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Computed tomographic morphology of the esophagus in brachycephalic dogs (pug, French bulldog, English bulldog)

Diploma thesis

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Claudia Mayer

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1 Introduction

Brachycephalic dogs, including pugs, French Bulldogs, and English Bulldogs, often show gastrointestinal symptoms such as regurgitation, vomiting, and choking on food, with French Bulldogs being particularly affected (1,2). Despite their well-recognized health problems, these breeds demonstrate increasing popularity. Given that affected dogs often endure significant suffering due to their symptoms, a comprehensive approach to diagnosis and treatment is essential to enhance their overall quality of life (3–5).

Because of airway obstructions and increased intrathoracic as well as abdominal pressure structural alterations are common findings in the gastrointestinal tract of brachycephalic dogs and contribute to gastrointestinal symptoms. They include esophageal inflammatory lesions which can be a sign of chronic reflux and sphincter atony often manifesting as regurgitation, vomiting, and aerophagia (6,7). Esophageal redundancy is also a common finding in these dogs and video fluoroscopic studies can reveal dysmotility and hiatal hernia, further worsening these symptoms (8,9). Gastric findings include diffuse inflammation and distinctive pyloric stenosis, often correlated with frequent vomiting of food and chronic gastric dilation. Duodenal mucosa typically appears unremarkable however the afore mentioned changes underline the complexity of alimentary tract abnormalities, emphasizing the importance of different diagnostic tools for effective evaluation and management(6).

Previous imaging studies have tried to find differences between brachycephalic and normocephalic dogs regarding gastrointestinal tract morphology and function. However, most methods have limitations in providing comprehensive information on esophageal position and wall thickness (9–12). Especially, measurements of the esophageal wall thickness are of interest, as chronic irritation and dysmotility may result in thickened walls, similar to the changes observed in many mucosal layers (13). This is why CT could be of special interest for a more detailed analysis of esophageal location, wall thickness, and content (14,15).

Esophageal changes play a significant role, especially in brachycephalic dogs however limited information on esophageal appearance in CT, especially in brachycephalic dogs, exists (15–17). Previous studies highlighted CT's efficacy in detecting esophageal masses, vascular ring anomalies (18,19), and identifying fluid in the esophagus as a potential indicator of gastroesophageal reflux (14,15).

The objective of this study is to contribute to the existing literature by providing additional insights into the morphology of the esophagus in brachycephalic breeds of dogs using CT. To the best of the author's knowledge, there have been no published studies describing systematically the specific appearance of the esophagus in larger populations of brachycephalic breeds of dogs in native CT-scans.

The primary goals of this retrospective study were to identify and describe variations of the dimension, position, and luminal content of the esophagus within three brachycephalic breeds and to assess whether there were differences among these breeds. The hypothesis was that pugs, French Bulldogs, and English Bulldogs exhibit distinct morphological characteristics concerning esophageal placement and wall thickness.

2 Literature

2.1 Normal structure and function of the esophagus

2.1.1 Anatomy

The esophagus originates at the cricopharyngeal sphincter as a direct extension of the pharynx. Predominantly, it runs parallel to the trachea within the thoracic region, where it is positioned more towards the left side. Crucial anatomical structures to distinguish include the common carotid artery, internal jugular vein, as well as the sympathetic trunk and recurrent laryngeal nerve. Upon bifurcation, the esophagus is in a median plane orientation, passing along the right side of the aortic arch. Within the caudal portion of the thoracic segment, it continues ventrally adjacent to the thoracic aorta until it reaches the diaphragm, subsequently traversing the esophageal hiatus. Shortly after entering the abdominal cavity, it arrives at the cardiac portion of the stomach (10,20).

The innervation of the esophagus in dogs involves a complex network of nerves, including twenty-five paired spinal ganglia from C2 to L5. Three major regions are recognized: the cervical region, supplied by paired para-recurrent laryngeal nerves; the cranial thoracic region, supplied by the left para-recurrent laryngeal nerve; and the caudal thoracic and abdominal region, supplied by the vagal trunk. There is also a myenteric plexus through the entire length of the esophagus, serving as a sensory function (10,21).

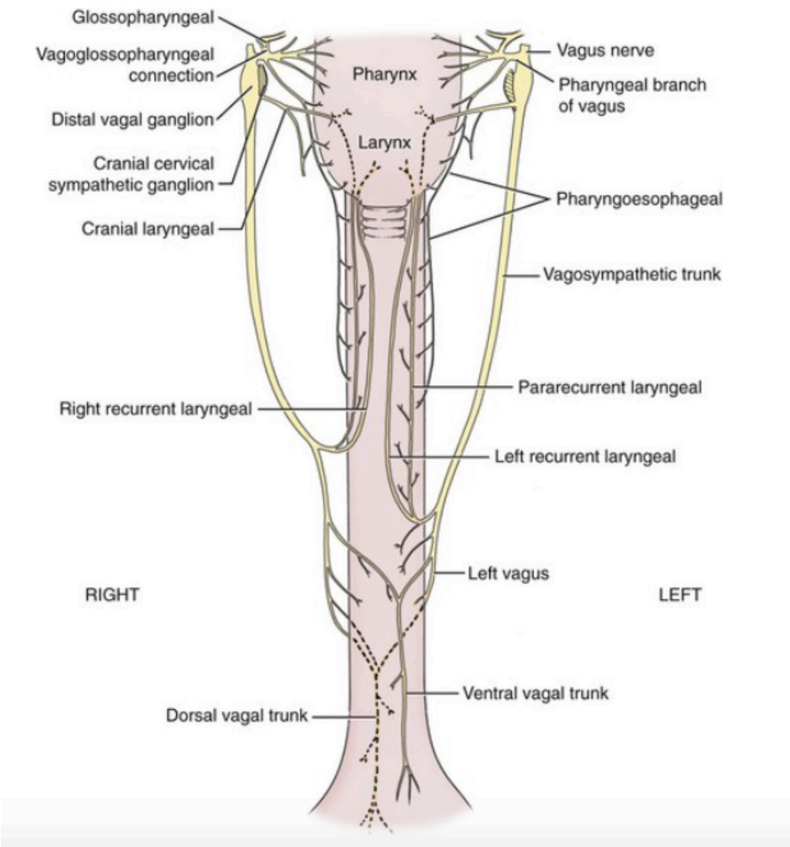

Figure 1. Innervation of the esophagus in the dog (20)

The cervical esophagus is supplied by cranial and caudal thyroid arteries, along with esophageal branches of the carotid arteries. The broncho-esophageal artery primarily supports the cranial two-thirds of the thoracic esophagus, while the caudal part receives blood from aorta or dorsal intercostal artery branches and the esophageal branch of the left gastric artery. Venous drainage is through external jugular and azygos veins, with adjacent veins anastomosing. Lymph vessels from the esophagus drain into various lymph nodes, including the retropharyngeal, deep cervical, and mediastinal nodes (10).

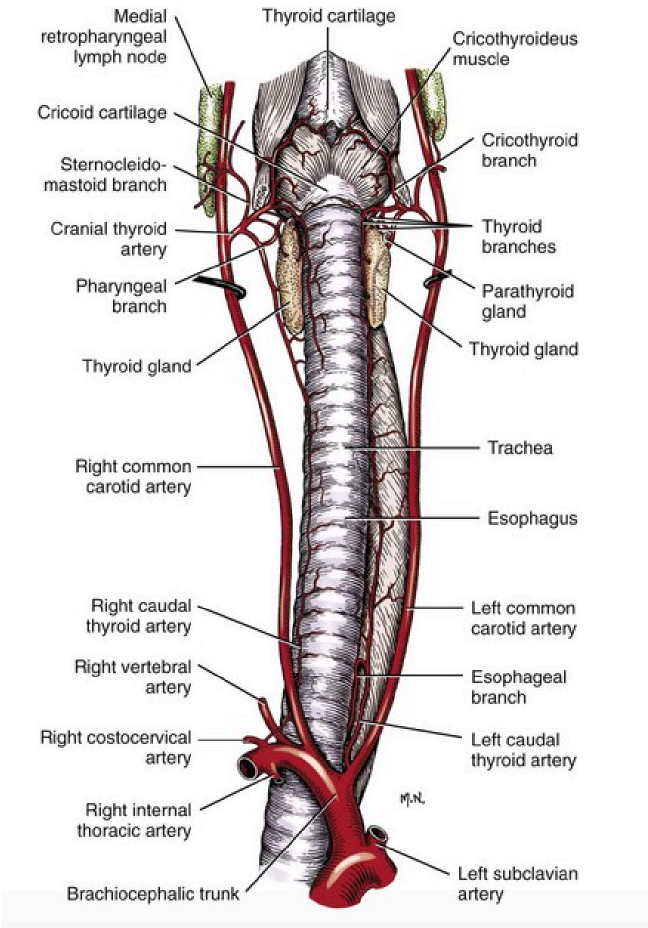

Figure 2. Ventral view of the carotid arteries and their relation to the esophagus and trachea in the dog (20)

2.1.2 Histology

The esophagus consists of four layers: Tunica mucosa, Tela submucosa, Tunica muscularis and serosa. Within the Tunica mucosa three separate layers are identified. These include an innermost epithelial lining, a supporting lamina propria, and a thin layer of smooth muscle, known as the muscularis mucosae. The stratified squamous epithelium of the esophagus changes at the pharyngoesophageal and especially at the gastroesophageal junction, here mucosal characteristics shift abruptly to a columnar gastric epithelium. The lamina propria contains small vessels, veins and glandular ducts (22). The Tunica mucosa forms longitudinal folds and its epithelial expression can also vary depending on the species, food structure and illness (23).

