ORIGINAL ARTICLE

Computed tomographic appearance of gastropexy sites in dogs

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Objectives: To describe the computed tomography appearance of gastropexy sites and report their anatomical and suspected functional abnormalities.

Materials and Methods: Medical records of dogs with prior gastropexy undergoing abdominal computed tomography between December 2010 and June 2021 were reviewed from two veterinary hospitals. Dogs were categorised into two groups based on gastric anatomic distortion: anatomic (10) or non-anatomic (12).

Results: A total of 22 dogs were included, with time since gastropexy ranging from 16 to 1552 days (median: 311 days). Computed tomography findings showed a median attenuation of 38.5 HU (range: 6 to 57) of the gastropexy site, as well as focal slight thickening of the gastric wall and adjacent muscle in all dogs. Neovascularisation at the gastropexy site was found in approximately 65% of the animals, while marked gastric dilatation was noted in 32%, and a gravel sign was observed in 73%. The anatomic group had broader pedicles and a greater distance from the xiphisternum and midline compared to the non-anatomic group. Median gastric angles were significantly smaller in the gastropexy groups (Anatomic: 85.5°; Non-anatomic: 52°) compared to a control group (132°).

Clinical Significance: The current study identified specific computed tomography imaging features of gastropexy sites contributing to a better understanding of the range of appearance and degree of detected anatomic distortion following gastropexy. It also identified signs of suspected gastric functional abnormalities in all gastropexy patients regardless of the degree of anatomic distortion.

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INTRODUCTION

Gastropexy is primarily performed in order to prevent the development or recurrence of gastric dilatation-volvulus (GDV) (Fossum, 2002; Rawlings et al., 2001; Wacker et al., 1998; Ward et al., 2003). A strong adherence between the stomach and the body wall without affecting the stomach's anatomic position or impairing gastric outflow is desirable. Different gastropexy procedures have been described in the literature, such as tube-, circumcostal-, incisional-, belt-loop- and laparoscopic-assisted-gastropexy (Allen & Paul, 2014; Pope & Jones, 1999; Przywara et al., 2014; Rawlings et al., 2002; Wilson et al., 1996). Depending on the surgical technique, a different extent of adhesion is accomplished with different rates of complications, as well as different short- and long-term outcomes. Described general complications of gastropexy include dehiscence of the incision, sepsis, pneumothorax, ulceration at anastomotic sites, gastric outflow obstruction and recurrence of gastric dilatation with or without volvulus (Hardie et al., 1996; Johnson et al., 1984; Whitney et al., 1989; Woolfson & Kostolich, 1986).

Complications from incisional gastropexy are reported to be minimal (Fossum, 2002; Hardie et al., 1996; MacCoy et al., 1982). However, direct apposition of gastric and body wall muscle is crucial for forming a strong adhesion, as well as length, depth and location of the incisions (MacCoy et al., 1982). According to a study evaluating permanent adhesions after incisional gastropexy in 22 dogs via histopathology, a fibrous connective tissue adhesion was present after 14 days (MacCoy et al., 1982).

The effects of gastropexy on gastric motility may be influenced by factors such as disease severity, surgical technique, and the angle formed between the duodenum and pylorus. Delayed gastric emptying has been observed in dogs post-GDV and gastropexy, though factors like stress, anxiety or pre-existing motility issues may also play a role (Hall et al., 1992; Tanno et al., 1998). One study noted significantly slower gastric emptying in GDV dogs undergoing circumcostal gastropexy (90% at 13 hours) compared to non-GDV dogs (90% at 5.5 hours) (Hall et al., 1992). Furthermore, one case report described recurrent gastric dilatation following GDV and gastropexy. In this instance, a gastroduodenal angle of 45° formed an inverted L-shape and was postulated to intermittently act as a gas-trapping valve (Jennings Jr et al., 1992). Decreased gastric motility can also occur due to an overstretched and damaged gastric muscle after GDV (Wacker et al., 1998; Whitney, 1989). However, studies have shown no significant changes in gastric electrical or contractile activity in dogs undergoing prophylactic circumcostal gastropexy without prior GDV (Hall et al., 1997). Similarly, prophylactic laparoscopic-assisted gastropexy has not been associated with changes in gastric, small or large bowel transit times post-surgery (Balsa et al., 2017; Coleman et al., 2019). Additionally, the majority of reported cases with decreases in gastric motility were only subclinical and temporary.

Regarding long-term outcome, varying recurrence rates of gastric dilatation (GD) have been cited in the literature. Following incisional, laparoscopic-assisted and circumcostal gastropexy, recurrence rates of 5% to 10% (Benitez et al., 2013; Przywara et al., 2014), 0% (Loy Son et al., 2016) and 3% to 9% (Eggertsdóttir et al., 2008; Leib et al., 1985), respectively, have been reported in dogs.

Only a few reports exist describing the computed tomography or ultrasound imaging appearance of the gastropexy sites themselves, and the relative impact of the procedure on the stomach and intestinal tract. According to one study investigating the location of the pylorus via computed tomography in canine breeds considered susceptible to GDV, the most frequently used gastropexy locations are significantly different to the natural anatomic location of the pylorus (Tomlinson et al., 2016). Further studies investigated gastropexy sites via ultrasonography, confirming there were firm adhesions after approximately 2 weeks and that the stomach was not malpositioned (Tavakoli et al., 2016; Wacker et al., 1998). They further mentioned that the gastric wall was thicker at the gastropexy site, and the pylorus was normal in all dogs (Tavakoli et al., 2016). In general, the gastropexy site presented as a hypoechoic mass-like structure associated with the abdominal wall (Wacker et al., 1998). Its appearance changed depending on the time since surgery. In early stages, the site was thicker and showed a lack of gastric wall layers, presumably due to inflammatory processes. The lack of gastric wall layers was also present in several dogs at late examinations (mean of 449 days) (Wacker et al., 1998).

For large breed dogs, a predisposition for chronic gastric instability is reported (Frendin et al., 1988; White et al., 2020). According to several studies, gastric instability can be an incidental finding; however, affected dogs may also show intermittent and chronic clinical signs including vomiting, lethargy, abdominal discomfort and weight loss (Funkquist & Garmer, 1967; Paris et al., 2011; White et al., 2020).

Possible short- and long-term consequences of permanent, excessive gastric displacement are unknown.

The aims of this current retrospective descriptive study were to (1) describe variations in the CT appearance of gastropexy sites in dogs; (2) determine whether the gastropexy leads to anatomic distortion of the stomach; (3) assess for imaging abnormalities that could support the presence of gastric dysfunction (gravel sign, gastric dilatation) and, if present, correlate presence of indicators of functional disturbance with anatomic alterations.

The authors hypothesised that gastropexy can lead to anatomic distortion and alterations potentially seen with functional abnormalities of the stomach.

MATERIALS AND METHODS

Study design and ethics

This was a retrospective observational study ethically approved by Nottingham University ethical review committee.

All owners gave their written consent for the use of clinical records and CT images for clinical research. Approval was granted by the University of Nottingham (Committee for Animal Research and Ethics, 3371 210504) (ZZ in anonymised document).

