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AUTHORS: Fitzgerald, E., Lam, R. and Drees, R

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Improving conspicuity of the canine gastrointestinal wall using dual phase contrast-enhanced computed tomography: a retrospective cross-sectional study

Fitzgerald, E.[1], Lam, R.[1] and Drees, R[1]

[1]Department of Clinical Science and Services, Royal Veterinary College, Hatfield, Hertfordshire, UK

Address correspondence and reprint requests to Dr. Randi Drees

E-mail: rdrees@rvc.ac.uk

Abstract

Gastrointestinal (GI) disease is a common clinical complaint in small animal patients; computed tomography (CT) examinations enable a global overview of the GI tract and associated structures. Previously, the GI wall has been reportedly identified from serosa to mucosa in 77% of standard postcontrast CT studies and wall layers seen in ultrasound have not been distinguished. Inconsistent strong contrast enhancement of the inner layer of the GI mucosal surface was noted on dual phase CT studies acquired in our institution, which increased the visibility of the GI tract and disease processes. The aim of this retrospective, observational, cross-sectional study was to determine the optimal portal vein attenuation for maximizing GI wall conspicuity using dual phase contrast-enhanced CT. Patients with abdominal CT for a non-GI related disease were included. In a pilot study, 175 GI segments from 35 CT studies were graded for presence of mucosal surface enhancement (MSE). The strongest mucosal surface enhancement grade correlated with portal vein attenuation of 43–150 HU; this value was used as inclusion criterion in the main study. A total of 441 GI segments were evaluated in 42 CT studies postcontrast for GI wall conspicuity. The GI wall was conspicuous in 56.7% precontrast, 84.5% at 30s, and 77.3% late postcontrast; 4.7% of segments were removed due to motion blur. At 30 s distinct mucosal surface enhancement was seen in the small intestine and gastric mucosal surface enhancement was poor. Findings supported the use of dual phase contrast-enhanced CT for improving conspicuity of the GI wall.

Key words: computed tomography, dog, intestine, portal vein, stomach.

Introduction

Gastrointestinal disease can represent a diagnostic challenge in small animals using noninvasive techniques. First-line modalities used in patients with gastrointestinal disease commonly include conventional radiography, contrast radiography, or ultrasound (US). The diagnostic value of these imaging studies is influenced by a number of factors.[1] In human medicine, computed tomography is broadly utilized for diagnosis and staging of gastrointestinal neoplasia, clinical workup of acute abdominal pain, detection of gastrointestinal bleeding as well as inflammatory or vascular disorders and assessment of postoperative complications of gastrointestinal surgery.[2–5] The utility of computed tomography (CT) for diagnostic workup of abdominal disease is established in the veterinary literature, however a limited focus has been placed on the use of computed tomography (CT) specifically for evaluation of the gastrointestinal tract.[6,7] Only one prior study describes standard pre- and postcontrast CT to evaluate the gastrointestinal tract in dogs. In that study, 62.8% of gastrointestinal segments and 77.7% of gastrointestinal walls were seen.[8] Wall layering on the postcontrast examination was only identified in 21.8% of gastrointestinal segments. Another study focused on the evaluation of the gastric wall using helical hydro CT.[9] Dual phase contrast-enhanced CT examinations have been routinely acquired at our institution for other clinical purposes using non individualized bolus injection timing at 30 s and 60–180 s (late postcontrast examination) after initiating the intravenous iodinated contrast bolus. Pronounced enhancement of the inner layer of the gastrointestinal tract, particularly the stomach and small intestine, was noted intermittently on the studies acquired in the 30 s and late postcontrast examinations. This enhancement subjectively aided in the depiction of the gastrointestinal wall compared to regular postcontrast studies acquired at approximately 60 s postcontrast injection. The sonographic

appearance of normal gastrointestinal wall layering is well described in the literature. A similar description of normal gastrointestinal wall layering in post- contrast CT examinations has not been described in veterinary patients.[10]

The overall goal of this study was therefore to evaluate dual phase CT as a possible future method for gastrointestinal disease evaluation in dogs. The first specific aim was to determine when this contrast enhancement pattern would appear in relation to abdominal vascular enhancement. The second specific aim was to determine if dual phase contrast CT would allow for improvement of intestinal wall conspicuity compared to prior veterinary studies, by enhancing the distinction between lumen and mucosal surface using a dual phase examination as compared to standard postcontrast CT.[8] Our hypotheses were twofold: (1) distinct enhancement of the inner layer of the gastrointestinal segments would occur early in postcontrast period; and (2) contrast enhancement of the inner layer of the gastrointestinal wall would increase detection of gastrointestinal segments as compared to standard postcontrast CT.

Material and Methods

Subject Selection

The design of this study was observational, cross- sectional, and retrospective. Computer records at the Royal Veterinary College were searched for dogs having had dual phase contrast CT examination of the abdomen between January 2013 and

December 2014. Prior to January 2013 and after December 2014, two postcontrast CT examinations were not routinely acquired. Dual phase contrast CT was defined as two postcontrast acquisitions. These acquisitions were generically timed at 30 s and at least 60 s after beginning of contrast administration. The initial exclusion criteria for the study were: recent history (previous 6 months) of gastrointestinal illness, a final diagnosis of gastrointestinal related disease, vascular anomalies (e.g. caudal vena cava duplication, portosystemic shunt), venous hind limb injection, or hand injection. Patients where CT studies were acquired after magnetic resonance imaging (MRI) examination were also excluded as the presence of residual gadolinium may have affected the enhancement patterns of the intestine. Patient selection was performed by the first author (second-year resident). The breed, age, and weight of each dog meeting the inclusion criteria were recorded.

As part of the inclusion criteria, all patients were scanned in sternal recumbency from cranial to caudal using 16 multidetector row computed tomography unit (MDCT) (Mx8000 IDT, Philips, Best, The Netherlands). The majority of patients had both thoracic and abdominal CT. The following helical CT protocol was used: 16 × 1.5 mm collimation, 1.5 cm slice overlap, tube rotation time of 0.5 s, 150 mA (nominal), 120 kVp, 3 mm slice thickness, and display field of view tailored to patient size.

Images were generated using a soft tissue reconstruction algorithm. Intravenous iodinated contrast medium (Omnipaque, iohexol, 300 mg I/ml, GE Healthcare AS,

Nycoveie 1–2, NO-0401 Oslo, Norway; 2 ml/kg body weight) was administered using a power injector (Stellant, Medrad Inc., PA), with pressure limit set at 150 psi. Postcontrast images were acquired at 30 s from the start of contrast administration. A second postcontrast scan was performed late postcontrast with variability in the timing of the late postcontrast study (range of 60–180 s).

A single review of retrieved images was performed by the primary author (E.F.) followed by consensus review with the last author (R.D.). For the image review studies were reviewed in three batches; precontrast, 30 s postcontrast, and late postcontrast. The patient's identification number was used to identify studies; patient name and age were removed from DICOM images prior to review. Both readers were unaware of patient breed, age, weight, and final diagnosis during the evaluation of the CT studies.