The submucosal tunic contains glands, blood vessels, nerves, and connective tissue, allowing for esophageal expansion. Another prominent feature of this layer are tubuloalveolar glands, especially in the lower third of the esophagus. The muscular tunic, primarily striated, undergoes characteristic changes at both ends of the esophagus, involving a decussating spiral arrangement and transitioning to outer longitudinal and inner circular layers. The Tunica muscularis is, according to its function, strongly developed and varies depending on the species (22).

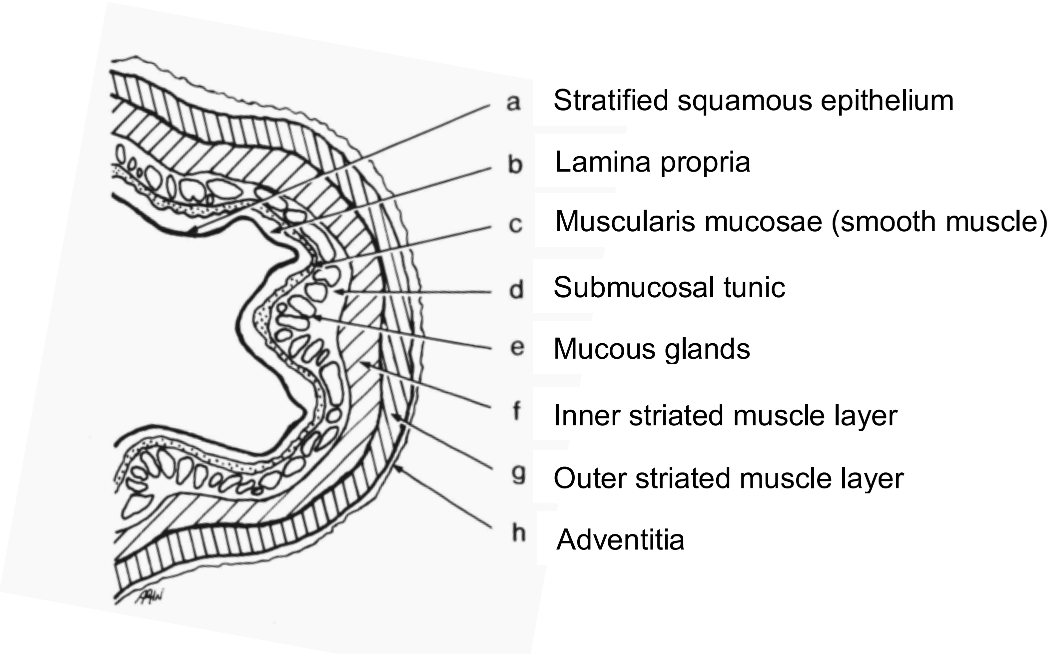

Figure 3. Transverse section through the canine esophagus

2.1.3 Function

The esophagus serves to transport liquids and food from the oral cavity to the stomach. During periods of fasting, both the cranial and caudal sphincters remain closed. When the animal swallows, the cranial esophageal sphincter relaxes, allowing the food to pass into the proximal part of the esophagus. Simultaneously, peristaltic waves propel the food bolus from the esophagus into the stomach. All of this is regulated by the cranial nerves and the swallowing center in the reticular formation (10,24). The vagus nerve supports by controlling the striated muscle of the esophagus, while a myenteric plexus serves a sensory function, synchronizing the movements of striated and smooth muscle. The swallowing reflex is coordinated by various cranial nerves, including trigeminal (V), facial (VII), glossopharyngeal (IX), vagus (X), hypoglossal (XII), and nuclei controlled by the reticular formation (10,24).

A particular study suggested a normal transit time of less than 10 seconds (25), while another recorded transit times ranging from 4.5 to 5.8 seconds, depending on the consistency of the food boluses (26). Notably, there is a lack of reliable studies examining the impact of bolus size on esophageal function, and scant information exists on the typical bolus size in dogs. In a study by Harris et al (26), the bolus area measured on videofluoroscopy was reported to be 3.1 cm^2 (+/- 2.7).

Criteria for proper motility include a smooth and rapid progress of the food bolus along the oesophagus and no retrograde movement of the bolus more than 10 cm (25). Notably, the caudal sphincter, located at the diaphragmatic hiatus, acts as a barrier to prevent the contents of the stomach from re-entering the esophagus, thereby preventing gastroesophageal reflux (GER) (27).

2.2 Diseases of the esophagus

Anatomical differences in the gastrointestinal (GI) tract of brachycephalic breeds are associated with related symptoms. Elevated intrathoracic and abdominal pressures, possibly due to aerophagia, have been proposed as factors contributing to changes in the anatomy of the upper GI tract, such as the esophageal hiatus, when compared to normocephalic breeds (9,17,28). Studies have reported a notably high prevalence of GI diseases in brachycephalic breeds, reaching rates as high as 97% (5,9,29).

2.2.1 Symptoms

Brachycephalic Obstructive Airway Syndrome (BOAS) is a term encompassing various symptoms. These symptoms range from reduced exercise tolerance, sleep disturbances, and heightened sensitivity to heat. In severe instances, owners have reported breathing difficulties and even acute respiratory distress (1). In addition to respiratory issues, owners of brachycephalic dogs frequently observe regurgitation, vomiting, or choking on food, with French Bulldogs appearing to be particularly susceptible to these symptoms (1,2). The connection between brachycephalic airway syndrome and digestive symptoms is reinforced by clinical improvements observed when addressing the former (30).

2.2.2 Gastroesophageal reflux

Reflux refers to the presence of stomach contents in the esophagus (9). Chronic vomiting, gastric emptying disorders, esophagitis, and hiatal hernia (HH) can all contribute to gastroesophageal reflux (GER), which is why these factors should be ruled out before making a diagnosis (27). GER is a significant complication in anesthetized dogs, especially among brachycephalic breeds. Anesthesia leads to reduced muscle tone in the caudal esophageal sphincter, increasing the risk of regurgitation. Brachycephalic dogs are at a higher risk of developing aspiration pneumonia, which can be a life-threatening postoperative complication (31).

The association between upper airway obstructions (UAO) and GER has been well-established (32). UAO in brachycephalic dogs is primarily characterized by stenotic nares, an elongated soft palate, and a hypoplastic trachea. To overcome these obstructions during inspiration, dogs need to exert more effort by actively using their abdominal muscles. This results in increased abdominal pressure and negative pressure within the thorax. It has been suggested that the powerful thoracoabdominal pressure gradients contribute to the development of GER by allowing ingesta, or even worse, bile, to overcome the caudal esophageal sphincter (32).

Esophagitis can also weaken the anti-reflux barrier. Given that 97% of brachycephalic dogs suffer from gastrointestinal diseases, they are at a higher risk of entering a cycle in which GER causes esophagitis and vice versa. A recent study used CT scans to assess the esophageal hiatal rim in brachycephalic dogs and confirmed significant malformations that could play a role in causing reflux and regurgitation (17). In a study on esophageal content in brachycephalic dogs, almost 67% had detectable fluid in the esophagus, compared to 17% of normocephalic dogs. BOAS was a significant factor contributing to the presence of GER, as well as age, gender and body weight (33).

2.2.3 Esophagitis

One major consequence of GER is esophagitis, an inflammation of the esophageal mucosa caused by exposure to gastric acid, bile and other digestive enzymes (7). The inflammation may be localized or diffuse but most often only the distal part of the esophagus is affected. Esophagitis can result in reduced esophageal motility, delayed transit or even stricture of the mucosal folds, which can lead to dysphagia, regurgitation and vomiting (7,34).

Inflammatory diseases of the distal esophagus, stomach, and duodenum have been associated with functional and anatomical abnormalities, including cardial atony, gastroesophageal reflux, gastric retention, pyloric mucosal hyperplasia, and pyloric stenosis (30).

2.2.4 Esophageal stricture and deviation

Esophageal strictures are constrictions of the esophageal lumen and are typically the result of chronic inflammation, trauma, the presence of foreign bodies, or neoplasia. In severe cases, these strictures can lead to obstruction, which can exacerbate gastrointestinal (GI) symptoms and result in weight loss (34).

A condition known as 'redundant esophagus' appears to be common in brachycephalic dogs (6). This anatomical disorder involves a local deviation of the esophageal wall and has been observed in breeds like English Bulldogs and French Bulldogs, as well as in some normocephalic breeds (8). As described in previous studies (8,25), these deviations were typically observed at the thoracic inlet or the cervical part of the esophagus.
Although esophageal deviation may potentially cause GI symptoms, some authors have suggested that there may be no direct association between redundant esophagus and the severity of GI signs (9). Accumulation of fluid, such as saliva and food, can occur in this area, potentially leading to local esophagitis. This accumulation of fluid may also explain previously reported hypersalivation in brachycephalic breeds (9).

2.2.5 Hiatal hernia

The displacement of abdominal organs, typically involving (part of) the stomach, through the esophageal hiatus into the mediastinum is known as a hiatal hernia (HH). In dogs, there are four types of HH, with type I (sliding hiatal hernia) being the most common form (25). Sliding HH has been reported to be associated with brachycephalic dogs suffering from BOAS, with French Bulldogs appearing to be particularly affected compared to other brachycephalic breeds (8,9,25).
Diagnosing HH can sometimes be achieved through plain radiographs, where an empty or gas-filled stomach may be seen overlaying the diaphragm. However, videofluoroscopy has emerged as the gold standard for investigating HH because other imaging methods, including endoscopy, may underestimate the occurrence of HH due to its transient nature (24,25).