Study population and eligibility criteria

To identify eligible cases, we conducted a search using the term 'gastropexy' in the imaging databases of two hospitals, covering the period from December 2010 to June 2021. This search identified dogs with CT reports mentioning a previous gastropexy. Dogs were included if they met the following criteria: (1) a gastropexy procedure prior to the CT examination, (2) a CT scan performed in sternal recumbency and (3) the CT images were of diagnostic quality, utilising smooth or low-frequency reconstruction algorithms.

The medical records for these patients were reviewed, and the following data were recorded: Breed, age, sex/neuter status, reason for abdominal CT examination (specifically were gastrointestinal signs recorded or not), date of gastropexy surgery (therefore time elapsed since surgery), surgical technique and reason for gastropexy.

In addition, a group of 11 dogs matched to the study cohort by breed and age were included in the study in order to assess gastric angles of a healthy control group.

Computed tomography

All dogs were subjected to a standardised fasting period of at least 12 h prior to undergoing CT. They were positioned in sternal recumbency. Sedative or anaesthetic protocols varied at the discretion of the attending anaesthetist. Each patient underwent an abdominal CT scan using a multidetector row scanner (Dick White Referrals: MX 8000 IDT, Philips Medical

Systems, Cleveland, Ohio [16 slice]; Royal Veterinary College: 09/2007-20 May 2018: MX8000 IDT [16 slice], Philips Healthcare, Amsterdam, Netherlands; 21 May 2018 to 16 July 2018: Aquilion CXL Edition [64 slice], Canon Medical Systems, Otawara, Japan; 17 July 2018–Present: Aquilion ONE Genesis Edition [320 slice], Canon Medical Systems, Otawara, Japan). A volume of helical data was acquired from the abdomen and reconstructed using high and low frequency algorithms with a 1 to 3 mm slice thickness. A comparable dataset was acquired after IV administration of iodinated contrast (Iohexol 300 and 350 mg I/mL, Omnipaque, General Electric Healthcare at 2 mL/kg) using an automated power injector in all except for two animals.

Retrospective review of CT images was made by a single ECVDI Diplomate (AC). All images were assessed and measured using DICOM image reading software (OsiriX V.4.1.1 64-bit; Pixmeo, Switzerland). Features examined included: Subjective assessment of gastric position was made, and any malpositioning of the duodenum, jejunum, ileum or colon was recorded to indicate anatomic disturbance; assessment of CT appearance of the gastropexy site (the body wall muscle to which the gastropexy was attached was identified and its thickness was measured and compared to the adjacent/unaffected muscle thickness in transverse images; the gastric wall thickness was measured directly at the gastropexy site and adjacent to the gastropexy site at the first point at which muscle and stomach could be distinguished on post contrast transverse images; the Hounsfield unit attenuation (HU) of the gastropexy site was measured in the pre-contrast images by using a circular ROI of variable size according to the patient and size of gastropexy site; and assessed to see if any suture was visible; the gastropexy site was further evaluated for the presence or absence of neovascularisation on post-contrast images); assessment of gastropexy location.

Comparison of these measurements was made between dogs that had subjectively normal anatomic gastric position *versus* those that were not considered anatomic (anatomic *vs*. non-anatomic groups, see below for data analysis): The width of the pedicle attachment was subjectively categorised as narrow or broad on transverse images (Fig 1); the length of the gastropexy site was measured from cranial to caudal by adjusting the dorsal plane using multiplanar reconstruction (MPR) to ensure the longest straight-line measurement; the location of the gastropexy site was defined by two measurements (Fig 2), using MPR: (1) the craniocaudal distance was measured as a straight line between the caudal tip of the xiphisternum and the cranial edge of the gastropexy site. This involved identifying the gastropexy site in transverse images and then using MPR to adjust the dorsal plane and align both landmarks; and (2) the distance from the medial aspect of the gastropexy site to the midline, measured in transverse images.

Gastric angle was defined as the angle between the pyloric antrum and the body of the stomach by adjusting the dorsal plane using MPR for accurate alignment (Fig 3). The control group was used for this measurement to obtain a 'normal range' of this gastric angle for comparison.

Finally, assessment of features associated with gastrointestinal function was made, and the presence or absence of these features was compared in dogs with and without presenting signs of gastrointestinal disease: Hyperattenuating material in the gastric lumen was recorded as present or absent; overall gastric filling

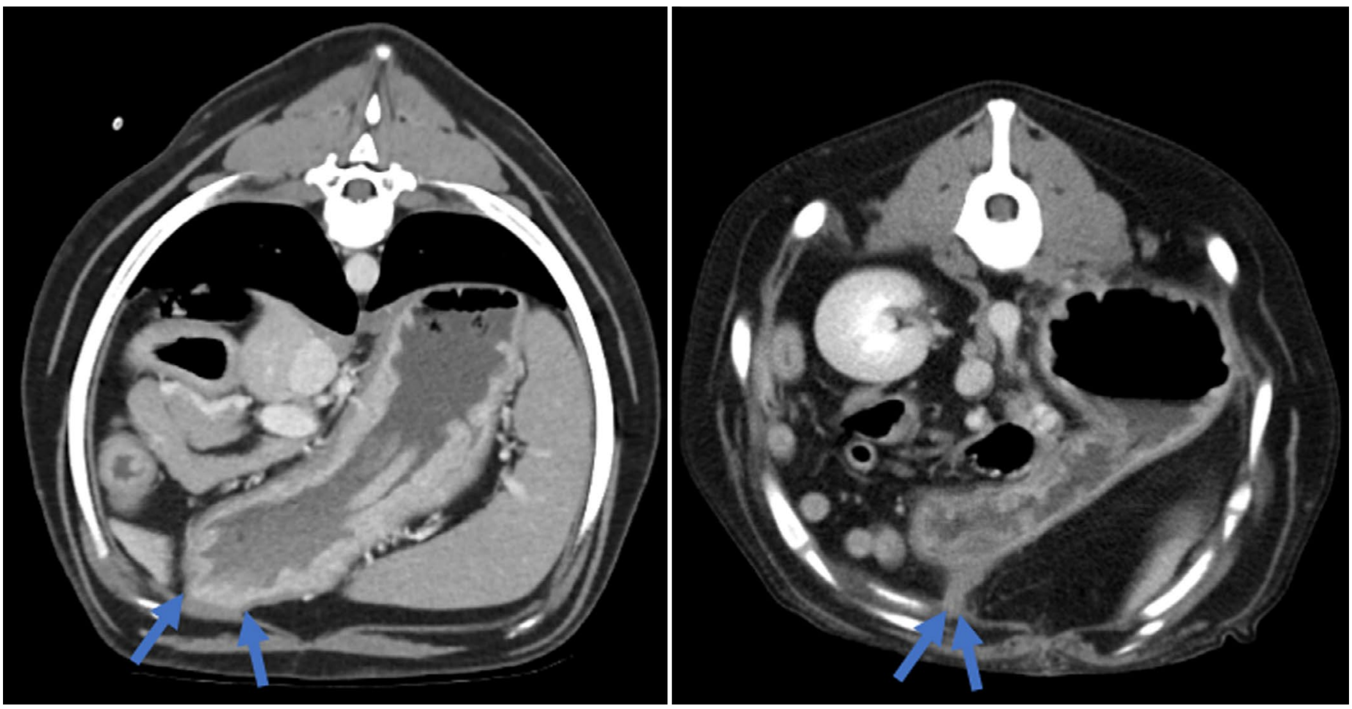

FIG 1. Post-contrast transverse CT images of the cranial abdomen at the level of the gastropexy site, displayed in a soft-tissue-window and illustrating a dog with a broad pedicle (left) and a dog with a narrow pedicle (right), marked by arrows.