Determining the Optimal Contrast Enhancement Time

A pilot study was conducted to select for studies with optimal contrast enhancement of the inner layer of the gastrointestinal tract (denoted as mucosal surface enhancement (MSE) for the purposes of this study) in the 30 s postcontrast examination within a narrow range of vessel attenuation using a representative sample of the population that met the inclusion criteria. The pilot study comprised three steps: (1) grade mucosal surface enhancement of five gastrointestinal segments, (2) record abdominal vessel attenuation at four sites, (3) correlate grade

of mucosal surface enhancement with vessel attenuation. To grade the mucosal surface enhancement, five representative gastrointestinal segments were selected from each of these CT studies: gastric body, descending duodenum, jejunum, ileum, and descending colon. A subjective three-tiered grading system was used (Fig. 1): good (1, distinct mucosal surface enhancement), moderate (2, faint mucosal surface enhancement), and poor (3, no difference between the inner surface and remainder of the gastrointestinal wall).

Abdominal vascular attenuation was recorded at four sites in each of these CT examination: portal vein and aorta at the level of the porta hepatis; aorta and caudal vena cava immediately cranial to the aortic bifurcation. This was achieved by placing a region of interest that covered >80% of the vascular lumen and recording the mean HU measured (Fig. 2). The ranges of attenuation values for the aortic, CVC, and portal vein measurements were recorded (Table 1). Abdominal vascular attenuation was evaluated for variability in contrast enhancement, to select the vessel with the narrowest range of Hounsfield units. Shapiro- Wilk test was performed to test for normalcy of distribution of vascular enhancement compared to mucosal surface enhancement recorded. The mean or median value and range of the portal vein values for these studies were calculated.

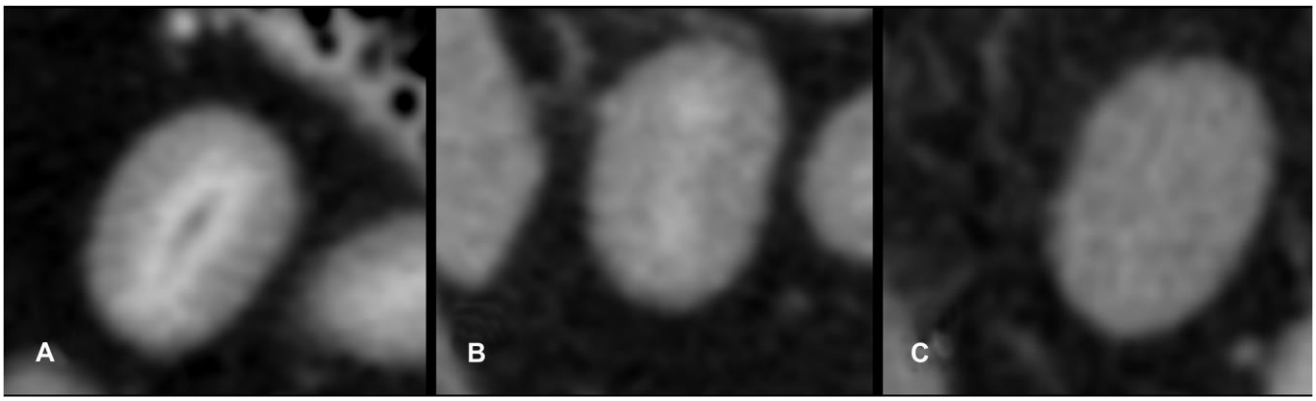

FIG. 1. Grades of mucosal surface enhancement (MSE); 1 = Good (A), 2 = moderate (B) and 3 = poor (C) as used for the pilot study in the first 35 dogs to meet the inclusion criteria.

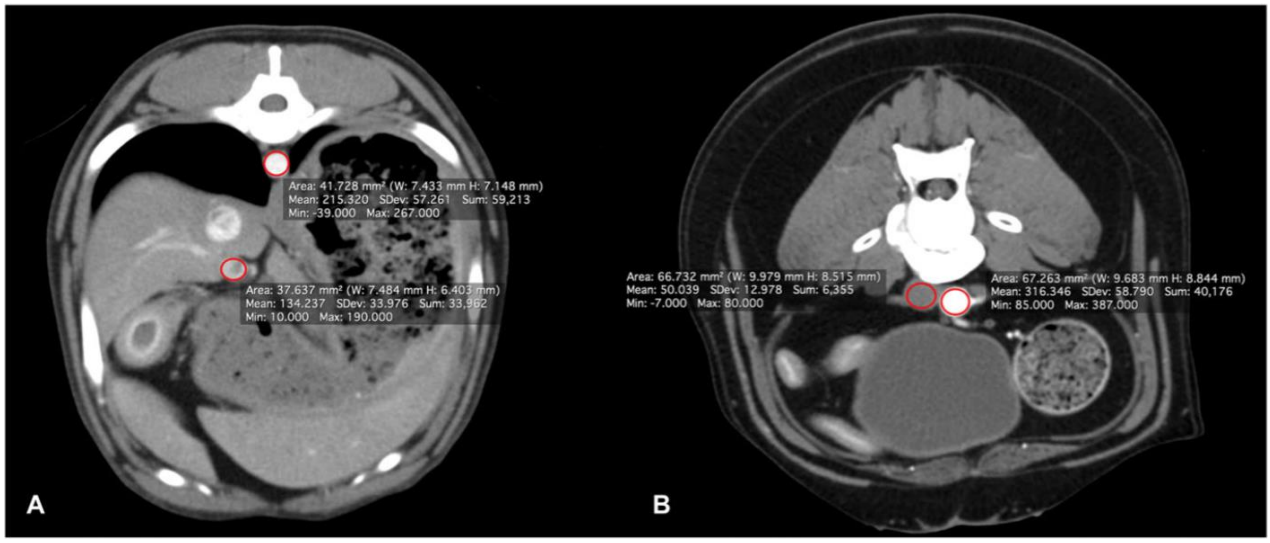

FIG. 2. (A) Cranial aorta and portal vein. (B) Caudal aorta and CVC measurements of vessel attenuation.