2.3 Diagnostic imaging

Previous studies have already researched morphology of the esophagus and have tried to find differences between brachycephalic and normocephalic dogs regarding gastrointestinal tract (GIT) using imaging modalities like endoscopy, videofluoroscopy, radiographs and ultrasonography (9,11,12,35).

2.3.1. Radiography

Typically, the esophagus appears empty on thoracic radiographs, making it challenging to identify. However, in cases where the patient is excited, experiencing dyspnea, or under anesthesia, gas can accumulate in the esophageal lumen, making it more visible. (35). Alternatively, the use of contrast medium-soaked food can be used to highlight the dimensions of the esophagus in radiographs. This positive contrast makes the visualization of strictures, foreign bodies, or dilations in the esophageal lumen easier (21,24,34). Dilations may manifest in either a specific segment or the entire length of the esophagus, a condition called megaoesophagus. (24)

Megaoesophagus can lead to a radiographic sign known as the 'tracheal stripe sign', which is formed by the superimposition of the esophageal and tracheal walls. If clinical symptoms are indicative of esophageal disease and air is detected on radiographs, an esophagram is recommended. The accumulation of gas may also be due to factors like foreign bodies or strictures (35).

Brachycephalic breeds often show symptoms of dysphagia like regurgitation or vomiting (1). A typical consequence of dysphagia can be aspiration pneumonia. Radiographs are often the first step in imaging for the evaluation of the esophagus and for visualizing related pathologies of the lung (6,10,24).

While radiographs can provide valuable information about the location, size, and presence of strictures in the esophagus, they often cannot provide detailed information about the layers of the esophageal wall or the surrounding soft tissues. This makes it less suitable for the detection of esophagitis (7).

2.3.2 Fluoroscopy

Videofluoroscopy using contrast medium, is recognized as the gold standard for assessing pharyngeal and esophageal function. It can detect subtle or temporary changes in the swallowing mechanism (8,26).

This technique helps in identifying issues such as prolonged esophageal transit time, the efficiency of primary and secondary peristaltic waves, and the occurrence of gastroesophageal reflux, bolus retention, as well as sliding hiatal hernia involving the abdominal esophagus and stomach (8,25,26). Brachycephalic dogs, in particular, are prone to disruptions in these functions, leading to symptoms like difficulty swallowing, regurgitation, and subsequently, the development of esophagitis, strictures, deviations, and an increased risk of aspiration (8).

2.3.3 Ultrasound

Transcutaneous and endoscopic ultrasound are valuable tools for evaluating both the cervical and abdominal parts of the esophagus in dogs (12,36). They can provide detailed information about the structure of the esophageal wall, as well as the contents of the lumen and the surrounding soft tissues (10,12). By utilizing an acoustic window through the left hepatic lobe, it is often possible to identify the layers of the esophagus. In a study by Gory et al. (2014), this technique was successful in 89% of dogs.

However, it's important to note that the use of ultrasound in clinically affected dogs is limited to cases with evident wall changes, as subtle histological changes may not be detectable through this method (10). The presence of intraluminal air can make it more challenging to visualize the entire esophageal wall. Additionally, the thoracic portion of the esophagus may be visualized insufficiently due to the presence of ribs and air within the lungs, even though this region is commonly affected by lesions (34).

2.3.4 Endoscopy

Endoscopy, just like videofluoroscopy is a valuable diagnostic tool for assessing both the upper respiratory and digestive tracts in brachycephalic dogs, even when no alimentary tract signs are evident. It allows for real-time evaluation of the esophagus and reveals inflammatory lesions, such as esophagitis as a sign of chronic gastroesophageal reflux or detection of lower esophageal sphincter atony. It also identifies sliding hiatal hernia (HH) and abnormalities at the gastroesophageal junction (6,9,11).

It is important to note that this imaging modality has limitations when it comes to describing the position of the esophagus within the body and in evaluating the esophageal wall thickness and surrounding structures since it can only provide an internal view (14).

2.3.5 Computed tomography

CT scans offer the advantage of evaluating the entire length of the esophagus, encompassing its cervical, thoracic, and abdominal segments. Dogs are typically positioned in ventral recumbency for image acquisition. Natural contrast is often provided by the adjacent lungs (37). Nevertheless the information obtained from pre-contrast images can be limited due to poor delineation of the esophagus from surrounding soft tissues (14). By demonstrating the perfusion of the esophageal wall, post-contrast images enable good delineation and assessment of wall thickness (16).

On CT scans, the esophagus appears as a tubular structure with an ovoid or crescent shape in the cervical and cranial-middle mediastinum regions. Toward the caudal mediastinum, it adopts a more triangular shape and may contain fluid from regurgitation. It is generally in a collapsed state but can also contain gas or fluid, especially in anesthetized animals. For assessing the esophageal wall, a gas-filled lumen is preferred. In veterinary medicine, insufflation of the lumen with gas for diagnostic purposes can be achieved using an orogastric or endotracheal tube, allowing for better delineation of mural conditions against luminal content (14).

In recent years, CT has proven useful in measuring the extent of upper airway anomalies in brachycephalic dogs, which significantly impact their well-being (38,39). While it is known that brachycephalic obstructive airway syndrome (BOAS) often co-occurs with gastrointestinal diseases, there is limited information available regarding the appearance of the gastrointestinal tract, including the esophagus, in CT scans of brachycephalic dogs (15–17).

CT scans can also reveal the presence of esophageal narrowing and help identify the location and extent of strictures. In the past studies have described the value of this modality for detection of esophageal masses (neoplastic vs. non-neoplastic) and vascular ring anomalies which can be the underlying cause of strictures (32). CT allows for further characterization of the mass as well as the surrounding tissues, vessels, mediastinal lymph nodes, and the detection of accompanying lung nodules (18,40).

Fluid or alimentary content in the esophagus can be easily detected with CT and it has been proposed that this could be suggestive of gastroesophageal reflux, especially in the caudal part of the esophagus close to the diaphragm (37). Other diagnosing techniques have proven to be more sensitive because the presence of fluid content is quite dependent on time of scanning and recumbency (15).

In human medicine, CT is used for various indications related to esophageal diseases, most commonly to identify signs of gastroesophageal reflux, inflammation, or neoplasia. While endoscopy and contrast studies are often more sensitive in diagnosing esophagitis in patients, CT scans have shown significantly thicker esophageal walls in individuals with clinical signs matching the diagnosis, suggesting its potential utility (13,41).

3 Materials and Method

3.1 Patient selection and image acquisition

This study uses archived, plain CT datasets of brachycephalic dogs presented at the University of Veterinary Medicine Vienna with symptoms consistent with Brachycephalic Obstructive Airway Syndrome (BOAS).

Electronic medical records TIS® (Tierspital-Informationssystem Orbis Vetware, Agfa HealthCare, Bonn, Germany) and the radiology picture archive and communication system (PACS, Visus, Essen, Germany) were searched. Inclusion criteria were the complete visualization of the esophagus and proper diagnostic image quality. Scans must include the entire esophagus, beginning with the pharynx and ending in the stomach. Studies of poor quality due to blurriness from respiration or due to incomplete display of the esophagus were excluded from the study.

All CT studies were performed using a 16-slice helical scanner (Siemens Somatom Emotion, Siemens Healthcare, Erlangen, Germany) with the dogs in sternal recumbency. Acquisition settings included 110 to 130 kVp, 80 to 180 mAs, a pitch of 1, a scan matrix of 512 x 512, a slice thickness of 0.75 or 1 mm. Field of view (FOV) was adapted to the size of the animal. All data were reconstructed with lung-, bone-, and soft-tissue algorithm.

All dogs underwent general anesthesia and breath-holding technique during thoracic scanning.

3.2 Image analysis

Images were analyised by the diploma student (C.M.) after training with the supervisor (E.L) using images subsequently not included in the study. A dedicated workstation and imaging software ((JiveX Diagnostic Advanced, Visus, Essen, Germany) was used. Measurements were conducted using soft tissue window setting (window level: +40 HU, window width: 400 HU). For all other parameter the whole spectrum of analyzing tools could be applied.

The esophagus was evaluated transversely in five different levels along its course through the thorax. Measurements were made according to specific criteria and data was collected in an Excel sheet sorted by breed (pugs, French bulldog, English bulldog).