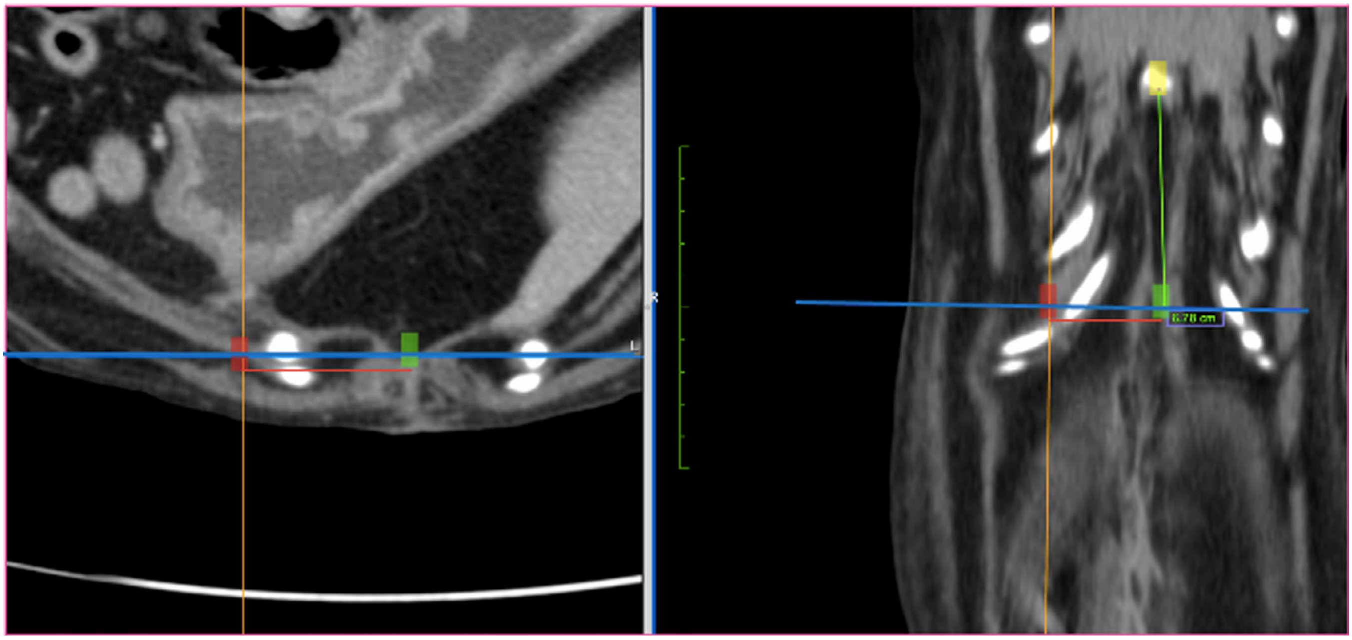

FIG 2. Transverse (left) and dorsal (right) CT images of the cranial abdomen at the level of the gastropexy site of the same dog, displayed in a post contrast soft-tissue-window and illustrating the distance measurement of the gastropexy site (red spot) from midline (green spot) and the xiphisternum (yellow spot), respectively. Red line = distance between gastropexy site and midline; green line = distance between xiphisternum and midline location at the level of the gastropexy site.

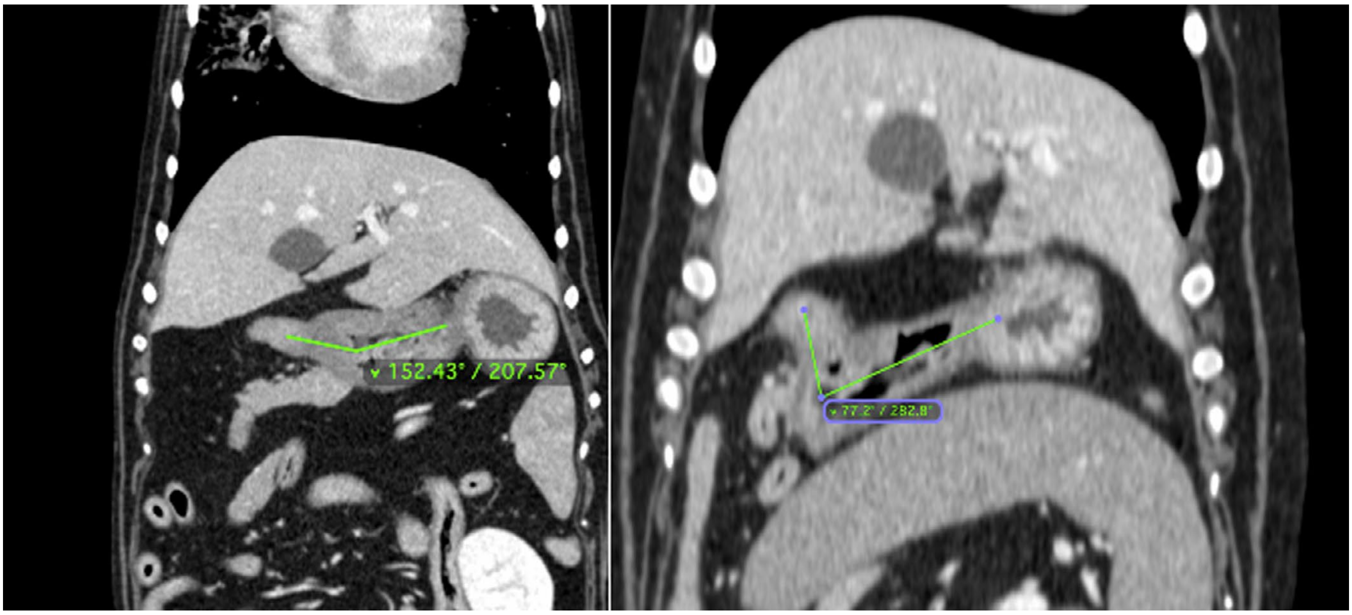

FIG 3. Post-contrast dorsal reconstruction CT images of the cranial abdomen at the level of the stomach, displayed in a soft-tissue-window and illustrating the measurement of gastric angle. The patient on the left has an obtuse angle, and one the right an acute angle.

was subjectively divided into two subgroups: empty to moderate filling or distended; and diffuse gastric wall thickening was recorded as present or absent.