TABLE 1. Range of Vessel Attenuation Values in the Pilot Study; Using 30 s Postcontrast Scans of the First 35 Examinations that Met the Initial Inclusion Criteria

	Range (HU)
Cranial Aorta	206-720
Caudal Aorta	210-654
Portal Vein	39-150

* CVC attenuation values were censored from further analysis

Determining Whether Dual Phase Contrast CT Improved Gastrointestinal Wall Conspicuity

An additional inclusion criterion of 43–150 HU portal vein attenuation in the 30 s postcontrast examinations was introduced for the main study to standardize portal vascular enhancement between studies in lieu of the absence of specific bolus timing. Analogous to the prior study, the gastrointestinal tract was divided into eleven segments: gastric body, pyloric antrum, pylorus, descending duodenum, transverse duodenum, jejunum, ileum, ileocolic junction, transverse colon, descending colon and rectum The gastrointestinal wall conspicuity of each segment was recorded for pre and both, the 30 s and late postcontrast studies. Gastrointestinal wall conspicuity was defined by the ability to identify the gastrointestinal segment wall from serosa to mucosa and to follow that section of gastrointestinal tract for greater than 75% of the entire length of the segment. Gastrointestinal wall conspicuity was recorded as seen (yes) or not seen (no); the reason for inability to detect the segment was recorded. In the case of ileocolic junction, the wall of the ileocolic orifice was evaluated. Each gastrointestinal segment was evaluated precontrast, at 30 s and late postcontrast. If motion caused blurring of a gastrointestinal segment that segment was excluded from evaluation in the pre, 30 s and late postcontrast examination. Statistical comparisons for gastrointestinal wall

conspicuity were per- formed by the first author (E.F.) using commercial software (SPSS version 19, SPSS Inc., Chicago, IL).

Results

The records of 1,396 patients with abdominal CT examinations were reviewed. Ninety-three CT examinations from 46 dogs met the initial inclusion criteria. The first 35 dogs from this population were selected for inclusion in the pilot study (Fig. 3). In patients with multiple studies, the initial CT examination was selected for evaluation.

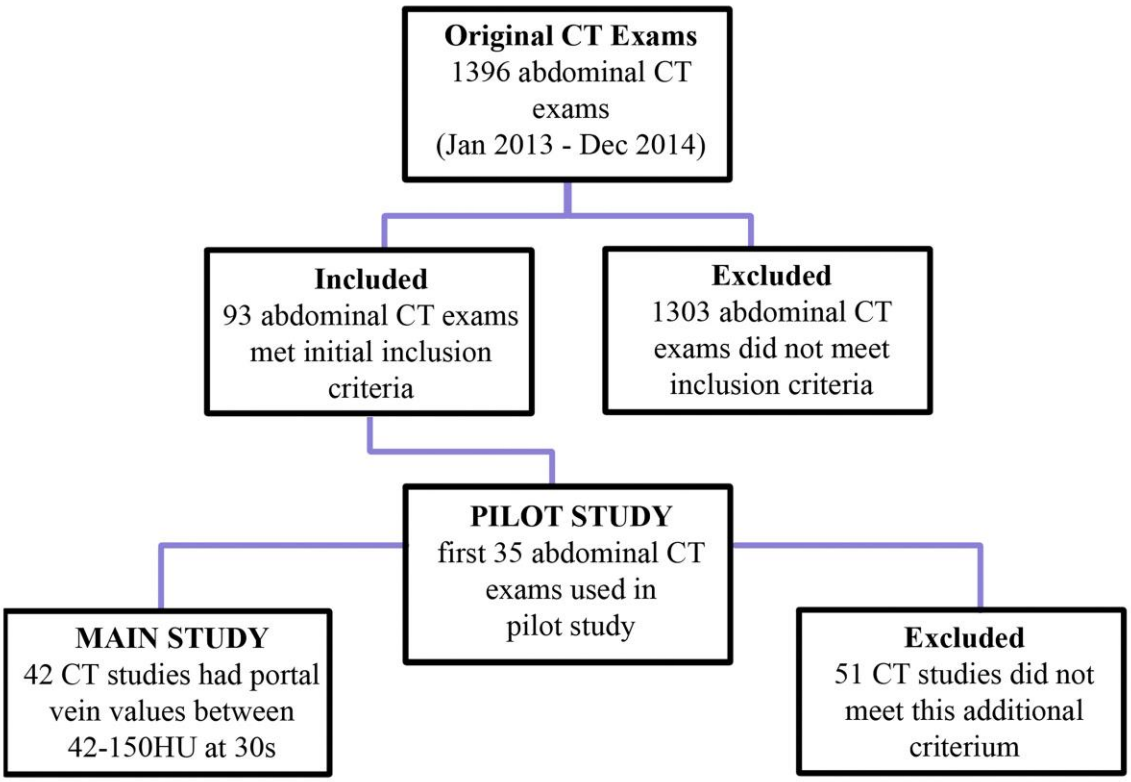

FIG. 3. Flow chart illustrating criteria used for patient selection.

In the pilot study, the intensity of mucosal surface enhancement differed markedly between different areas of the gastrointestinal tract in 30 s postcontrast studies. A good mucosal surface enhancement (grade 1) was frequently identified in the small intestine (duodenum, jejunum, and ileum) and large intestine at 30 s in the pilot study. Mucosal surface enhancement of the gastric body was found to be poor (grade 3) at 30 s postcontrast. During evaluation of vascular contrast enhancement in the pilot study, a number of cases showed the caudal vena cava dorsoventrally flattened due to inappropriate placement of positioning aids and/or a markedly distended urinary bladder. Thus, the vessel lumen could not be reliably identified, making measurements of vessel attenuation unreliable. Therefore, the caudal vena cava attenuation values were censored from further analysis.

Intrapatient variation in aortic attenuation between the cranial and caudal sites was considered low (4–136 HU). Therefore, an average aortic attenuation of the cranial and caudal sites was calculated and used for further interpatient comparisons. There was a large range in the interpatient average aortic attenuation (218.5–603.5 HU). When comparing interpatient aortic and portal vein values, less variation was noted in the portal vein attenuation measurements (portal vein attenuation range 39–150 HU). Thus portal vein attenuation was selected for correlation with grade 1 mucosal surface enhancement.

Tests for normality (Shapiro-Wilk) indicated the portal vein attenuation values for grade 1 mucosal surface enhancement of duodenum, jejunum, and ileum were

normally distributed (P-value > 0.05). The portal vein attenuation values for grade 1 colonic mucosal surface enhancement were not normally distributed; thus a median portal vein attenuation value was calculated for the colon.

Mean and median portal vein attenuation values for the grade 1 mucosal surface enhancement of the duodenum, jejunum, ileum, and descending colon were 94, 87, 81, and 64 HU, respectively (Table 2); hence the range of 43–150 HU portal vein attenuation in the 30 s postcontrast examinations was used as an additional criterion for patient selection. This criterion standardized portal vascular enhancement between studies in the absence of patient-specific bolus timing based on grade 1 mucosal surface enhancement of the duodenum, jejunum, ileum, and colon.

TABLE 2. Portal Vein Value for Grade 1 Enhancement of Gastrointestinal Segments of the Thirty-Five Studies of the 30 s Postcontrast Scan in the Pilot Study

	Mean PV* attenuation (HU)	**SD PV attenuation (HU)**	**Range PV attenuation (HU)**
Gastric body	N/A	N/A	
Duodenum	94	31	45-150
Jejunum	87	36	43-150
Ileum	81	27	43-150

Colon	64†	N/A	45-150

*Portal vein, †median value

The introduction of the additional selection criterion excluded 54/96 CT examinations. The remaining 42 CT examinations from 39 dogs were finally included in the main study.