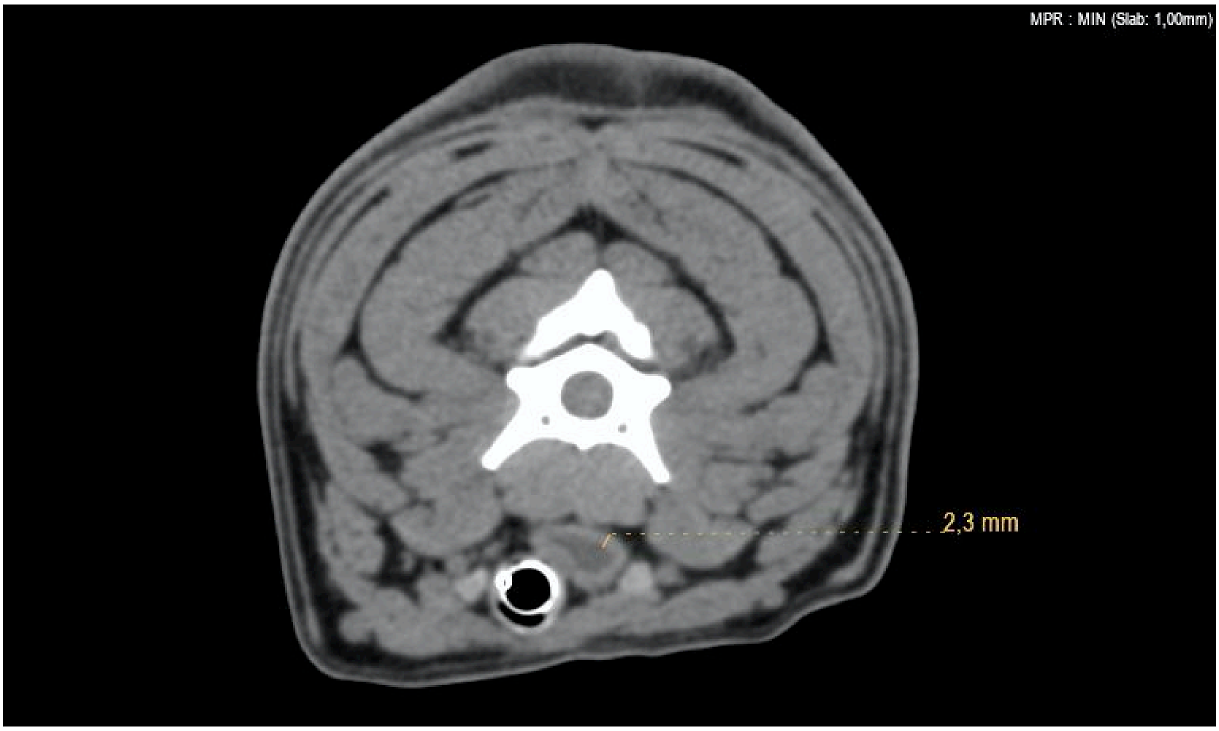

Figure 4. Representative pre-contrast CT image of a French Bulldog at the level of the third cervical vertebra

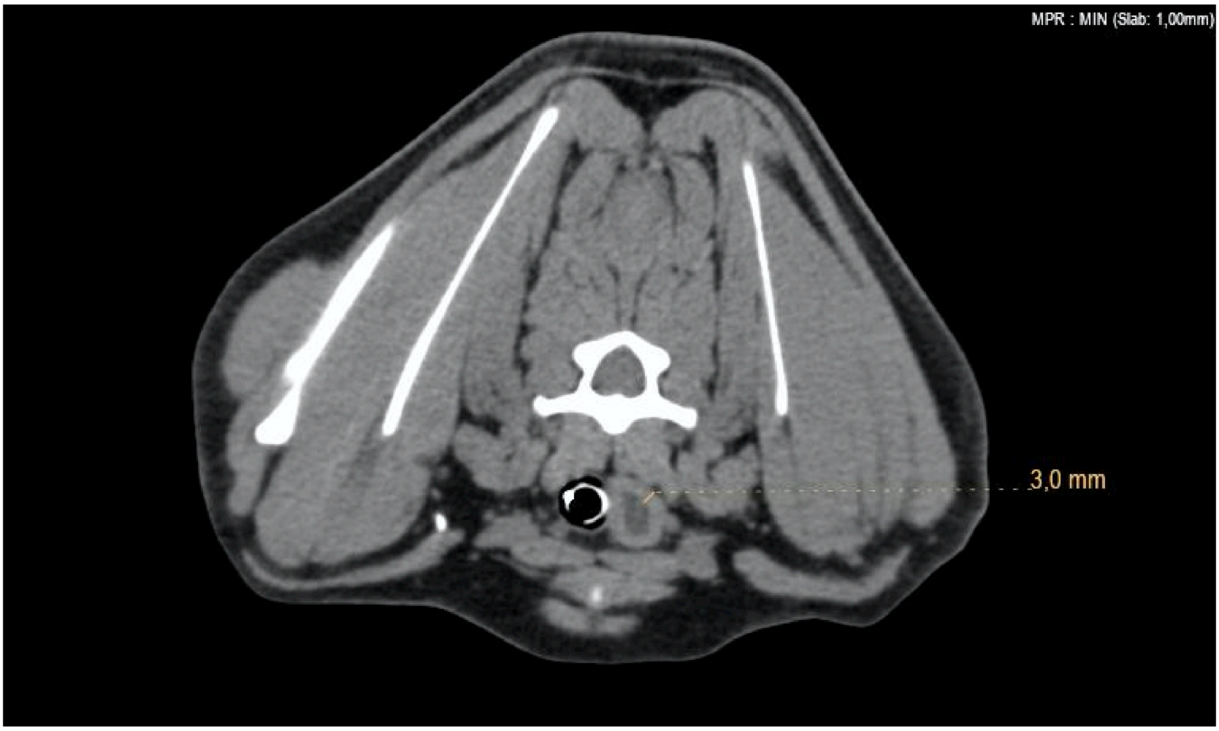

Figure 5. Representative pre-contrast CT image of a French Bulldog at the level of the cranial manubrium sterni

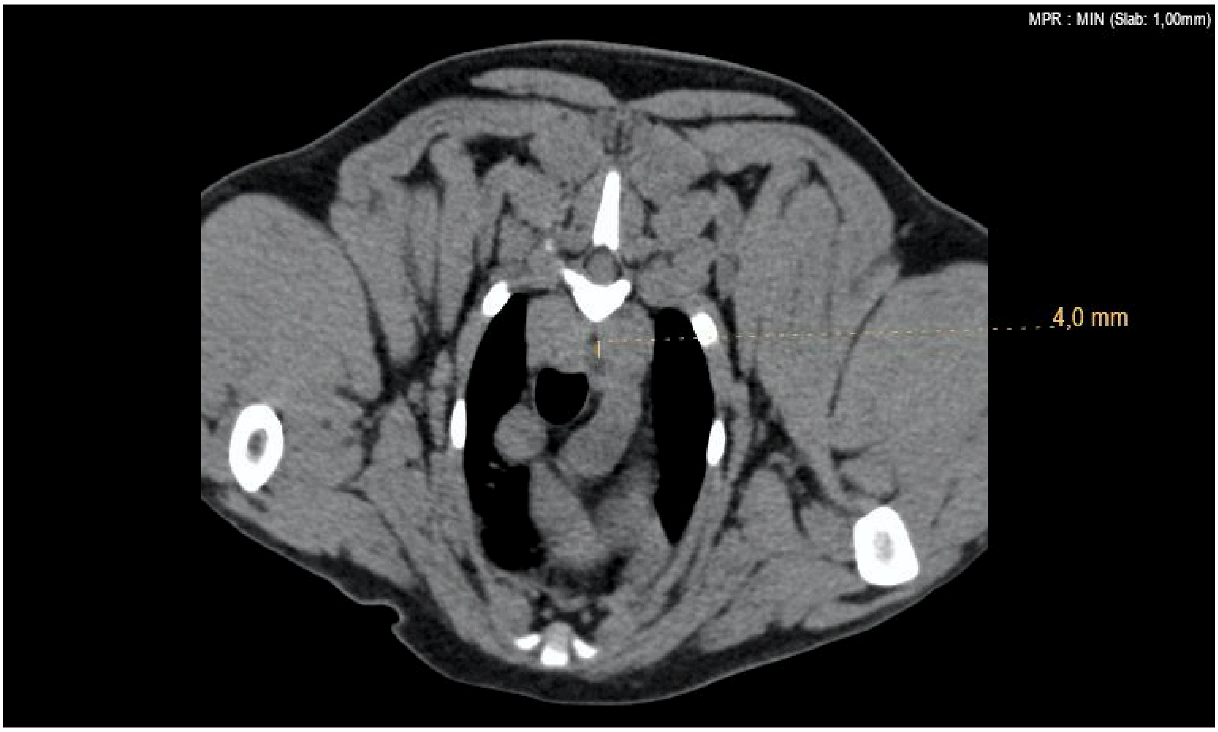

Figure 6. Representative pre-contrast transverse CT image of a French bulldog obtained at the level of the aortic arch

Figure 7. Representative pre-contrast CT image of a French Bulldog at the level of the tracheal bifurcation

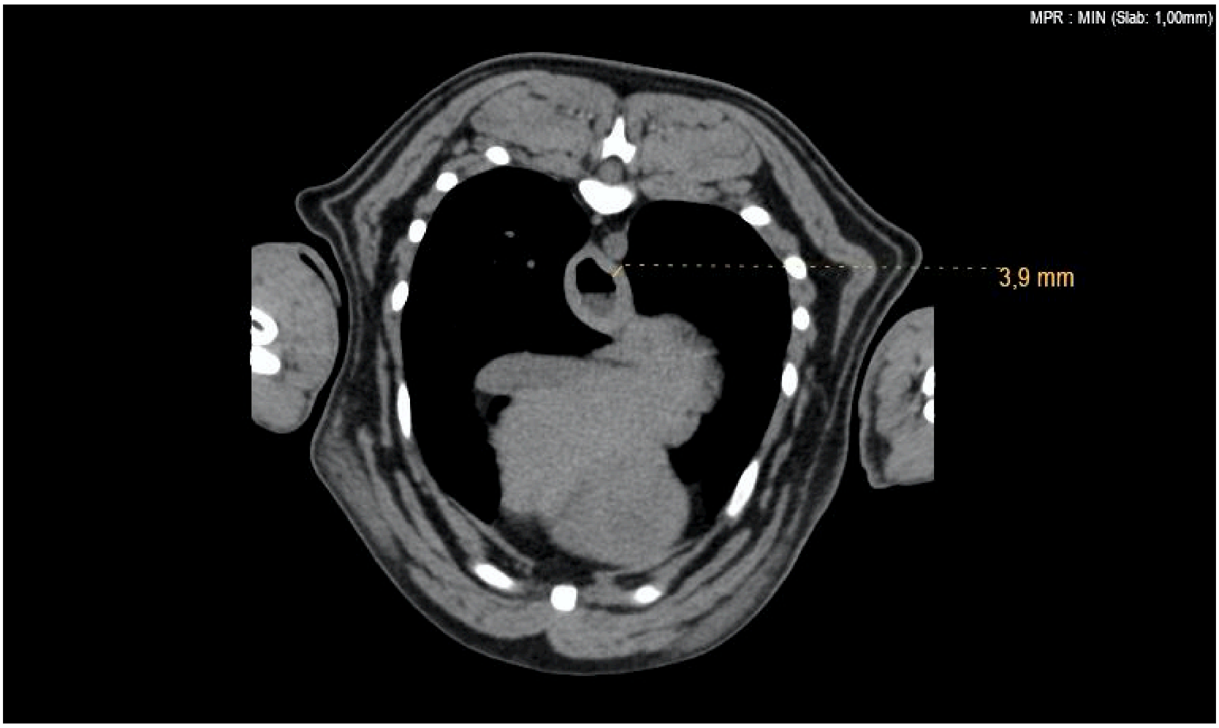

Figure 8. Representative pre-contrast CT image of a French Bulldog close to the diaphragm.