Data analysis

For descriptive analysis, animals were subjectively subdivided into two groups depending on an overall assessment of the position of the stomach and gastropexy site, looking for specific features including:

1. *Anatomic*: Normal position of stomach, including pylorus and gastropexy site, maintaining the pylorus at the expected location to the right of the midline.
2. *Non-anatomic*: Any deviations from standard anatomic positions (*e.g.* stomach displaced to midline, unusual pyloric gastropexy locations *e.g.* midline).

Statistical analysis is based on data from the 22 included animals and was performed by the use of a commercially available software (SPSS, version 12.0.0, SPSS Inc, Chicago, IL, USA).

The Kolmogorov–Smirnov's test was used to check for normal distribution in the data. Levene's test was used to test for homoscedasticity between groups. For data showing no deviation from normal distribution or homoscedasticity, a *t*-test for two independent means was used to assess significant differences between two groups (gastric angle: control group *vs*. anatomic and non-anatomic).

Statistical significance was set at $p<0.05$.

RESULTS

Study population

In total, 22 dogs met the inclusion criteria, with 17 being male (8 neutered) and 5 being female (2 neutered) (Table 1). Median age at presentation for CT was 91 months (range: 14 to 150 months). Fourteen different large breed dogs were assessed in the study, including Newfoundland ($n=3$), great Dane ($n=3$), Irish Setter ($n=2$), Italian Spinone ($n=2$), Labrador retriever ($n=2$), Rhodesian Ridgeback ($n=2$), Saint Bernard ($n=1$), German Short-Haired Pointer ($n=1$), Flat-Coated retriever ($n=1$), Bloodhound ($n=1$), German shepherd ($n=1$), Golden Doodle ($n=1$), boxer ($n=1$) and Beauceron ($n=1$). Body condition score was available for 15 of the 21 dogs, and median body condition score was 3/9 (range: 2 to 5).

The control group for gastric angles consisted of the following breeds, great Dane ($n=2$), Rhodesian Ridgeback, Dobermann, German shepherd, Rottweiler, Golden retriever, Weimaraner, Flat Coated retriever, Labradoodle and Newfoundland, with a median age of 108 months (range: 96 to 144). BCS data were not available for the control group. As a result, potential variations in body condition could not be accounted for when analysing gastric angles, which may have introduced some variability into the measurements. All dogs in the control group exhibited clinical signs that were not associated with gastrointestinal issues, and CT scans revealed no pathological changes in the gastrointestinal tract.

Time between CT examination and surgery, and reason for surgery are summarised in Table 1. In most cases, an incisional gastropexy was performed, apart from one laparoscopic and one belt-loop gastropexy (Table 1).

Clinical presentation

The clinical indications for CT examination in the study population varied and included gastrointestinal signs (*e.g.* vomiting, diarrhoea and melaena), orthopaedic/neurological signs (*e.g.* lameness and ataxia), respiratory signs (*e.g.* cough) and unspecific signs (*e.g.* weight loss, exercise intolerance, anaemia and pyrexia) (Table 1).

Gastrointestinal signs were the most common reason for clinical presentation in 11 dogs, whereas 11 dogs presented for other clinical signs. Gastrointestinal signs included vomiting ($n=6$), melaena ($n=5$), diarrhoea ($n=2$) and haematemesis ($n=1$).

Table 1. Signalment and patient history of the study population

ID	BCS (1 to 9)	Breed	Age (months)	Gender	Neutered	Surgical procedure	Reason for gastropexy	Time between surgery and CT (days)	Reason for CT	Group
1	2.5	Newfoundland	86	Male	Yes	NA	GDV	416	Gastrointestinal	NoA
2	2	Italian Spinone	122	Male	No	Incisional	GDV	679	Gastrointestinal	A
3	NA	Labrador Retriever	128	Male	No	NA	GDV	31	Gastrointestinal	A
4	3	Saint Bernard	91	Male	No	Incisional	GDV	627	Gastrointestinal	A
5	3	German Short-Haired Pointer	41	Male	Yes	Incisional	GDV	141	Gastrointestinal	NoA
6	5	Flat-Coated Retriever	79	Female	No	NA	Chronic GI-disease	1215	Respiratory	NoA
7	NA	Rhodesian Ridgeback	85	Male	No	Belt-loop with splenectomy	GDV	1306	Orthopaedic/ neurologic	A
8	5	Bloodhound	91	Male	No	Incisional	GDV	1339	Thoracic wall mass	NoA
9	NA	Italian Spinone	75	Male	Yes	NA	GDV	352	Gastrointestinal	A
10	NA	Irish Setter	91	Male	No	Incisional	GDV	52	Abdominal mass	NoA
11	5	German shepherd	107	Male	Yes	Incisional with splenectomy	GDV	339	Abdominal mass	A
12	NA	Great Dane	109	Female	Yes	Incisional	GDV	223	Pyrexia	NoA
13	5	Boxer	104	Male	Yes	Incisional	GDV	78	Respiratory	A
14	NA	Great Dane	14	Female	No	Laparoscopic	Prophylactic	16	Gastrointestinal	NoA
15	NA	Goldendoodle	87	Male	Yes	NA	GDV	18	Gastrointestinal	NoA
16	5	Great Dane	51	Male	No	NA	NA	NA	Respiratory	NoA
17	3	Newfoundland	91	Female	Yes	Incisional	GDV	992	Pyrexia	NoA
18	3	Labrador	150	Male	Yes	Incisional with splenectomy	GDV	456	Gastrointestinal	A
19	3	Newfoundland	129	Female	No	NA; with splenectomy	GDV	283	Respiratory	A
20	4	Beauceron	96	Male	Yes	Incisional with splenectomy	GDV	102	Gastrointestinal	A
21	2	Irish red white setter	70	Male	No	NA	GDV	1552	Weight loss	NoA
22	5	Rhodesian Ridgeback	105	Male	Yes	NA	GDV	233	Gastrointestinal	NoA

A Anatomic group, BCS Body condition score, GDV Gastric dilatation volvulus, GI, Gastrointestinal, NA Not available, NoA, Non-anatomic group

CT findings

Post-contrast CT images were obtained for 20 patients, while two did not receive contrast. Various anatomical abnormalities of the stomach were identified in the study population, with several dogs presenting with more than one abnormality. Pyloric displacement was observed in three cases: two showed a deviation towards the midline, while one exhibited a caudal, ventral, rightward displacement. Gastric shape distortion was also evident in a few cases. One dog had the fundus fixed ventrally, resulting in dorsal displacement of the body and pylorus with subsequent gas distension. Another dog, which had undergone a laparoscopic-assisted gastropexy, exhibited a *Z*-shaped deviation in the gastric body, characterised by a cranial bend, followed by a caudal deviation and an acute cranial angle. Gastric shape was further distorted by narrow pedicles with or without the formation of acute angles.

The proximal section of the duodenum showed a pronounced kink or abnormal course in three dogs as well as displacement medial to the right kidney in another three dogs. The ascending colon was displaced to the left in three dogs and the transverse colon was displaced to the right in another three dogs.

Free abdominal fluid was detected in two dogs; however, both dogs had concurrent pathologies (hepatic neoplasia and splenic neoplasia).

Data are reported as median with range.