The 39 dogs included in the main study had a me- dian age of 10 years (range 2.5–14 years). Of the dogs included there were 19 neutered males, 14 neutered females, and six entire male dogs. The study population consisted of 12 crossbreeds, five Labradors, three English Springer Spaniels, two Dobermans, and one each of 16 other breeds (Basset Hound, Beagle, Boxer, Cavalier King Charles Spaniel, Cocker Spaniel, Chow Chow, Golden Retriever, Hungarian Vizsla, Irish setter, Irish Terrier, Jack Russell Terrier, Lurcher, Poodle, Rottweiler, Tibetan Terrier, West Highland White Terrier). The median weight of the dogs was 24 kg (range 10–47 kg).

A total of 441 gastrointestinal segments in 42 CT examinations (one patient had four CT studies) were evaluated for wall conspicuity in the main study. Twenty-one segments (4.7%) were excluded due to motion blur. A summary of the results is included in Table 3.

TABLE 3. Results of Main Study: Number (%) of Gastrointestinal Segments Identified in Each Examination (n = 39 dogs)

	Pre-contrast	30s post contrast	Late post contrast	Segments excluded
Gastric body	9(22.5%)	17(42%)	24(60%)	2(5%)
Pyloric antrum	10(24.3%)	22(53.6%)	31(75.6%)	1(2.3%)
Pylorus	17(42.5%)	18(45%)	28(70%)	2(5%)
D. Duodenum*	28(66.6%)	42(100%)	36(85.7%)	0(0%)
T. Duodenum†	22(55%)	40(100%)	32(80%)	2(5%)
Jejunum	6(16.2%)	37(100%)	9(24.2%)	5(12.5%)
Ileum	19(52.7%)	34(94.4%)	28(77.75)	6(16.6%)
ICJ‡	33(82.5%)	40(100%)	38(95%)	2(5%)
T. Colon§	37(92.5%)	40(97.5%)	38(92.6%)	1(2.3%)
D. Colon||	39(92.8%)	42(100%)	41(97.6%)	0(0%)
Rectum	29(69%)	41(97.6%)	39(92.8%)	0(0%)

* Descending duodenum, † Transverse duodenum, ‡ Ileocolic junction, §Transverse colon, ||Descending colon

Gastric Wall Conspicuity

Two of the gastric body segments were removed from calculations due to motion blur. The remaining 40 gastric body segments were included in the evaluation. The highest number of clearly defined gastric body segments (24/40, 60%) was seen in the late examinations (Fig. 4). In 17 of these late postcontrast examinations the mucosal surface enhancement had intensified since the 30 s scan was acquired. The

gastric lumen was collapsed in all examinations where the gastric body wall could not be distinguished. In precontrast examinations the gastric body wall was only identified if the lumen was distended with fluid and/or gas. At 30 s the gastric wall was not defined in 22/40 (55%) segments due to poor mucosal surface enhancement with or without a collapsed lumen. In the late postcontrast study, collapse of the lumen was a common cause for inability to distinguish the gastric wall and was seen in 40% (16/40) of the examinations.

Pyloric Antrum Wall Conspicuity

The pyloric antral wall was clearly identified most frequently in late postcontrast examinations (Fig. 5). One segment was removed from the calculations due to motion. The pyloric antral wall was clearly visible in 10/41 (24.3%) examinations precontrast, 22/41 (53.6%) at 30 s and 31/41(75.6%) late postcontrast. Precontrast the pyloric antral wall was only clearly delineated in the presence of luminal gas and/or fluid. At 30 s postcontrast poor mucosal surface enhancement alone inhibited delineation of the pyloric antral wall in 12/41 (29.2%) segments. In combination with poor mucosal surface enhancement, luminal collapse prevented distinguishing the wall from serosa to mucosa in a further six pyloric antral segments.

Pylorus Wall Conspicuity

Two pyloric segments were removed from calculations due to motion. In the remaining 40 examinations the pyloric sphincter wall was clearly defined in almost

equal numbers precontrast (17/40, 42.5%) and at 30 s postcontrast (18/40, 45%). In the late postcontrast examination this figure in- creased to 28/40 (70%) segments (Fig. 4). In the absence of intraluminal gas or fluid or in the presence of ingesta, the pyloric lumen/mucosal interface could not be defined in precontrast images. At 30 s postcontrast, mucosal surface enhancement allowed identification of the pyloric wall in three additional segments. Poor mucosal surface enhancement at 30 s in the remaining 20/40 (50%) cases prevented delineation of the pyloric wall. In the late postcontrast examination the pyloric wall of 12/40 (30%) cases could not be defined; the pyloric lumen was collapsed in all of these 12 cases.

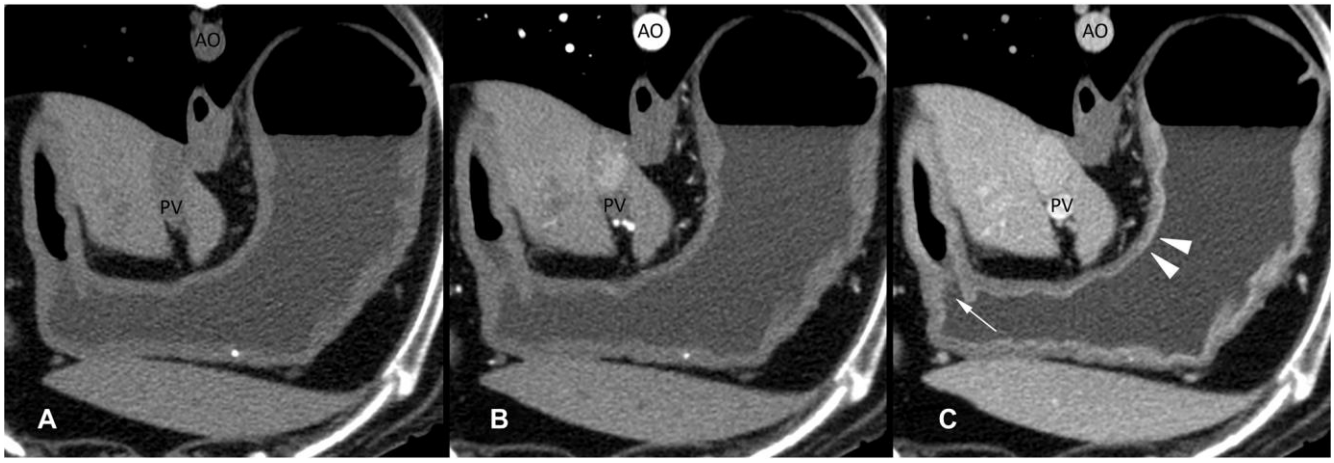

FIG. 4. Gastric body, pyloric antrum and pylorus (white arrow) precontrast (A), at 30 s (B) and late (C) postcontrast in the main study population. Contrast enhancement of the mucosal surface of the gastric body and pyloric antrum is poor at 30 s. Enhancement of the gastric body mucosal surface (white arrowheads) improves in the late postcontrast examination. AO, aorta; PV, portal vein.

