Animal Use at the University of Liège, Reference No. 1730; December 2015). Each dog was scanned every month from 4 to 12 months of age, and then every 3 months up to 24 months old according to the protocol of the research project. The second group (weight group) included adult dogs of variable breeds, weights and pathologies, but all were considered haemodynamically normal and were free of any vascular abnormality which could have influenced the diameter of these vessels. This second group was subdivided into three intervals according to the weight of the dogs: < 10, 10–30 and > 30 kg.

2.2 | Measurement and CT Procedures

Abdominal CT scan was performed in lateral recumbency for the first group and sternal recumbency for the second group, both under general anaesthesia. Images were acquired by a 16 slices multidetector scanner (Siemens, Somatom 16, Erlangen, Germany). Acquisition parameters were a tube voltage of 120 kV, a reference tube current of 70–102 mA, a scan rotation of 0.7–1.15 s and a pitch of 0.8. Scan tube current was modulated by automatic exposure control (Care Dose, Siemens Medical Solutions, International). Image data sets were reconstructed using a 200–500 mm field of view, 512 × 512 matrix, 1–2 mm slice thickness and soft tissue medium smooth reconstruction algorithm (B20f or B30f, window level 40 Hounsfield unit (HU) and window width 400 HU). Postcontrast images were acquired directly after manual injection of 2 mL/kg of iodinated contrast medium (Group 1: Sodium ioxitalamate and meglumine

ioxitalamate, Télébrix 35, 350 mg of I/mL, Guerbet, Belgium; and Group 2: Iohexol, Omnipaque 350, 350 mg of I/mL, GE Healthcare, Diegem, Belgium).

For the age group, postcontrast images were acquired immediately and 3 min after the injection of iodinated contrast medium. Measurements of Ao, CVC, PV and L2 length were obtained from the first postcontrast acquisition, corresponding to the early venous phase. For the weight group, postcontrast images were acquired immediately and between 3 and 5 min after the injection of iodinated contrast medium, depending on the dog's weight. Measurements of Ao, CVC, PV and L2 length were taken during the delayed phase. In both groups, an angiographic scan was not performed so arterial phase images were not available.

All measurements were repeated three times by three different blinded operators: a last-year veterinary student, a second-year resident in diagnostic imaging and a board-certified radiologist.

The Ao and the CVC were measured in the dorsoventral direction at three different locations: cranially to the celiac trunk (Ao1 and CVC1), caudally to the left renal artery (Ao2 and CVC2) and cranially to the aortic trifurcation (Ao3 and CVC3) on acquired transverse CT images (Figure 1A). A mean value for the Ao and the CVC was obtained from these three different measurement locations. The aortic length was also measured in the sagittal plane between the celiac trunk and the aortic trifurcation. The PV was measured in the dorsoventral direction caudally to the splenic vein insertion (Figure 1B) on acquired transverse CT images. The length of L2 was measured in the sagittal plane (Figure 1C). CVC/Ao, Ao/L2 and CVC/L2 ratios were calculated.

2.3 | Statistical Analysis

R Core Team software (R version 3.6.2 software, 2019, Vienna, Austria) was used.

In age group, the relationships of segmented measures (Ao1, Ao2, Ao3 and CVC1, CVC2, CVC3) and corresponding segmented ratios (CVC/Ao, Ao/L2 and CVC/L2) with age, segment and reader as fixed effect and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$). A correlation structure between successive ages was added. The relationships of the nonsegmented variables (PV, Ao length and L2) with age and reader as fixed effects and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$). A correlation structure between successive ages was added.

In the weight group, the relationships of segmented measures (Ao1, Ao2, Ao3 and CVC1, CVC2, CVC3) and corresponding segmented ratios (CVC/Ao, Ao/L2 and CVC/L2) with age, sex, neutered status, weight interval, segment and reader as fixed effect and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$). The relationships of the nonsegmented variables (PV, Ao length and L2) with age, sex, neutered status, weight interval and reader as fixed effects and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$).



FIGURE 1 | CT images showing location of measurements: (A) Volume rendering technique (VRT) of the major vessels of the abdomen with location of the aorta (Ao) and caudal vena cava (CVC) measurements (lines) named Ao1, Ao2, Ao3 and CVC1, CVC2, CVC3; (B) Dorsal oblique reconstructed image centred on the portal vein (PV) displayed in soft tissue windowing after intravenous contrast injection, the line perpendicular to the PV and caudal to the splenic vein insertion (splenic v.) represents the level of measurement of the PV; (C) Sagittal reconstructed images displayed in bone window, the line represents the length of the vertebral body of the second vertebra (L2).

As the age group was made up of dogs of a single breed, this group at 24 months old was also compared with dogs of the same weight (<17 kg) of the weight group. The relationships of segmented measures (Ao1, Ao2, Ao3 and CVC1, CVC2, CVC3) and the corresponding segmented ratios (CVC/Ao, Ao/L2 and CVC/L2) with age, sex, neutered status, weight subgroups (age group at 24 months old and weight group <17 kg), segment and reader as fixed effects and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$). The relationships of nonsegmented variables (PV, Ao length and L2) with age, sex, neutered status, weight subgroups (age group at 24 months old and weight group <17 kg) and reader as fixed effects and dogs as random effect were analysed by mixed linear regression models ($p \leq 0.05$).