Assessment of CT appearance of the gastropexy site

The right transverse abdominus muscle was the site of gastropexy in the majority of cases. In one case, however, it was fixed to the external body wall. This latter gastropexy was performed laparoscopically.

The body wall thickness at the gastropexy site (4 mm; range: 2 to 10 mm) was greater than in adjacent areas (2.6 mm; range: 1.7 to 3.7 mm). There was a greater body wall thickness at the gastropexy site observed with the laparoscopic approach (10 mm) than with incisional gastropexy (4 mm; range: 2 to 7.3 mm).

The gastric wall itself was also slightly thicker at the gastropexy site (5.7 mm; range: 2.6 to 11 mm) compared to adjacent gastric wall (4 mm; range: 2.3 to 8.7 mm).

The gastropexy site showed a soft-tissue-attenuation with median HU of 38.5 (range: 6 to 57).

Thirteen dogs exhibited neovascularisation at the gastropexy site (Fig 4, Table 2). In two dogs, neovascularisation could not be evaluated since contrast was not administered. In two other dogs, lacy fat was present immediately adjacent to the gastropexy site (16 and 102 days since surgery). No suture material was detected.

Assessment of gastropexy location

This is performed in dogs with a subjectively anatomic gastric orientation *versus* those without: Of the 22 dogs included, 45% ($n = 10$) were classified into the anatomic group, characterised by a subjectively normal anatomical position of the stomach, including the pylorus. In contrast, the remaining 55% ($n = 12$) made up the non-anatomic group and exhibited a subjectively abnormal positioning of the stomach and gastropexy site.

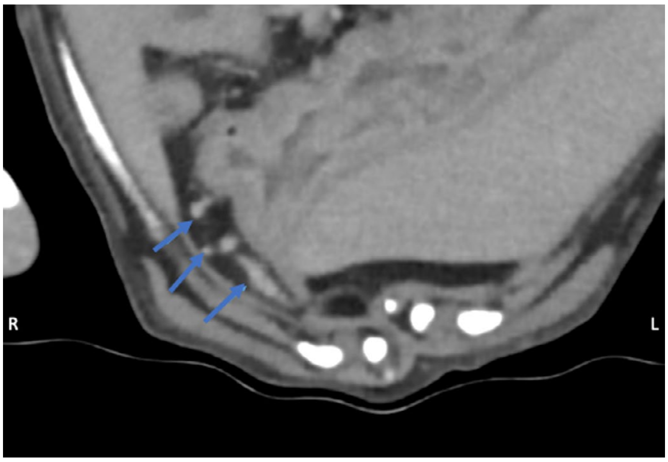

FIG 4. Post-contrast transverse CT image of the cranial abdomen at the level of the stomach, displayed in a soft-tissue-window post-contrast medium injection and illustrating a patient with several vessels (neovascularisation) adjacent to the gastropexy site (arrows).

Table 2. Overview of qualitative CT parameters and their distribution among the study groups (anatomic [A] vs. non-anatomic [NoA])

	Grading/category	A ($n = 10$)	NoA ($n = 12$)
Neovascularisation	Absent	2	5
	Present	8	5
Pedicle width	Broad	8	3
	Narrow	2	6
Hyperattenuating material	Absent	10	6
	Present	8	5
Gastric filling	Empty/moderate	6	9
	Dilated	4	3

n = number of animals. One dog could not be assigned to having a broad or narrow pedicle width. Two dogs in the non-anatomic group did not have contrast administered, therefore were not assessed for presence of neovascularisation

Abnormal gastropexy locations of the non-anatomic group included fixation at the midline body wall ($n = 1$), cranial to the gastric body ($n = 1$) and fixation of the pylorus ($n = 2$).

The anatomic group had broader gastropexy pedicles (Table 2) and longer gastropexy sites (3.3 cm; range: 1.3 to 5 cm) than the non-anatomic group (1.7 cm; range: 0.7 to 3.1 cm).

Distance from the xiphisternum to the gastropexy site was greater in the anatomic group (11.2 cm; range: 2.5 to 12.7 cm) than in the non-anatomic group (7.2 cm; range: 3.8 to 14.5 cm). Similarly, the distance from the midline was greater in the anatomic group (4.5 cm; range: 2.2 to 7.5 cm) compared to the non-anatomic group (2.6 cm; range: 0 to 8.5 cm).

The anatomic group had a larger median angle (85.5°; range: 65° to 140°) than the non-anatomic group (52°; range: 31° to 73°). Both the anatomic ($p = 0.007$; Hedges' $g = 1.26$) and non-anatomic groups ($p < 0.001$; Hedges' $g = 3.99$) had significantly smaller angles than the control group population (132°; range: 77° to 157°).

Assessment of features associated with gastrointestinal function

Severe gastric dilatation was present in 4/10 dogs in the anatomic group and 3/12 dogs in the non-anatomic group (Table 2).

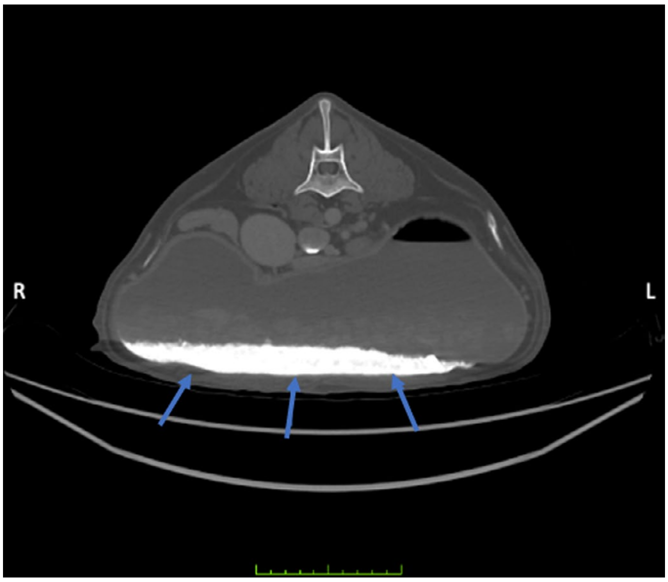

FIG 5. Transverse CT image of the cranial abdomen at the level of the stomach, displayed in a bone-window post-contrast medium injection and illustrating a patient with a marked gastric dilatation and hyperattenuating material, compatible with gravel sign (arrows).

Hyperattenuating gastric content (Fig 5) was present in all 10 dogs in the anatomic group and 6/12 dogs in the non-anatomic group (Table 2).

Specifically looking at the 11 dogs presenting with gastro-intestinal signs (6/10 in the anatomic group and 5/12 in the non-anatomic group; Table 1), CT findings that could be associated with gastric dysfunction were found in 9/11 cases. These included five dogs with hyperattenuating content, six with severe gastric dilatation and four with gastric wall thickening, with some dogs exhibiting multiple findings. Additionally, four out of the 11 dogs showed a diffuse small intestinal ileus on CT.

DISCUSSION

The objective of the current study was to describe the CT appearance of gastropexy sites in dogs. Using CT, we identified anatomical abnormalities of the stomach that commonly occur after gastropexy. We also described the appearance of the gastropexy site and provided evidence of secondary functional abnormalities along with their corresponding radiologic features, such as gravel sign and gastric dilatation.