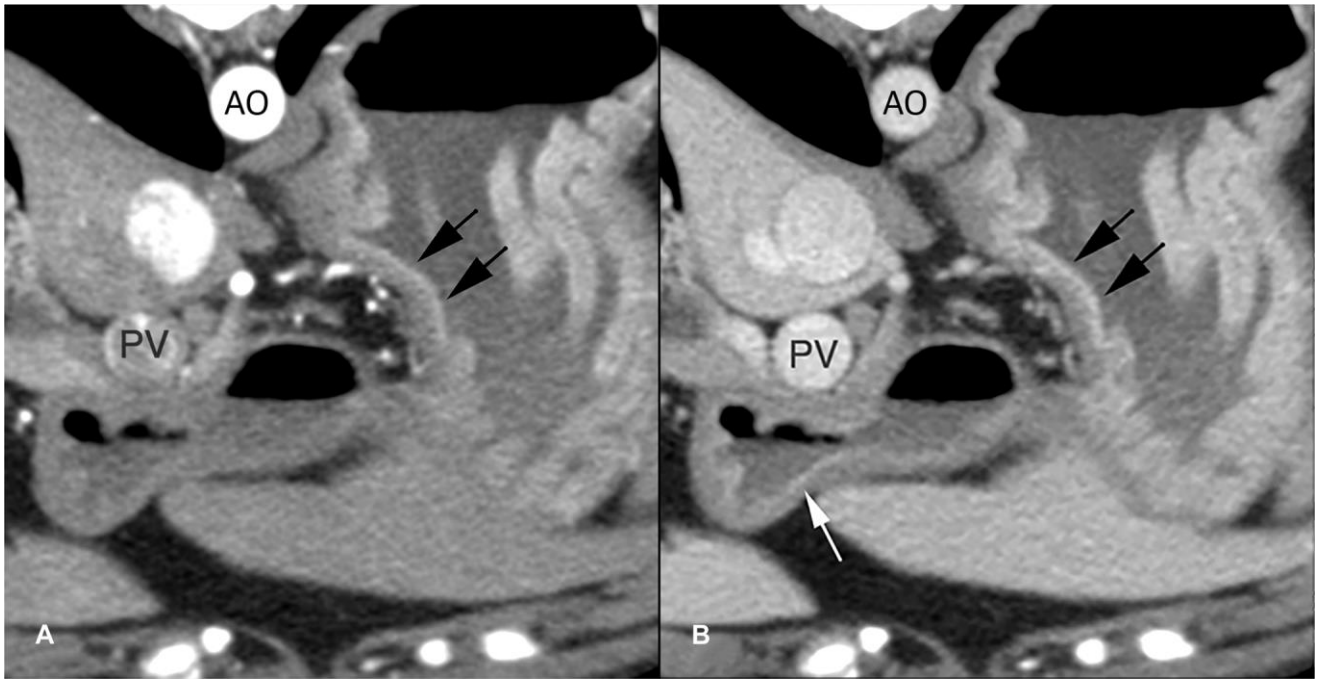

FIG. 5. Close-up images of the pyloric antrum at 30 s (A) and late (B) postcontrast in the main study population. Mucosal enhancement of the gastric wall (black arrows) and pyloric antrum (white arrow) are seen late postcontrast.

Descending and Transverse Duodenum Wall Conspicuity

In the 42 examinations the descending duodenal wall was delineated in 28/42 (66.6%) precontrast, 42/42 (100%) at 30 s and 36/42 (85.7%) late postcontrast.

Two transverse duodenal segments were removed due to motion. Of the remaining 40 examinations the transverse duodenal wall was clearly defined in 22/40 (55%) precontrast, 40/40 (100%) at 30 s and 32/40 (80%) late post- contrast. Precontrast, 14/42 (33.3%) descending duodenal wall segments and 8/40 (20%) transverse duodenal wall segments were not identified. In all descending and transverse duodenal segments not identified, the lumen was collapsed devoid of either

intraluminal gas or fluid.

In the late postcontrast images, 6/42(14%) descending duodenum and 8/40(20%) transverse duodenum wall segments were not defined. The absence of a fluid/gas filled lumen prevented differentiation of the mucosal surface of opposite intestinal walls. The mucosal surface enhancement identified in these cases at 30 s was no longer present.

Jejunum Wall Conspicuity

Five jejunal segments were removed from calculations due to motion blur. In the remaining 37 examinations, the jejunal wall was clearly delineated in 6/37(16.2%) precontrast, 37/37 (100%) at 30 s and 9/37 (24.3%) in the late postcontrast examination. Similar to the duodenum, there was poor definition of jejunal wall segments in precontrast images when the intestinal lumen was collapsed. In the late postcontrast examination, 28/37 (75.6%) jejunal wall segments were poorly defined. This was due to a combination of luminal collapse and the absence of the mucosal surface enhancement seen at 30 s.

The typical pattern of wall enhancement identified in duodenum and jejunum was initial enhancement of the luminal surface of the gastrointestinal wall. This was followed by progressive enhancement of the wall from the luminal to serosal surface. In the late postcontrast examination, the mucosal surface was indistinguishable from the remainder of the gastrointestinal wall due to the absence

of sufficient mucosal surface enhancement. Finally, there was washout of contrast on the luminal surface and prolonged homogeneous enhancement of the outer gastrointestinal wall (Fig. 6).