Permutation analysis of variance was used to test the intra- and interagreements ($p \leq 0.05$).

3 | Results

Six healthy male beagle dogs were included in the first group (age group) and 26 adult dogs were included in the second group (weight group). The mean age of the weight group was 10 years old (4–14 years old) and the mean weight was 24.3 kg (4.1–53.6 kg). There were 12 males of which 6 were neutered, and 14 females of which 12 were neutered.

In the age group, the diameters of the Ao, CVC and PV were statistically different from 4 to 7 months (Figure 2). The growth of the major abdominal vessels stopped at 7 months of age in these medium-sized breed dogs. The Ao decreased in diameter cranially to caudally from the celiac trunk to the trifurcation of the Ao. The diameter of the first location measurement was statistically larger than the diameter of the second or third aortic location measurements, but there was no statistically significant difference between Location Measurements 2 and 3. Unlike the Ao, there was no statistically significant difference between the three location measurements of the CVC. The length of the Ao increased progressively until 8 months of age and stabilised at 9 months of age. The growth of L2 was relatively comparable to that of the major abdominal vessel diameters and was not statistically different after 7 months of age.

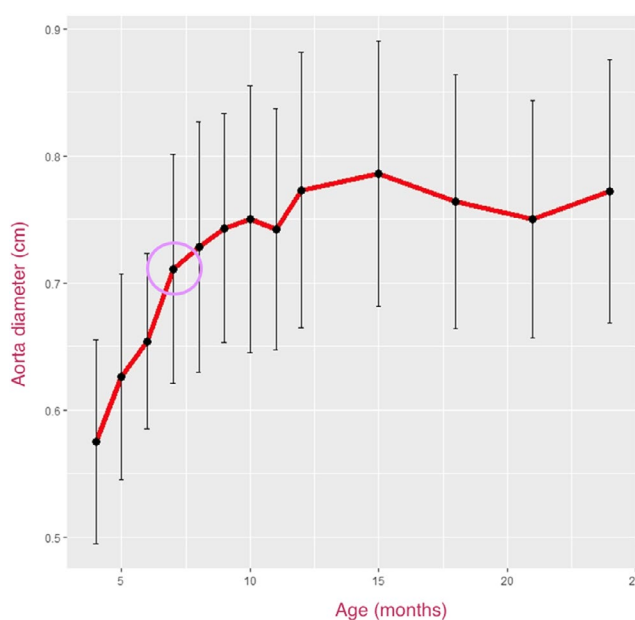


FIGURE 2 | Mean aortic measurements (cm) in relation to age (months). The circle at 7 months indicates the age from which the values of the aortic diameter were no longer considered statistically different.

In the weight group, the mean diameter (with standard deviation (SD)) in transverse section for the Ao, CVC and PV for all dogs are listed in Table 1. The aortic diameter and length increased with increasing weight intervals but were statistically stable within the same interval. As in the age group, the Ao decreased in diameter cranially to caudally from the celiac trunk to the iliac arteries and the diameter of the first location measurement was statistically larger than the diameter of the second or third aortic location measurements, but there was no statistically difference between Location Measurements 2 and 3. The CVC, PV and L2, like the Ao, increased in diameter with increasing weight intervals and were statistically different between the three intervals (Table 1).

In both groups, the CVC/Ao, Ao/L2 and CVC/L2 ratios did not show any statistically significant differences whatever the parameters studied, such as age or weight (Table 2).

TABLE 1 | Mean diameter (cm) with standard deviation (SD) in transverse section of the aorta (Ao), caudal vena cava (CVC) and portal vein (PV) and mean length (cm) with standard deviation (SD) of the second lumbar vertebral body (L2) in the different weight intervals of dogs.

	< 10 kg		10–30 kg		> 30 kg	
	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)	Mean (cm)	SD (cm)
Diameter						
Ao	0.75	0.15	1.06	0.13	1.29	0.19
CVC	0.74	0.19	1.13	0.27	1.36	0.33
PV	0.66	0.2	0.91	0.21	1.05	0.28
L2	1.56	0.2	2.35	0.32	3.01	0.41

Note: There was no significant difference between the dogs within the same weight intervals, but there was a significant difference between the dogs in different weight intervals ($p \leq 0.05$).

TABLE 2 | Values of CVC/Ao, Ao/L2 and CVC/L2 according to the dogs' weight intervals.

	< 10 kg		10–30 kg		> 30 kg	
	Mean	SD	Mean	SD	Mean	SD
Ratios						
CVC/Ao	0.98	0.18	1.07	0.22	1.06	0.21
Ao/L2	0.48	0.07	0.46	0.07	0.43	0.07
CVC/L2	0.47	0.11	0.49	0.12	0.46	0.12

Note: The CVC/Ao, Ao/L2 and CVC/L2 ratios showed no statistical differences between the different weight intervals ($p \leq 0.05$). Abbreviations: Ao = aorta; CVC = caudal vena cava; L2 = length of the second lumbar vertebral body; SD = standard deviation.