Regarding breeds, the 22 dogs of the present study were considered representative of the classical population at risk of GDV, including large- and giant-breed dogs (Glickman et al., 2000). The most commonly performed surgical technique is currently an incisional gastropexy (Allen & Paul, 2014), which is in accordance with the present study. Surgical protocols were available for 13 dogs, including two dogs undergoing laparoscopic-assisted and belt-loop gastropexy and 11 dogs undergoing incisional gastropexy. Although there are various surgical gastropexy techniques described, no single procedure is currently recommended as the gold standard (Allen & Paul, 2014). Gastropexy is indicated following repositioning of the stomach after GDV, as well as following splenectomy and as a prophylactic procedure in predisposed breeds, such as the great Dane (Allen & Paul, 2014; Goldhammer et al., 2010; Marconato, 2006; Millis et al., 1995).

Time since surgery varied among the dogs from 16 to 1552 days. This should be considered when interpreting the appearance of stomach and gastropexy sites, such as thickness of surrounding skeletal muscle and smooth muscle of the stomach. Histopathology of gastropexy sites in dogs showed an intact adhesion with fibrous connective tissue after 14 days, which would be the case in all dogs in this current study (MacCoy et al., 1982). Early (2 to 4 days), intermediate (8 to 20 days) and late (57 to 79 days) ultrasonographic assessments of gastropexy sites in dogs after incisional gastropexy demonstrated a decrease in thickness of the site over time as well as abnormal gastric wall layers at the late examinations (Wacker et al., 1998). The authors presumed these findings were attributed to inflammatory reactions and scar tissue formation. Unfortunately, in the present study, we were not able to test for significant effects of time on the thickness of the body wall muscle due to large variance in time since surgery and the small sample size. The thickness of the affected body wall muscle and gastric wall was larger than the unaffected muscle in all included dogs regardless of time since surgery and anatomic group. A study in dogs investigating the ultrasonographic appearance of gastropexy sites demonstrated a mean gastropexy thickness of 4 to 7.5 mm (including gastric wall and portions of the abdominal wall), with thinner walls at earlier and thicker walls at later post-operative stages (Wacker et al., 1998). Neovascularisation at the gastropexy site was observed in more than half of the study population (Anatomic = 8; non-anatomic = 5). This characteristic feature might be helpful in detecting gastropexy sites in cases with unknown patient history. Microscopic neovascularisation of the gastropexy site has been documented as part of the physiological healing process in 94 dogs that underwent a modified circumcostal gastropexy (Formaggini et al., 2001). Neovascularisation may also be influenced by other factors such as regional ischemia, as demonstrated by a study investigating the impact of ischaemic conditioning on gastroesophageal anastomotic wound healing in opossums (Perry et al., 2013).

In the present study, deviations from the anatomical gastric position were present in approximately 55% ($n = 12$) of the dogs and included pyloric deviation, gastric body distortion, narrow pedicles associated with distorted gastric shape and abnormal gastropexy locations. A study investigating pyloric localisation in 57 dogs of breeds susceptible to GDV suggested that common gastropexy locations may result in considerable displacement of the pylorus relative to its natural anatomic location (Tomlinson et al., 2016). This is in accordance with previous studies performing positive contrast gastrography in dogs following belt-loop (Whitney et al., 1989) and circumcostal gastropexy (Leib et al., 1985) and documenting non-anatomical locations of the pylorus. In the present study, markedly abnormal gastropexy locations were detected in four dogs and included midline body wall, cranial to the body of the stomach, as well as fixations of the pylorus. The gastric angles of the present study population were significantly lower than the control group, with the gastric angles of the non-anatomic group being even lower than those of the anatomic group. Therefore, gastropexy may lead to a decrease in gastric angles, irrespective of the position of the gastropexy site. Possible reasons for markedly acute gastric angles may be malpositioning of the gastropexy site, for example, caudal or midline displacement or fixation of the gastric body or fundus, as well as pedicle width, for example, very narrow pedicles. In the present study, a narrow pedicle was much more likely identified in the non-anatomic group, whereas a broad pedicle was more likely identified in the anatomic group. In addition, a shorter gastropexy length was detected in the non-anatomic group, which might be interrelated with the narrow pedicles. The length measured in the anatomic group is in accordance with the mean length of gastropexy sites in dogs reported via ultrasonography (approximately 3 cm, Wacker et al., 1998). Malpositioning of the gastropexy may lead to a tension effect on the stomach and pedicle, making the pedicle narrower and leading to acute gastric angles. When the angle between the duodenum and pyloric antrum is too acute, gastric outflow obstruction might occur (Jennings Jr et al., 1992).

The gastropexy site in the non-anatomic group was positioned closer to the xiphisternum and had a shorter distance from the midline compared to the anatomic group. To the authors' knowledge, there are no exact distance-guidelines from midline or the xiphisternum for normal pyloric or gastropexy positions available in the literature. Usually, the last rib is used as an anatomic landmark for the gastropexy site (Fossum, 2002). Therefore, this might provide some useful information for future studies investigating effects of gastropexies.

The majority of dogs included in this study demonstrated features that could be associated with functional disturbance, including gastric dilatation or a gravel sign. Nearly half of the study population (9/22) exhibited gastrointestinal clinical signs accompanied by gastric abnormalities (*e.g.* gastric dilatation, gravel sign), although two dogs had no CT features of gastric dysfunction yet reported clinical signs.

The majority of the study population (16/22) demonstrated intraluminal gastric accumulation of granular mineral material. When observed alongside gastric dilatation, this finding is consistent with a 'gravel sign'. A gravel sign may indicate delayed gastric emptying, further suggesting altered gastrointestinal motility and/or chronic partial obstruction (Raul et al., 2018; Seiler & Mai, 2009). Interestingly, in the present study, all animals of the A group showed hyperattenuating material within the stomach to a certain degree. According to a study in dogs, 28.3% of patients with acute GDV demonstrated gastric gravel sign on the preoperative radiographs, indicative for chronic and partial gastric obstruction before admission (Raul et al., 2018). In the present study, only 3/22 dogs were judged to have an empty stomach, despite the dogs having been starved for at least 12 hours prior to the CT examination. A study investigating pyloric localisation in 57 dogs of breeds susceptible to GDV reported varying degrees of gastric dilatation either with gas and/or food material despite the dogs having been starved for 12 hours (Tomlinson et al., 2016). Consequently, gravel sign and gastric dilatation might be present irrespective of the gastropexy and its position.