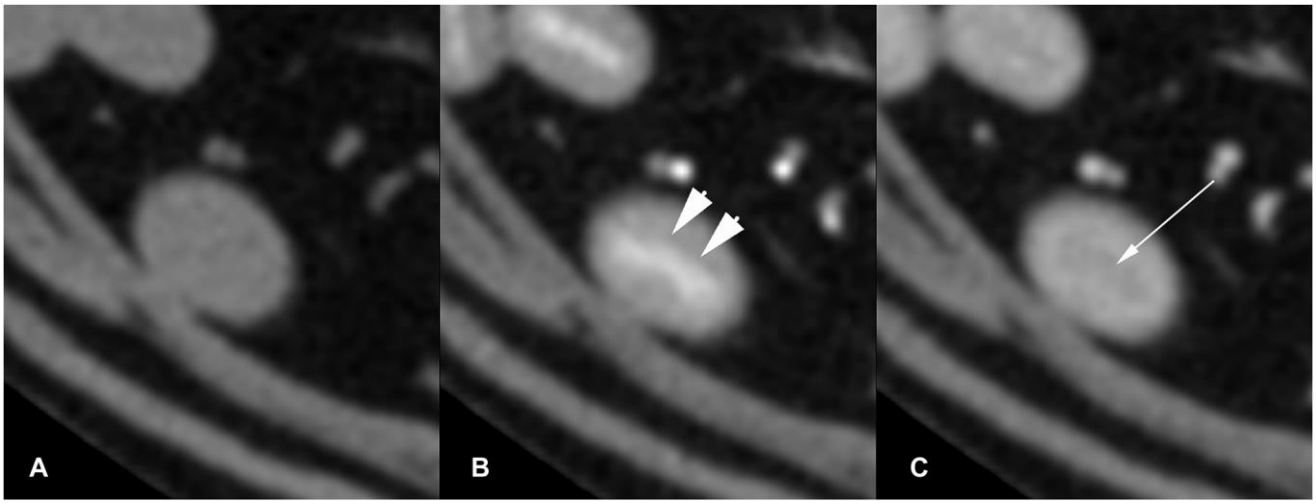

FIG. 6. Images of a jejunal segment precontrast (A), at 30 s (B) and late (C) postcontrast in the main study population. Note the intense enhancement of the mucosal surface at 30 s (white arrow heads). Late postcontrast, there is washout of contrast from the luminal surface (single white arrow) and enhancement is seen more in the depth of the wall.

Ileal Wall Conspicuity

Of all segments evaluated, the ileum was most frequently affected by motion blur; 6/42(14%) cases were removed from calculations. The ileal wall was clearly defined pre- contrast images in 19/36 (52.5%) segments, 34/36 (94.4%) at 30 s and 28/36 (77.7%) late postcontrast (Fig. 7). In pre- contrast images, the ileal wall not identified in 17/36 (47%) cases due to luminal collapse. Poor mucosal surface enhancement in 2/36 (5.5%) segments prevented delineation of the ileal wall at 30 s. The wall of the ileum could not be defined in 8/36 (22.2%) segments due to a

combination of poor mucosal surface enhancement and luminal collapse in the late postcontrast examination.

Ileocolic Junction Wall Conspicuity

Two ileocolic junction segments were removed from calculations due to motion blur. In the remaining 40 segments the ileocolic junction wall was conspicuous from mucosa to serosa at similar frequency in pre- and postcontrast ex- aminations: precontrast 33/40, 40/40 at 30 s and 38/40 late postcontrast (Fig. 7). Similar to the ileum, the ileocolic junction wall could not be distinguished from the oppos- ing wall if the lumen did not contain either gas or feces in precontrast images. In the late postcontrast examination, in 2/40 cases mucosal surface enhancement was poor and therefore distinguishing the lumen/mucosa interface was not possible.

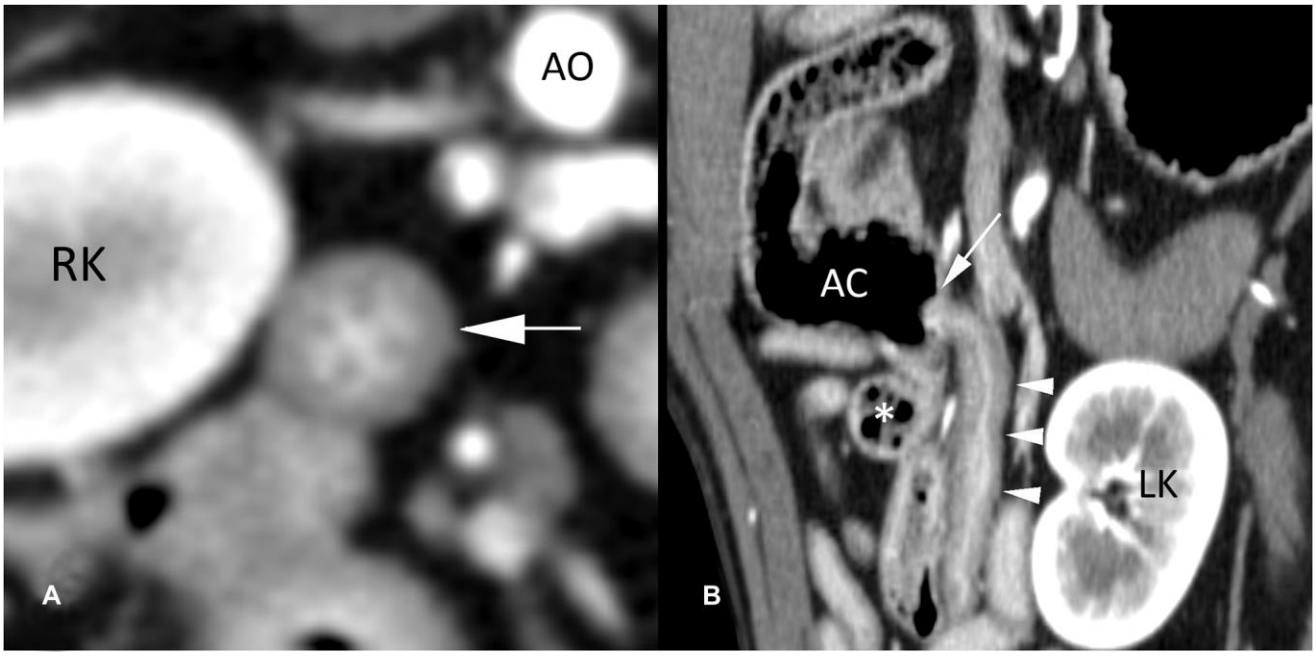

FIG. 7. Transverse image of the ileum at 30 s postcontrast (A) and a dorsal reconstructed image of the ileocolic junction

(B) in the main study population. The ileal mucosal surface enhancement has a characteristic appearance in a transverse section. Ileum (white arrowheads), ileocolic junction (single white arrow), caecum (∗), ascending colon (AC), aorta (AO), right kidney (RK), and left kidney (LK).

Transverse and Descending Colon Wall Conspicuity

One transverse colon segment was removed due to motion blur. In the remaining 41 examinations, the transverse colon wall was clearly defined in 37/41 (92.5%) precontrast images, 40/41 (97.5%) at 30 s and 38/41 (92.6%) in the late postcontrast examination. The descending colon wall was clearly defined in 39/42 (92.8%) precontrast images, 42/42 (100%) at 30 s and 41/42 (97.6%) late postcontrast. In the majority of colon segments, the lumen was either distended with gas or hyperattenuating feces, both of which provided excellent contrast with the mucosal surface of the colonic wall. In 2/41 transverse colon and 2/42 descending colon segments where the wall was not visible precontrast the lumen was collapsed. At 30 s, mucosal surface enhancement of these four segments enabled identification of the colonic wall (Fig. 8). In the late postcontrast study, three transverse and one descending colon wall segment were not identified due to poor mucosal surface enhancement in the presence of a collapsed lumen.