No statistical differences were observed concerning the different measurements and ratios between dogs from the age group at 24 months old and dogs from the weight group of < 17 kg.

Regarding the intraobserver agreement, no statistical differences were identified between the three measurements of the same operator. However, regarding the interobserver agreement, statistical differences were observed between the different operators. The student measurements were most often statistically different from the resident's and board-certified radiologist's measurements. No statistically significant difference was observed between the resident and the board-certified radiologist.

4 | Discussion

The increase in diameter of the major abdominal vessels appears to stop at 7 months in the age group. However, growth duration varies according to the breed of the dog (Evans and De Lahunta 2012). Beagle dogs at 24 months old were compared to dogs of similar weight from the weight group, and there was no significant difference in vessel measurements between beagle dogs and dogs of different breeds < 17 kg. Therefore, this age time point can be extended carefully to similar medium breeds, but

should not be translated to dogs from smaller or larger breeds. Knowing the age of vascular maturity is very useful for surgical planning of endovascular procedures in young animals. As an example, when a metal device is necessary, its size needs to be chosen carefully (Konstantinidis et al. 2023; Weisse et al. 2014).

In future studies, it might be interesting to see whether organ growth correlates with the dog's growth. In human medicine, a study comparing the paediatric growth curve of the CVC diameter showed a linear correlation with the size and the age of the patient (Haines et al. 2012).

Our measurements appear to be consistent with what has been previously published in other studies where measurements were performed by ultrasonography, especially regarding the CVC/Ao ratio (Darnis et al. 2018; Holland et al. 2020; Kwak et al. 2018). Moreover, recent studies using computed tomography showed similar results for the CVC measurements (Hanazono et al. 2022; Reeves et al. 2023). As frequently mentioned in the literature (Choi et al. 2013; Graham, Lord, and Harrison 1998; Lobacz et al. 2012), ratios erase the weight differences between the dog breeds and should therefore be prioritised to absolute measurement of the vessels.

To the author's knowledge, a ratio with L2 had never been published for the Ao or CVC. In CT scan, it is very simple measurement to perform and could probably allow for a quick assessment of the blood volume or any other anomalies related to these vessels without comparing two different vessels in between, especially given the limited clinical information available about the patients in teleradiology. Due to the lack of board-certified radiologists or experimented ultrasonographers in private practices, and with the increased number of CT scanners available, teleradiology is being used more frequently to assess dog diseases by CT scan even if some of these diseases could be assessed by ultrasonography.

The interobserver differences can be explained by the lack of experience of one of the operators, as the statistical differences were only observed in the student's results.

Regarding the limitations, only few dogs were included in this study, especially in the age group. Furthermore, in this group, all dogs were beagle dogs. However, this has enabled us to follow ethical rules and reduce the number of animals used in research through refinement.

The number of dogs in the weight group was slightly larger but still limited and was heterogeneous in breeds and weights but this represents more usual clinical conditions.

In our study, patient position was not consistent between the groups. The age group was positioned in left lateral recumbency, which was required by the other research project, while the weight group was positioned in sternal recumbency, as in daily clinical practice. In human medicine, patient position is known to influence the diameter of major vessels, particularly the diameter of the CVC (Ciozda et al. 2015; van Zandwijk et al. 2024). However, to the authors' knowledge, in veterinary medicine, no study has examined the effect of patient position on vessel diameter. To address this potential error between groups, dogs of the

age group, positioned in left lateral recumbency, were compared to dogs of the same weight from the weight group, positioned in sternal recumbency and no statistically significant difference was observed between the age group and the dogs of the same weight from the weight group. For this reason, the position of the patient was considered to have a minimal influence on the measurement of major abdominal vessels in this study.

Another limitation was that the variability of the CVC diameter was not taken into account in this study, and it is known that this vessel can vary greatly depending on different factors such as cardiac disease, anaemia, intra-abdominal mass, hypovolaemia or airway pressure (Hanazono et al. 2022; Meneghini, Rabozzi, and Franci 2016; Rahman et al. 2016). Similarly, to the study recently published by Reeves et al. (2023), transverse sections of the CVC as circular as possible with no area of extraluminal compression were chosen and the most cranial measurement was made slightly more caudally (at the level of the celiac trunk) to minimise the impact of diaphragm movements. Furthermore, all the dogs included were haemodynamically normal during anaesthesia. Consequently, this limitation is considered minimal in our study. In addition, the purpose of this study was also to acquire clinical usable values to use in daily clinical practice, and only a single measurement was chosen rather than measurements involving formulas.

5 | Conclusion

The adult vascular standards published in the literature should not be used in beagle dogs and similar medium-breed dogs younger than 7 months old. As variability is observed between weight intervals, measurements should be used with care in very small or very large dogs. Ratios should be used preferentially to erase the variability in those measurements.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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