The location of the esophagus compared to the trachea was recorded as well as length, width, and wall thickness of the esophagus. If wall thickness could not be measured properly it was left out. Filling with gas was scored subjectively from 0 to 2 (0 = empty, 1 = mild, 2 = marked). Other special structures (e.g. focal dilatations) between the thoracic aperture and the esophageal hiatus were noted additionally. To relate the esophageal width with body size, the width of the spinal canal at C3 and C6 was measured and a quotient was generated.

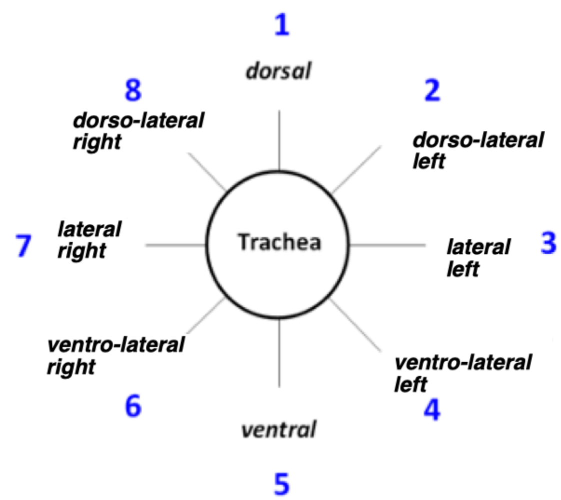

Figure 9. The position of the esophagus in relation to the trachea was documented with numbers 1-8. Each number representing a position according to the graph © E.L.

3.3 Statistical analysis

Descriptive statistics were made for esophageal wall thickness, width, and height. The amount of intraluminal air and position of the esophagus in relation to the trachea was noted and the distribution was represented graphically. Wall thickness, width, and height were compared regarding their difference in each of the five anatomical locations and whether there were significant differences between pugs and French bulldogs using the Mann-Whitney-U test. P-values of ≤ 0.05 were considered significant. Statistical analysis was performed using IBM SPSS version 24 software (IBM Corp., Armonk, New York, USA).

4 Results

4.1 Study population

After searching the radiology picture archive a total of 70 dogs were included in this study, 38 French Bulldogs, 24 pugs and eight English Bulldogs. Three French Bulldogs and four English Bulldogs were excluded as their scans did not cover the entire length of the esophagus. Due to the limited number of remaining English Bulldogs, they were not included in the statistical analysis. In the French Bulldogs which met the inclusion criteria, the mean age was 41 months, ranging from 5 to 133 months old, and the mean weight was 12.06 kg, with weights ranging from 6.2 to 16.3 kg. Pugs had a mean age of 56 months, ranging from 12 to 149 months, and the mean weight was 8.19 kg, with weights ranging from 6.2 to 11.2 kg. The gender distribution included 14 intact females, 13 neutered females, 30 intact males, and six neutered males. All dogs underwent general anesthesia and were intubated before undergoing CT examination. The indication for CT examination was the presence of symptoms correlating with Brachycephalic Obstructive Airway Syndrome (BOAS).

4.2 CT findings

4.2.1 Position of the esophagus

The position of the esophagus was consistently identified in all dogs. In the case of most French Bulldogs, it entered the cervical region dorsally (49%) or dorsolaterally on the left side (46%). As it progressed to the level of the cranial manubrium sterni, it continued laterally (57%) or ventrolaterally (29%), often inclined to the left. It remained on this side for the majority of its course and then moved dorsally again at the level of the tracheal bifurcation (97%) (Fig. 10).

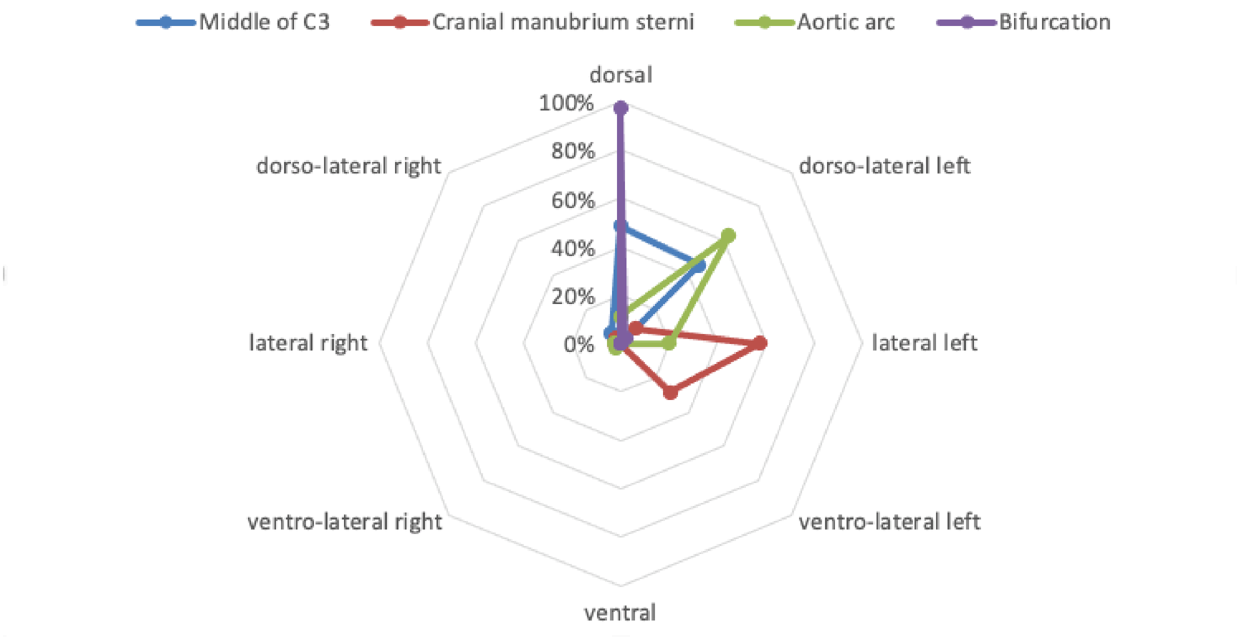

Figure 10. Position of the esophagus in relation to the trachea in French bulldogs at four different locations.

The esophagus of pugs showed a similar course as seen in the diagram below (Fig.11). Along the neck it remained dorsal to the trachea or deviated slightly to the left. Upon entering the thoracic cavity, it positioned itself on the left side of the midline and then shifted dorsally again at the level of the tracheal bifurcation.

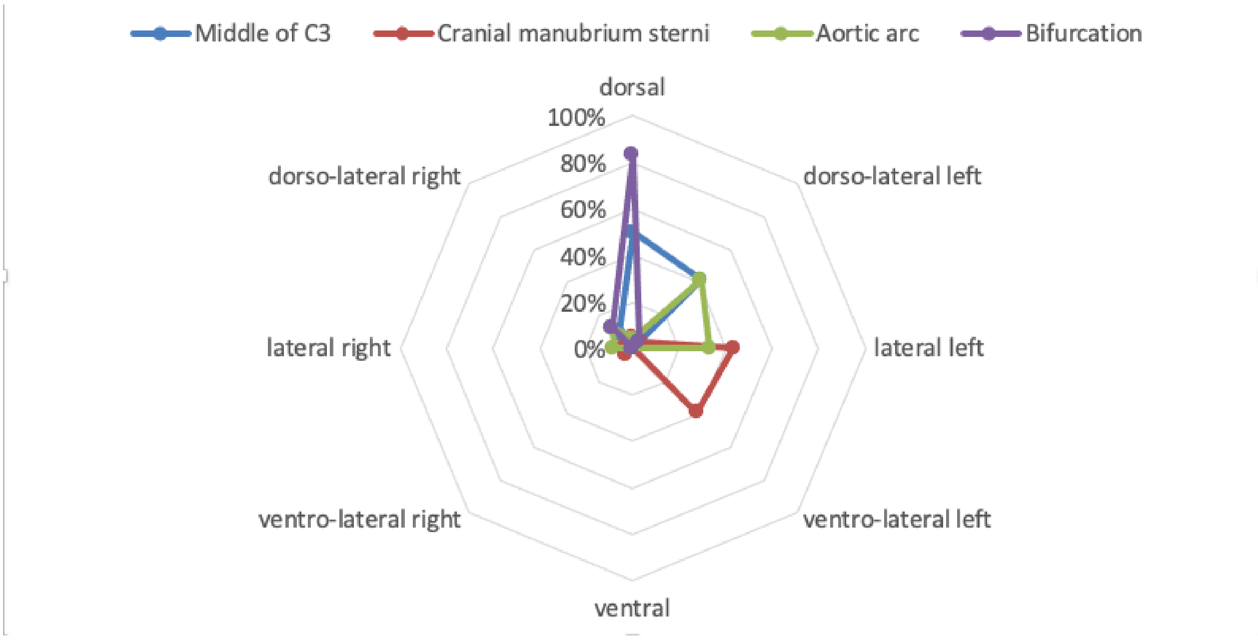

Figure 11. The position of the esophagus in relation to the trachea in Pugs was evaluated in four different locations. The graph shows the frequency of occurrence at previously defined positions (dorsal, dorso-lateral left, …)

In English Bulldogs, the esophagus was identified dorsolaterally on the left side in the neck region, shifting to a lateral or ventrolateral position at the thoracic inlet. Subsequently, it returned to a dorsolateral position, and at the level of the tracheal bifurcation, it consistently assumed a dorsal position in all dogs.