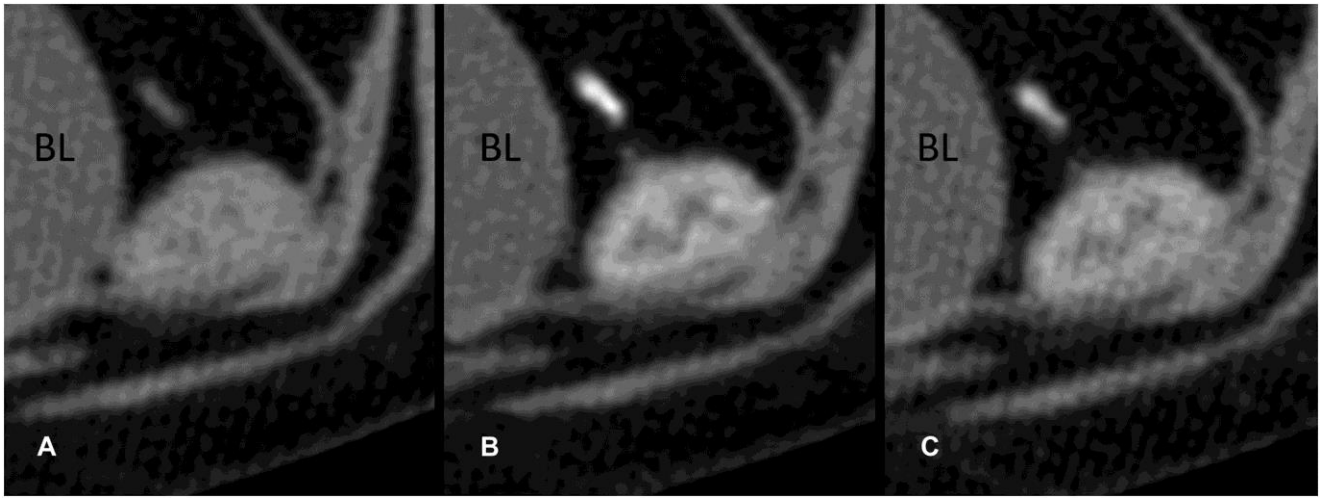

FIG. 8. Transverse images of the descending colon with a collapsed lumen precontrast (A), at 30 s (B), and late (C) postcontrast in the main study population. In precontrast images the opposing luminal surfaces are indistinguishable. Postcontrast, there is enhancement of the luminal surface that is subjectively better at 30 s. Urinary bladder (BL).

Rectum Wall Conspicuity

In the 42 examinations, the rectal wall was conspicuous in 29/42 (69%) precontrast, 41/42 (97.6%) at 30 s and 39/42 (92.8%) in the late postcontrast examination. Precontrast luminal collapse or presence of isoattenuating feces with a similar attenuation to rectal wall prevented delineation of the luminal/mucosal interface (Fig. 9). Poor mucosal surface enhancement was identified in 1/42 cases at 30 s and 3/42 in the late examination in which the luminal/mucosal interface could not be defined.

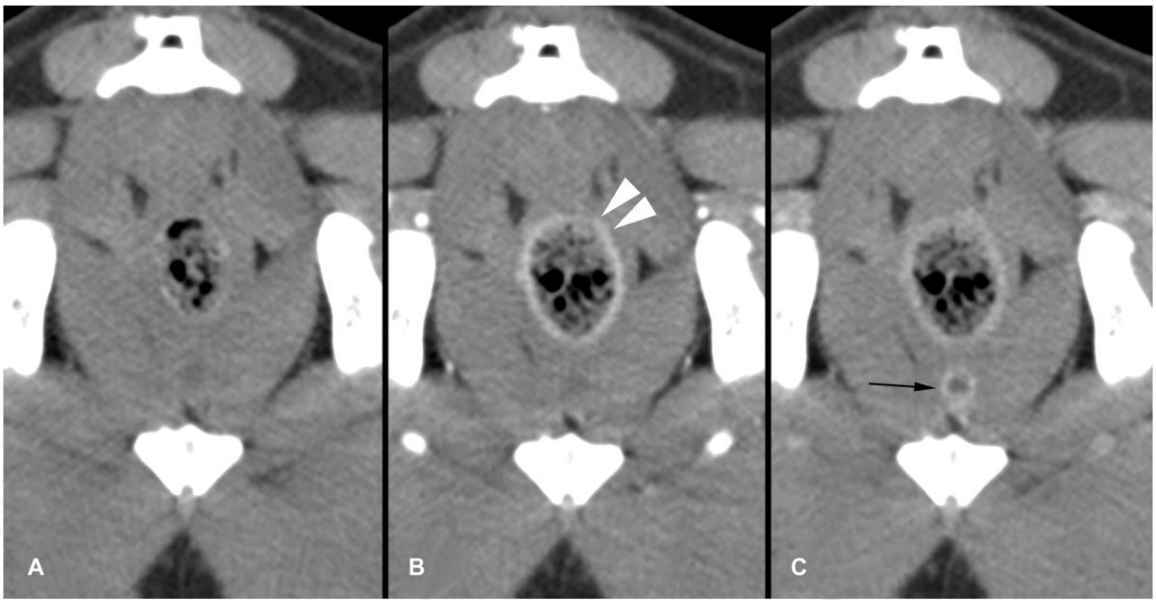

FIG. 9. Transverse images of the rectum within the pelvic canal precontrast(A), at 30 s (B), and late (C) postcontrast in the main study population. In precontrast images the rectal wall is indistinguishable from the luminal contents (A). At 30 s postcontrast, there is intense enhancement of mucosal surface (white arrowheads). This enhancement persists in the late postcontrast examination. Note enhancement of the mucosal surface of the urethra in the late examination (single black arrow)

In summary, the wall conspicuity of the eleven gastrointestinal wall segments was 56.7% precontrast, 84.5% at 30 s and 77.3% in the late postcontrast examinations.

Discussion

The findings of this study have partially supported the first part of our hypothesis; that distinct mucosal surface enhancement occurs in early (30 s) postcontrast examinations for the majority of the evaluated gastrointestinal segments. In the pilot study mucosal surface enhancement occurred at mean portal vein attenuation values

of 94, 87, and 81 HU for the duodenum, jejunum, and ileum, respectively. The large intestinal mucosal surface enhancement was identified at a median portal vein attenuation value of 64.5 HU. In contrast, there was poor mucosal surface enhancement of the gastric body in the 30 s examination. This was an unexpected finding. The variation of mucosal surface enhancement between different gastrointestinal segments, i.e., small intestine vs. gastric body and pyloric antrum was possibly associated with variations in arterial blood supply. The cranial mesenteric artery in the dog is the largest visceral branch of the abdominal aorta measuring up to 5 mm in diameter.[11] The vascular supply to the duodenum, jejunum, ileum, and colon is via the cranial mesenteric artery. Branches of the coeliac artery supply the gastric wall, liver, spleen, and pancreas. An experimental study by Delorme et al.[12] demonstrated that in 8/13 dogs, 50 to 70% of the circulating splanchnic blood volume was within the intestine area. A combination of a larger arterial supply and fewer large organs (liver, spleen, and pancreas) to supply may ac- count for the early marked mucosal surface enhancement noted in the 30 s examinations. Depending on the timing of a standard postcontrast examination, mucosal surface enhancement may be missed. Therefore, to evaluate mucosal surface enhancement of the small and large intestine an early postcontrast phase is recommended, authors recommending aiming for a portal vein enhancement at or above 43 HU.