Gastric dilatation can be due to primary or secondary gastric dysfunction attributed to various reasons, such as reduced motility secondary to sedation, neuromuscular disorders, gastric ulceration or chronic pyloric outflow obstruction (Nyland et al., 2014). Gastric dilatation is usually associated with clinical signs, such as non-productive retching, vomiting, salivation, abdominal distention and weakness (Simpson, 2017). In the cases with severe gastric dilatation (anatomic = 4; non-anatomic = 3), six presented with gastrointestinal signs. However, it remains unclear whether these functional disturbances are due to a pre-existing motility disorder, the effects of the gastropexy or a combination of both. It is important to note that postoperative paralytic ileus can be a potential complication following recent abdominal surgery, as observed in both dogs (Tsukamoto et al., 1999) and horses (Freeman et al., 2000). In the four cases with more recent surgeries (16 to 52 days; anatomic = 1, non-anatomic = 3), three showed gastrointestinal signs and two of these three also had additional abnormalities on CT, including gastric lumen infolding as well as gastric invagination. There was no association of presence of gravel sign or gastric dilatation with subjective non-anatomic gastric position, and indeed, there was no increase in the presence of clinical gastrointestinal signs in the group that had non-anatomic gastric positions.

Future studies with a prospective design are needed to investigate the role of gastropexy in gastric motility disorders. Such studies could include prophylactic gastropexy in animals without prior motility issues, allowing for a more precise evaluation of post-operative changes at different stages, and to help distinguish between pre-existing conditions and those induced by the surgery itself. Limitations of the study are attributed to its retrospective design, small sample size and data assessment by one observer. In addition, time since surgery varied markedly among the individuals, as well as surgical techniques and reason for surgery, with some data missing. In addition, it was not known whether changes such as gastric dilatation or gravel sign had been present prior to the gastropexy surgery to appropriately assess the effect of gastropexy on functional status of the stomach. Further limitations include the lack of standardised anaesthesia and sedation protocols, as well as variability in diaphragm positioning during different phases of respiration (inspiration and expiration), which may have affected the accuracy of gastric angle measurements. Authors are aware of the broad variety among the study population and that presented results might be of limited validity in terms of being a thorough representation of a wider population of post-gastropexy dogs. Future studies are required to establish a baseline of CT features associated with different types of gastropexy, allowing for a comparative analysis of their consequent appearances. Additionally, investigating the relationship between the identified CT features and gastric function could provide valuable insights into the impacts of various surgical techniques on gastrointestinal health.

The majority of dogs demonstrated anatomical abnormalities of the stomach and gastropexy sites. Computed tomographic findings of the stomach included gastric malpositioning, slight thickening of the gastric wall and adjacent body wall, presence of increased vascularity in the region of the gastropexy, gastric dilatation, gravel sign and acute gastric angles. The gastropexy itself demonstrated either narrow or broad pedicles. Anatomic distortion was more commonly associated with a narrow pedicle, acute gastric angles, shortened gastropexy length and a close proximity to the midline and xiphisternum but anatomic distortion was not always linked to current gastrointestinal signs as the main reason for CT. While this study offers valuable retrospective insights into the post-gastropexy appearance of the stomach, the true difficulty lies in determining the clinical significance of these imaging findings in individual cases with gastrointestinal signs.

These findings provide a guide for radiologists of the variable CT appearance of gastropexy sites in dogs and may act as a baseline for future studies to further investigate the short- and long-term consequences of anatomic distortion on the stomach during gastropexy.

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Author contributions

J. Einwaller: Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); writing – original draft (equal); writing – review and editing (equal). **F. Llabres-Diaz:** Conceptualization (equal); formal analysis (equal); writing – original draft (equal); writing – review and editing (equal). **C. Jones:** Data curation (equal); formal analysis (equal); writing – review and editing (equal). **A. Caine:** Conceptualization (equal); formal analysis (equal); investigation (equal); methodology (equal); writing – original draft (equal); writing – review and editing (equal).

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Conflict of interest

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

Data availability statement

The data that support the findings of this study are available on request from the corresponding author (JE).