4.2.2 Intraluminal gas

Gas was detected in the esophagus of 27 out of 35 (77%) French Bulldogs at some point during the examination. Among these dogs, the esophagus was mildly dilated with gas in 22 out of 35 (62%) cases, while 5 out of 35 dogs (14%) had moderate amounts of gas in the esophagus. Gas accumulation was most prominent at the thoracic inlet and near the diaphragm. In these locations, 20 dogs (57%) each had at least a mild gas-filled esophagus. On the level of the aortic arch, intraluminal gas was rarely observed and was only mildly visible in 3 dogs (9%). Moderate amounts of gas were mostly noted in the cranial parts of the esophagus (Fig 12).

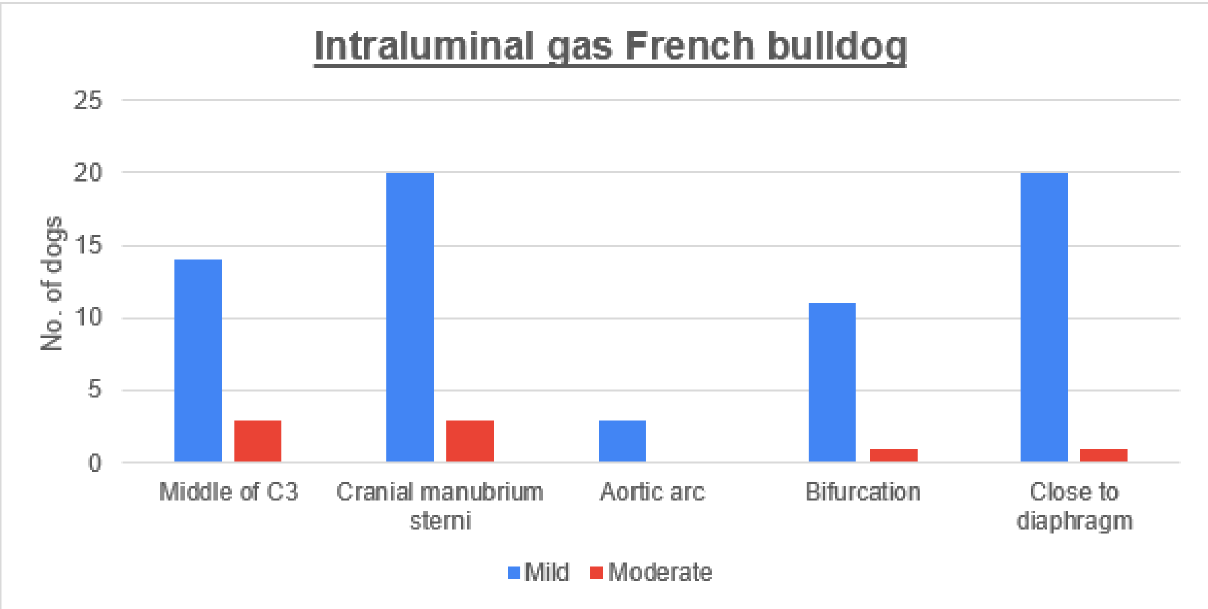

Figure 12. The number of French Bulldogs with intraluminal gas was documented. It was noted whether there was mild or moderate amount of gas in the esophagus in five different locations

In pugs, gas was observed in the esophagus of 23 out of 24 dogs (96%), with 16 dogs (67%) displaying mild gas filling, and 7 dogs (29%) having a moderate amount of gas in one or more anatomical locations. Gas accumulation was most frequently detected near the diaphragm, with 22 out of 24 Pugs showing mild or moderate intraluminal gas at this level. Additionally, the distribution of gas primarily concentrated in the cranial parts of the esophagus, with 14 out of 24 dogs exhibiting at least mild amounts of intraluminal gas (Fig. 13).

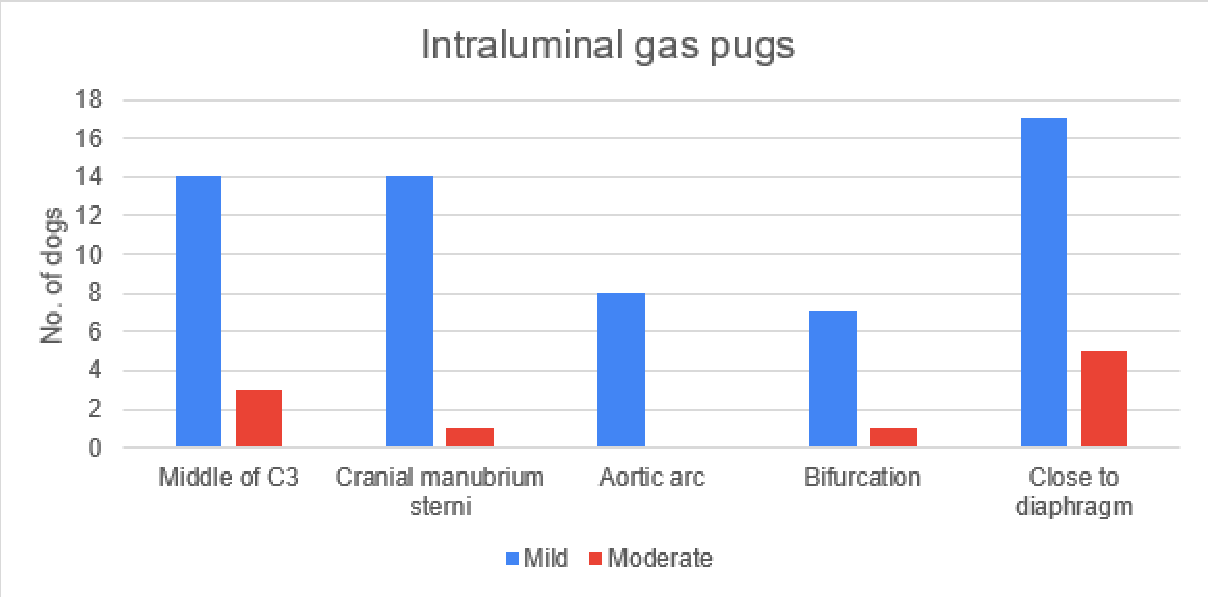

Figure 13. The number of pugs with intraluminal gas was documented. It was noted whether there was mild or moderate amount of gas in the esophagus in five different locations.

All English bulldogs had intraluminal gas detected on CT scans. 3/4 dogs had moderate amounts of gas in the esophagus either on the level of C3 (1/4) or right in front of the diaphragm (2/4).

4.2.3 Wall thickness

In French Bulldogs, esophageal wall thickness (EWT) ranged from 2.70 mm to 4.15 mm across different segments. Measurements in at least one of the five anatomical locations were obtained in 31 out of 35 dogs (89%), while it was possible to measure in all locations in 2 out of 35 dogs (6%). The mean EWT (± standard deviation) for the segments was as follows:

- On the level of C3: 2.7 ± 1.17 mm
- On the level of the cranial manubrium sterni: 3.29 ± 1.71 mm
- On the level of the aortic arch: 2.75 ± 0.60 mm
- On the level of the bifurcation: 3.86 ± 1.33 mm
- Cranial to the diaphragm: 4.15 ± 1.34 mm

There were significant differences in EWT between cervical segments and the EWT at the level close to the diaphragm ($p < 0.001$), as well as to the level of the tracheal bifurcation ($p < 0.013$). The EWT at the level of the thoracic inlet also differed significantly from measurements closer to the diaphragmatic hiatus ($p < 0.032$) (Fig. 14).