References

Allen, P. & Paul, A. (2014) Gastropexy for prevention of gastric dilatation-volvulus in dogs: history and techniques. *Topics in Companion Animal Medicine*, **29**, 77–80.
Balsa, I.M., Culp, W.T.N., Drobatz, K.J., Johnson, E.G., Mayhew, P.D. & Marks, S.L. (2017) Effect of laparoscopic-assisted gastropexy on gastrointestinal transit time in dogs. *Journal of Veterinary Internal Medicine*, **31**, 1680–1685.
Benitez, M.E., Schmiedt, C.W., Radlinsky, M.G. & Cornell, K.K. (2013) Efficacy of incisional gastropexy for prevention of GDV in dogs. *Journal of the American Animal Hospital Association*, **49**, 185–189.
Coleman, K.A., Boscan, P., Ferguson, L., Twedt, D. & Monnet, E. (2019) Evaluation of gastric motility in nine dogs before and after prophylactic laparoscopic gastropexy: a pilot study. *Australian Veterinary Journal*, **97**, 225–230.
Eggertsdóttir, A.V., Langeland, M., Fuglem, B. & Mohn, A. (2008) Long-term outcome in dogs after circumcostal gastropexy or gastrocolopexy for gastric dilatation with or without volvulus. *Veterinary Surgery*, **37**, 809–810.
Degna, M., Formaggini, L., Fondati, A. & Assin, R. (2001) Using a modified gastropexy technique to prevent recurrence of gastric dilatation-volvulus in dogs. *Veterinary Medicine*, **96**, 39–50.
Fossum, T.W. (2002) Surgery of the digestive system. In: Fossum, T.W. (Ed.) Small animal surgery, 2nd edition. St Louis, MO: CV Mosby Co, pp. 354–366.
Freeman, D.E., Hammock, P., Baker, G.J., Goetz, T., Foreman, J.H., Schaeffer, D.J. et al. (2000) Short-and long-term survival and prevalence of postoperative ileus after small intestinal surgery in the horse. *Equine Veterinary Journal*, **32**, 42–51.
Frendin, J., Funkquist, B. & Stavenborn, M. (1988) Gastric displacement in dogs without clinical signs of acute dilatation. *Journal of Small Animal Practice*, **29**, 775–779.
Funkquist, B. & Garmer, L. (1967) Pathogenetic and therapeutic aspects of torsion of the canine stomach. *Journal of Small Animal Practice*, **8**, 523–532.
Glickman, L.T., Glickman, N.W., Schellenberg, D.B., Raghavan, M. & Lee, T.L. (2000) Incidence of and breed-related risk factors for gastric dilatation-volvulus in dogs. *Journal of the American Veterinary Medical Association*, **216**, 40–45.
Goldhammer, M.A., Haining, H., Milne, E.M., Shaw, D.J. & Yool, D.A. (2010) Assessment of the incidence of GDV following splenectomy in dogs. *Journal of Small Animal Practice*, **51**, 23–28.
Hall, J.A., Willer, R.L., Seim, H.B., III, Lebel, J.L. & Twedt, D.C. (1992) Gastric emptying of nondigestible radiopaque markers after circumcostal gastropexy in clinically normal dogs and dogs with gastric dilatation-volvulus. *American Journal of Veterinary Research*, **53**, 1961–1965.
Hall, J.A., Willer, R.L., Solie, T.N. & Twedt, D.C. (1997) Effect of circumcostal gastropexy on gastric myoelectric and motor activity in dogs. *Journal of Small Animal Practice*, **38**, 200–207.
Hardie, R.J., Flanders, J.A., Schmidt, P., Credille, K.M., Pedrick, T.P. & Short, C.E. (1996) Biomechanical and histological evaluation of a laparoscopic stapled gastropexy technique in dogs. *Veterinary Surgery*, **25**, 127–133.
Jennings, P.B., Jr., Mathey, W.S. & Ehler, W.J. (1992) Intermittent gastric dilatation after gastropexy in a dog. *Journal of the American Veterinary Medical Association*, **200**, 1707–1708.
Johnson, R.G., Barrus, J. & Greene, R.W. (1984) Gastric dilatation-volvulus: recurrence rate following tube gastrostomy. *Journal of the American Animal Hospital Association*, **20**, 33–37.
Leib, M.S., Konde, L.J., Wingfield, W.E. & Twedt, D.C. (1985) Circumcostal gastropexy for preventing recurrence of gastric dilatation-volvulus in the dog: an evaluation of 30 cases. *Journal of the American Veterinary Medical Association*, **187**, 245–248.
Loy Son, N.K., Singh, A., Amsellem, P., Kilkenny, J., Brisson, B.A., Oblak, M.L. et al. (2016) Long-term outcome and complications following prophylactic laparoscopic-assisted gastropexy in dogs. *Veterinary Surgery*, **45**, 077–083.
MacCoy, D.M., Sykes, G.P., Hoffer, R.E. & Harvey, H.J. (1982) A gastropexy technique for permanent fixation of the pyloric antrum. *Journal of the American Animal Hospital Association*, **18**, 763–768.
Marconato, L. (2006) Gastric dilatation-volvulus as complication after surgical removal of a splenic haemangiosarcoma in a dog. *Journal of Veterinary Medicine. A, Physiology, Pathology, Clinical Medicine*, **53**, 371–374.
Millis, D.L., Nemzek, J., Riggs, C. & Walshaw, R. (1995) Gastric dilatation-volvulus after splenic torsion in two dogs. *Journal of the American Veterinary Medical Association*, **207**, 314–315.
Nyland, T.G., Neelis, D.A. & Mattoon, J.S. (2014) Gastrointestinal tract. In: Mattoon, J.S. & Nyland, T.G. (Eds.) Small animal diagnostic ultrasound, 3rd edition. St. Louis, MO: Elsevier Saunders, pp. 468–500.
Paris, J.K., Yool, D.A., Reed, N., Ridyard, A.E., Chandler, M.L. & Simpson, J.W. (2011) Chronic gastric instability and presumed incomplete volvulus in dogs. *Journal of Small Animal Practice*, **52**, 651–655.
Perry, K.A., Banarjee, A., Liu, J., Shah, N., Wendling, M.R. & Melvin, W.S. (2013) Gastric ischemic conditioning increases neovascularization and reduces inflammation and fibrosis during gastroesophageal anastomotic healing. *Surgical Endoscopy*, **27**, 753–760.
Pope, E.R. & Jones, B.D. (1999) Clinical evaluation of a modified circumcostal gastropexy in dogs. *Journal of the American Veterinary Medical Association*, **215**, 952–955.
Przywara, J.F., Abel, S.B., Peacock, J.T. & Shott, S. (2014) Occurrence and recurrence of gastric dilatation with or without volvulus after incisional gastropexy. *Canadian Veterinary Journal*, **55**, 981.
Raul, A., Rosa, N., Yvonne, E. & Elisabet, D. (2018) Assessment of the prevalence of gastric “gravel sign” in dogs with acute gastric dilatation-volvulus. *Acta Veterinaria*, **68**, 161–167.
Rawlings, C.A., Foutz, T.L., Mahaffey, M.B., Howerth, E.W., Bement, S. & Canalis, C. (2001) A rapid and strong laparoscopic-assisted gastropexy in dogs. *American Journal of Veterinary Research*, **62**, 871–875.
Rawlings, C.A., Mahaffey, M.B., Bement, S. & Canalis, C. (2002) Prospective evaluation of laparoscopic-assisted gastropexy in dogs susceptible to gastric dilatation. *Journal of the American Veterinary Medical Association*, **221**, 1576–1581.

Seiler, G. & Mai, W. (2009) The stomach. In: BSAVA manual of canine and feline abdominal imaging. Gloucester: British Small Animal Veterinary Association, pp. 87–109.

Simpson, K.W. (2017) Diseases of the stomach. In: Ettinger, S. & Feldman, E. (Eds.) Textbook of veterinary internal medicine, 8th edition. Philadelphia, PA: Elsevier, pp. 3598–3642.

Tanno, F., Weber, U., Wacker, C., Gaschen, L., Schmid, V. & Lang, J. (1998) Ultrasonographic comparison of adhesions induced by two different methods of gastropexy in the dog. *Journal of Small Animal Practice*, **39**, 432–436.

Tavakoli, A., Mahmoodifard, M. & Razavifard, A.H. (2016) The superiority of paracostal endoscopic-assisted gastropexy over open incisional and belt loop gastropexy in dogs: a comparison of three prophylactic techniques. *Iranian Journal of Veterinary Research*, **17**, 118.

Tomlinson, A.W., Lillis, S.M., German, A.J. & Burrow, R.D. (2016) Pyloric localisation in 57 dogs of breeds susceptible to gastric dilatation-volvulus using computed tomography. *Veterinary Record*, **179**, 626.

Tsukamoto, K., Mizutani, M., Yamano, M. & Suzuki, T. (1999) The relationship between gastrointestinal transit and motility in dogs with postoperative ileus. *Biological and Pharmaceutical Bulletin*, **22**, 1366–1371.

Wacker, C.A., Weber, U.T., Tanno, F. & Lang, J. (1998) Ultrasonographic evaluation of adhesions induced by incisional gastropexy in 16 dogs. *Journal of Small Animal Practice*, **39**, 379–384.

Ward, M.P., Patronek, G.J. & Glickman, L.T. (2003) Benefits of prophylactic gastropexy for dogs at risk of gastric dilatation-volvulus. *Preventive Veterinary Medicine*, **60**, 319–329.

White, C., Dirrig, H. & Fitzgerald, E. (2020) CT findings in dogs with gastric malposition: 6 cases (2016–2019). *Journal of Small Animal Practice*, **61**, 766–771.

Whitney, W.O. (1989) Complications associated with the medical and surgical management of gastric dilatation-volvulus in the dog. *Problems in Veterinary Medicine*, **1**, 268–280.

Whitney, W.O., Scavelli, T.D., Matthiesen, D.T. & Burk, R.L. (1989) Belt-loop gastropexy: technique and surgical results in 20 dogs. *Journal of the American Animal Hospital Association*, **25**, 75–83.

Wilson, E.R., Henderson, R.A., Montgomery, R.D., Kincaid, S.A., Wright, J.C. & Hanson, R.R. (1996) A comparison of laparoscopic and belt-loop gastropexy in dogs. *Veterinary Surgery*, **25**, 221–227.

Woolfson, J.M. & Kostolich, M. (1986) Circumcostal gastropexy: clinical use of the technique in 34 dogs with gastric dilatation-volvulus. *Journal of the American Animal Hospital Association*, **22**, 825–830.