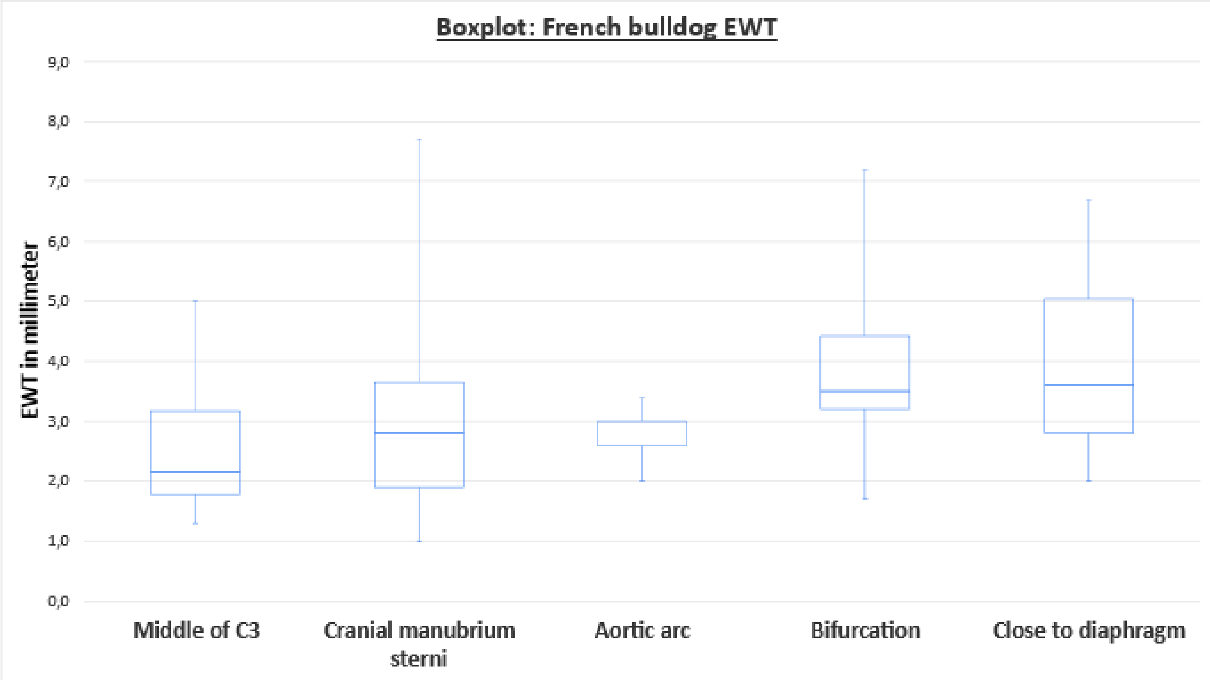

Figure 14. Boxplots describing the esophageal wall thickness in French Bulldogs at five locations.

In pugs, the measured mean esophageal wall thickness (EWT) (± standard deviation) were as follows:

- On the level of C3: 2.69 ± 0.88 mm
- On the level of the cranial manubrium sterni: 2.91 ± 0.69 mm
- On the level of the aortic arch: 2.44 ± 0.61 mm
- On the level of the bifurcation: 2.74 ± 0.91 mm
- Cranial to diaphragm: 3.12 ± 1.12 mm

Proper conditions for measurement in all five anatomical locations were observed in 4 out of 24 dogs. However, EWT measurements could be obtained on at least three levels in 16 out of 24 dogs (67%). In only one dog, EWT could not be measured at all due to poor visualization of the esophagus. There were no statistically significant differences observed between any of the segments, although EWT displayed minimal changes with low standard deviations (Fig 15).

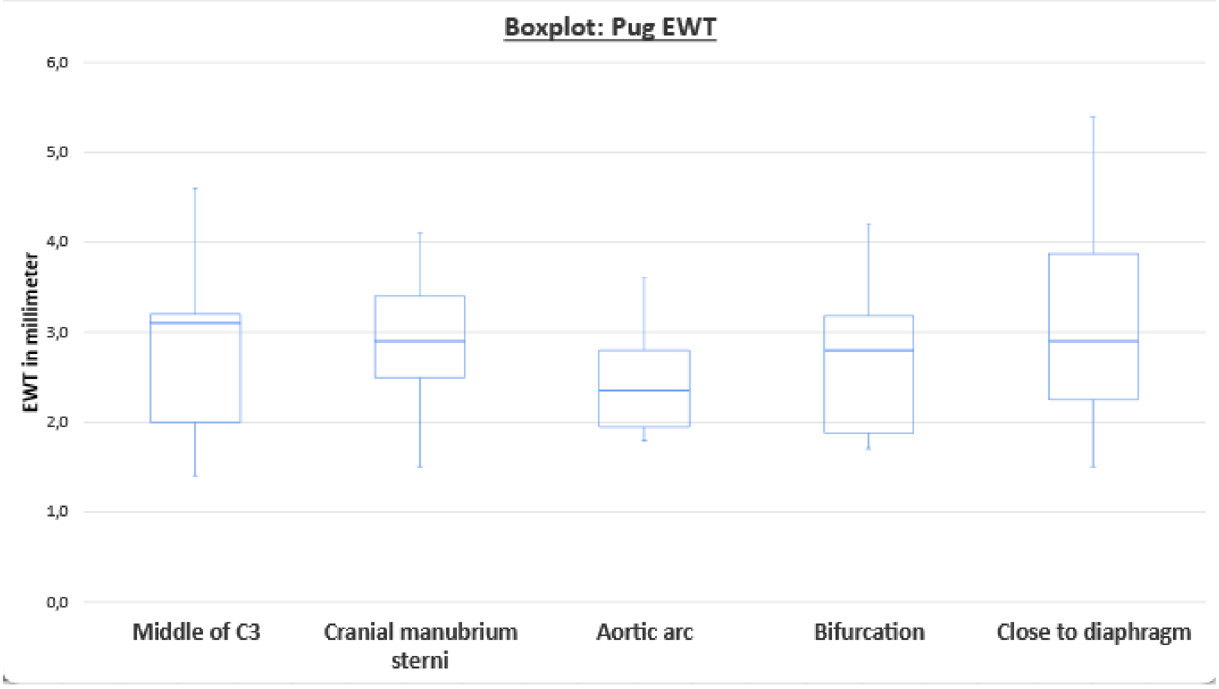

Figure 15. Boxplots describing the mean esophageal wall thickness in pugs in five locations

In English Bulldogs, the mean esophageal wall thickness (EWT) was 4.36 mm across all segments. However, reliable measurements were challenging in most anatomical locations due to poor contrast. Proper measurements were only feasible in cervical segments and those close to the diaphragm.

4.2.4 Dimension

In French Bulldogs, the esophagus had a mean width of 18.12 mm ± 4.74 mm, and measurements could be obtained in at least three anatomical locations in 34 out of 35 dogs (97%), with data available in all five locations in 17 dogs. The measurement was least likely to be feasible on the level of the aortic arch (54%). Significant differences were observed between cranial segments, particularly between measurements on the level of C3 compared to those on the level of the cranial manubrium sterni ($p < 0.03$) and the aortic arch ($p < 0.004$). The width at the level of the bifurcation was also significantly different from the previously mentioned locations ($p < 0.043$ and $p < 0.01$). When comparing the width of the spinal canal at the level of C3 and C6 to the mean width at the level of C3 and the thoracic inlet, a quotient of 1.86 and 1.36, respectively, was obtained, and the difference was statistically significant.

The average height of the esophagus in French Bulldogs was 12.31 mm ± 3.9. Similar to width measurements, the height measurement could be easily obtained in three out of five anatomical locations in 34 out of 35 French Bulldogs. However, it was more challenging at the level of the aortic arch due to poor demarcation. Significant differences in height were observed in almost all segments ($p < 0.05$) except for two.

In pugs, the mean width of the esophagus was 15.83 mm ± 4.24. Measurement in at least three locations was possible in 23 out of 24 pugs. The width was notably different only between the level of C3 and the cranial manubrium sterni ($p < 0.001$) as well as at the level of the thoracic inlet and the bifurcation ($p < 0.002$). When compared to the width of the spinal canal, the quotient was 2.13 at the level of C3 and 1.09 at the thoracic inlet, and the difference was statistically significant.

The mean esophageal height in pugs was 12.61 mm ± 4.12, and measurements in all five anatomical locations were possible in 12 out of 24 dogs (50%).

4.3 Breed differences

In both, pugs and French Bulldogs, there were significant differences in esophageal wall thickness (EWT) at the level of the bifurcation ($p < 0.05$) and close to the diaphragm ($p < 0.015$). Additionally, in the most caudal location the width of the esophagus also differed between both breeds ($p < 0.029$). Further cranially, results were significant regarding the width of the esophagus at the level of the manubrium sterni ($p < 0.011$). However, no further comparisons were made between these two breeds. English Bulldogs were not compared to the others due to a lack of data.

5 Discussion

The findings of this study reveal that esophageal wall thickness exceeds 2 mm in all dogs over the entire length of the esophagus. Particularly in French Bulldogs, the wall thickness increases gradually from the cervical part (2.7 mm) to its most caudal part (4.15 mm). In pugs, there were no significant changes in wall thickness along the esophagus, but it consistently exceeded 2 mm in all segments. In French Bulldogs, esophageal wall thickness (EWT) was significantly different in the last two segments, close to the diaphragm and at the level of the bifurcation. One possible explanation for these differences in EWT could be the presence of esophagitis, which is inflammation of the esophageal wall. Esophagitis can be caused by various factors, including acid reflux or infections. Gastroesophageal reflux (GER), a condition where stomach acid and contents flow back into the esophagus, leading to irritation and inflammation, has been described in brachycephalic breeds previously. It is a disease highly associated with these breeds because higher negative intrathoracic pressure favors the emergence of GER (9).

French Bulldogs tend to be more often presented with digestive signs and diagnosed with esophageal reflux and esophagitis compared to pugs (42). This could explain the breed differences in EWT at the level of the bifurcation and close to the diaphragm. CT could be a valuable tool to identify signs of inflammation, such as thickening and increased enhancement of the esophageal wall. Additionally, esophageal pneumatosis, which is the presence of gas in the esophageal wall, has also been described in dogs before, and it has been proposed that brachycephalic obstructive airway syndrome (BOAS) should be considered as a potential cause if it occurs (43).

Position of the esophagus and the amount of intraluminal gas can be evaluated with CT (14). In this study, delineation of the esophageal body against surrounding soft tissue was good enough in most cases and intraluminal content could be distinguished well. Once there was gas within the lumen, demarcation of the esophageal wall was best, which is why it has been discussed to use esophageal insufflation as a standard method for evaluation of the esophageal wall (14). Further studies are necessary to assess the real benefit of this method or whether pre-contrast scans are sufficient. In this study most gas accumulated close to the diaphragm or in the cervical segments which could be indicative of swallowed air either prior to anesthesia or during intubation. Especially pugs seemed to be affected by this since almost all of them had intraluminal gas in the esophagus at some point during scans.

Since brachycephalic dogs often require surgery to address airway abnormalities it is recommended to perform CT scans beforehand in order to help plan the procedure. By providing information about the esophagus, CT scans can reduce the risk of complications during anesthesia. As mentioned before brachycephalic breeds may be predisposed to gastroesophageal reflux (9). CT evaluation allows for the identification of any factors contributing to GER, such as the position of the lower esophageal sphincter or hiatal hernia (17). Because of these conditions it must be taken into consideration for peri- and post anesthetic management that in severe cases, regurgitation can lead to aspiration pneumonia if the ingested material enters the airways (42). That is especially the case if they have a previous history of GI symptomatic (44). Evaluating the position of the esophagus helps in identifying any factors that may contribute to regurgitation or aspiration risk such as fluid or ingesta in the esophagus at the time of scan (45).

In this study there was a significant difference regarding the measurements of the esophageal width at the level of the cranial manubrium sterni in French Bulldogs and pugs. Reason for this could be the cranial aperture acting more as a bottleneck for the esophagus in one breed than the other before it enters the thoracic cavity. Therefore causing esophageal redundancy as defined by Reeve et al. especially French bulldogs seem to be at risk for this anomaly (8). Another explanation for distention of the esophageal lumen can be vascular ring anomalies, which is most commonly a congenital persistence of a right aortic arch. Food and gas accumulate prior to the vascular ring, causing the distension and eventual loss of function (18). No such anomalies were noted in this study. However its presence should be taken into consideration whenever the diameter of the esophagus is unusual. In these cases CT angiography can be of valuable use in confirming the vascular anomaly since it can visualize the relationship of the esophagus to its surrounding structures clearly (46).

Width and height of the esophagus varies greatly in this population of dogs depending on the content within the lumen and location of measurement. Width was significantly greater closer to the diaphragm, especially in French Bulldogs. Whether this is in correlation with a more frequent appearance of gastrointestinal diseases is unclear, however one study confirmed a bigger hiatus area in French bulldogs compared to pugs and therefore increased risk of GER and esophagitis (17).

This study was limited by little sample size of brachycephalic dogs for CT scans. Especially English bulldogs could not be included at all since there was too little data. Comparison of the three most popular brachycephalic breeds would be beneficial to evaluate the population more thoroughly. Another limitation was lack of data because of too little enhancement of the esophageal wall to surrounding tissue in order to make proper measurements. Esophageal insufflation has proven to be a valuable tool for improving delineation and could be contemplated to use as an additional diagnostic tool.

In summary, CT has certain limitations when it comes to assessing the esophagus in brachycephalic dogs. Unlike some other imaging methods that can evaluate how the esophagus moves and functions, CT provides only a static snapshot of it. However, CT does provide a comprehensive view of the esophagus and its surrounding structures and allows for measurements of wall thickness in most cases. In some cases, it can help diagnose related conditions like hiatal hernia or gastroesophageal reflux, but this depends on when the scan is performed to ensure the necessary visualization. This is why it is recommended to use more than one imaging modality in unclear cases to improve overall outcome in these patients.

6 Summary

The aim of this diploma thesis was to describe the morphological appearance of the esophagus in plain CT images and to compare three popular breeds of brachcephalic dogs in terms of wall thickness, esophageal width and height, position in relation to the trachea, and the presence of intraluminal gas. For this we studied CT features in dogs presented with symptoms of BOAS at the clinic.

Images of 63 dogs (35 French bulldogs, 24 pugs, 4 English bulldogs) were analyzed, and different characteristics of the esophagus were evaluated at five different anatomical locations along the course of the esophagus. Due to the small number of English Bulldogs, parameters in this breed were exclusively described. These data underwent no statistical analysis.

It was found that gas accumulations in the esophagus were detectable in 77% of French Bulldogs, 96% of Pugs, and all English Bulldogs. The distribution of gas displayed distinct patterns, particularly concentrating at the thoracic inlet and near the diaphragm.
Esophageal wall thickness varied in French Bulldogs, ranging from 2.70 mm to 4.15 mm across different segments. Significant differences were observed between cervical segments, areas near the diaphragm and tracheal bifurcation, and the thoracic inlet. In Pugs, esophageal wall thickness showed variation, but without significant differences between segments. French Bulldogs exhibited an average esophageal width of 18.12 mm ± 4.74 mm and a height of 12.31 mm ± 3.9. Pugs displayed an average width of 15.83 mm ± 4.24 and a height of 12.61 mm ± 4.12. English Bulldogs, predominantly measured in cervical segments, had an average width of 4.36 mm, and specific height measurements were not provided.

French Bulldogs and pugs exhibited similar characteristics in terms of esophageal width, position in relation to the trachea. The position of the esophagus conformed to descriptions found in common literature, entering the thoracic cavity on the left side of the trachea and moving dorsally after passing the aortic arc and tracheal bifurcation.

Despite to intrinsic limitations, such as the inability to evaluate esophageal function or the risk of missing pathological conditions such as sliding hiatal hernias or gastroesophageal reflux, CT proved to be a useful diagnostic tool to study the esophagus. Specific characteristics in brachycephalic dogs, such as increased esophageal wall thickness, should be considered when interpreting CT studies of these dogs.

7 Zusammenfassung

Ziel dieser Diplomarbeit war es, das morphologische Erscheinungsbild des Ösophagus in nativen CT-Bildern zu beschreiben und drei gängige Rassen brachzephaler Hunde hinsichtlich Wanddicke, Ösophagusbreite und -höhe, Position im Verhältnis zur Trachea und Vorhandensein von intraluminalem Gas zu vergleichen. Zu diesem Zweck untersuchten wir die CT-Merkmale bei Hunden, die auf der Klinik mit BOAS-Symptomen vorgestellt wurden.

CT-Datensätze von 63 Hunden (35 Französische Bulldoggen, 24 Möpse, 4 Englische Bulldoggen) wurden analysiert, und verschiedene Merkmale der Speiseröhre wurden an fünf verschiedenen anatomischen Stellen entlang des Speiseröhrenverlaufs bewertet. Aufgrund der geringen Anzahl von Englischen Bulldoggen wurden ausschließlich Parameter dieser Rasse beschrieben. Diese Daten wurden keiner statistischen Analyse unterzogen.

Es wurde festgestellt, dass Gasansammlungen in der Speiseröhre bei 77 % der Französischen Bulldoggen, 96 % der Möpse und allen Englischen Bulldoggen nachweisbar waren. Die Verteilung des Gases wies deutliche Muster auf, die sich insbesondere am Thoraxeingang und in der Nähe des Zwerchfells konzentrierten.

Die Dicke der Speiseröhrenwand variierte bei Französischen Bulldoggen und reichte von 2,70 mm bis 4,15 mm in den verschiedenen Segmenten. Signifikante Unterschiede wurden zwischen zervikalen Segmenten, Bereichen in der Nähe des Zwerchfells und der Luftröhrenverzweigung sowie dem Thoraxeingang beobachtet. Bei Möpsen variierte die Speiseröhrenwanddicke, jedoch ohne signifikante Unterschiede zwischen den Segmenten. Französische Bulldoggen wiesen eine durchschnittliche Ösophagusbreite von 18,12 mm ± 4,74 mm und eine Höhe von 12,31 mm ± 3,9 auf. Möpse wiesen eine durchschnittliche Breite von 15,83 mm ± 4,24 und eine Höhe von 12,61 mm ± 4,12 auf. Englische Bulldoggen, die überwiegend in den Halssegmenten gemessen wurden, hatten eine durchschnittliche Breite von 4,36 mm, und es wurden keine spezifischen Höhenmessungen vorgenommen.

Französische Bulldoggen und Möpse wiesen ähnliche Merkmale in Bezug auf die Breite der Speiseröhre und ihre Position im Verhältnis zur Luftröhre auf. Die Lage der Speiseröhre entsprach den Beschreibungen in der Literatur: Sie tritt auf der linken Seite der Luftröhre in die Brusthöhle ein und verläuft nach Passieren des Aortenbogens und der Bifurkation der Trachea eher dorsal.

Trotz bestehender Einschränkungen, wie fehlender Möglichkeiten zur Darstellung funktioneller Störungen oder der Risiken, gleitende Hiatushernien oder gastroösophagealen Reflux zu übersehen, hat sich die CT-Untersuchung als nützliches diagnostisches Instrument zur Untersuchung des Ösophagus erwiesen. Spezifische Merkmale bei brachyzephalen Hunden, wie z. B. eine erhöhte Ösophaguswanddicke, sollten bei der Interpretation von CT-Untersuchungen dieser Hunde berücksichtigt werden.

8 List of abbreviations

BOAS	brachycephalic obstructive airway syndrome
CT	computed tomography
GER	gastroesophageal reflux
GIT	gastrointestinal tract
HH	hiatal hernia
UAO	upper airway obstruction
EWT	esophageal wall thickness

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