Gastrointestinal wall conspicuity increased with the use of dual phase contrast-

enhanced CT compared to the prior research using standard postcontrast examination only,[8] thus supporting the second part of our hypothesis. In pre-contrast images, the conspicuity of the gastrointestinal segments was consistently dependent on dilation of lumen with either gas or fluid, as previously described.[8] Collapse of the gastrointestinal lumen made opposing mucosal surfaces in-distinguishable from each other in 40.9% of the precontrast gastrointestinal segments analyzed.

In a previous study evaluating standard postcontrast CT, 77.7% of gastrointestinal wall segments were identified.[8] By utilizing the 30 s postcontrast examinations the rate of gastrointestinal wall detection was increased to 84.5% in the current study. This was especially true for small intestine (duodenum and jejunum) where all segments were clearly defined at 30 s (Fig. 6). Addition of the late postcontrast examinations had a positive impact on the number of gastric body and pyloric antral wall segments delineated (Fig. 4 and 5). Pronounced mucosal surface enhancement of the gastric wall was noted in an additional third of cases in the late postcontrast examination. Similarly, the pyloric sphincter wall was identified in more cases in the late postcontrast examination than either precontrast or at 30 s postcontrast. The lack of luminal distension was often the reason for lack of pyloric wall conspicuity. The ileocolic junction and colonic wall segments were routinely well defined in precontrast images with gas and/or feces distending the colonic lumen in most cases. On rare occasions, the colonic lumen was empty and collapsed. In these cases,

458 mucosal surface enhancement de- fined the luminal surface of the ileal and colonic
459 walls (Fig. 8). Finally, the rectal wall was conspicuous in over two-thirds of cases
460 precontrast due to the presence of in- traluminal gas or hyperattenuating feces. In
461 the absence of rectal lumen dilatation, mucosal surface enhancement in- creased the
462 number of rectal wall segments seen at 30 s and late postcontrast. As illustrated in
463 Fig. 9, the intensity of mucosal surface enhancement is subjectively greater at 30 s
464 compared to the late postcontrast examination.

465 The unique enhancement pattern of the small intestinal wall was an unexpected
466 finding. As described above, initially there is intense mucosal surface enhancement.
467 This enhancement can be attributed to extensive arterial vascular supply to the
468 intestinal mucosa. As time passes there is progressive enhancement of the remainder
469 of the intestinal wall with concurrent washout of the contrast from the mucosal
470 margin. The marked arterial enhancement and lack of accumulation of contrast
471 within the mucosa is attributable to the microvascular anatomy of intestinal mucosa.
472 In dogs (and cats) the mucosal surface consists of multiple finger-like villi that
473 project into the intestinal lumen. A single arteriolar loop projects into each
474 individual villus. This capillary connects to a submucosal venule.[13] Thus a lack of
475 mucosal veins/venules and the unidirectional flow of blood through the villus
476 capillary account for enhancement and early washout of contrast from the mucosal
477 margin.

478 Dual phase contrast-enhanced CT has been used in people since 1980's to

investigate gastrointestinal disease. Many advances have been made in the use of CT for diagnosing, monitoring, and prognosticating neoplastic and inflammatory conditions such as Crohn's disease in humans.[14,15] In people, abnormal patterns of wall and mucosal enhancement have been correlated with different inflammatory dis- ease processes.[16] Characteristic intestinal wall changes, particularly of the ileum, are visible in patients with chronic inflammatory diseases such as Crohn's disease.[17]

Currently, ultrasonography is the imaging modality of choice for investigating diseases of the gastrointestinal tract in veterinary patients. There are many extrinsic and intrinsic factors that can negatively impact on the quality of the ultrasound images acquired. These include, but are not limited to the body habitus of the patient, intraluminal gas, the quality of the ultrasound equipment used, and the experience of the operator performing the examination.[1,18] In larger patients, ultrasound may not be appropriate for detecting subtle lesions as image resolution deteriorates with increasing depth and presence of subcutaneous or abdominal fat. A recent paper comparing computed tomography and ultrasonography demonstrated that significantly more clinically relevant lesions were identified using CT in patients over 25 kg.[1] Computed tomography could therefore be considered as an alternative to ultrasound for a noninvasive evaluation of the gastrointestinal tract, however the intestinal wall layering displayed on CT evaluation is inferior compared to that displayed on US examination and also likely

different features of the gastrointestinal wall are seen on CT examination, such as perfusion.

Intestinal obstruction is major differential for veterinary patients presenting with vomiting as the primary clinical sign. Intestinal or gastric mucosal surface enhancement provides a clear distinction between wall and intraluminal contents, which may have similar attenuation values pre- contrast administration. This may enable identification of intraluminal partial/complete obstructions with a higher degree of confidence. Mural or extramural causes of intestinal obstruction may therefore be delineated without inference from intestinal gas or adjacent abdominal structures. However, further research is required to evaluate the sensitivity and specificity of dual phase contrast-enhanced CT for detecting intestinal obstruction.

Specific CT features of acute and chronic inflammatory conditions in dogs and cats such as enteritis and inflammatory bowel disease have not yet been reported. There is a single case report of the CT appearance of a granulomatous lesion associated with inflammatory bowel disease in a Yorkshire terrier.[19] These granulomatous type lesions are commonly seen in Crohn's patients, which is a major type of inflammatory bowel disease (IBD) in the human population. The more common histological presentation of canine inflammatory bowel disease is lymphoplasmacytic enteritis.[20] In full thickness intestinal biopsy samples, the main features of canine inflammatory bowel disease include cellular infiltration of the mucosa, focal, or transmural lymphangiectasia, and blunting of the villi.[21] All of

these changes are subtle and unlikely to be detected macroscopically regardless of which imaging modality is used. Measurement of intestinal wall thickness is not a useful indicator of intestinal pathology in cases of inflammatory bowel disease.[22] A previous study has demonstrated that there is partial agreement between previously reported sonographic reference ranges and CT wall measurements.[8]

One of the reported disadvantages of CT is that it does not allow for identification of distinct gastrointestinal wall layering as seen with ultrasonography. The cur- rent study demonstrated recognizable enhancement of the inner/luminal layer of the gastrointestinal tract segments using dual phase contrast-enhanced CT at optimal portal vein attenuation values. Subjectively, this enhancement involves one-third to half the wall thickness. The mucosal layer of the small intestine in particular has been demonstrated to contribute to up to two-thirds of the intestinal wall in both large and small breed dogs.[23] Therefore, the authors assume that this enhancement correlates with part of, or the entire mucosal layer of the gastrointestinal wall.

A large population of dogs with inflammatory or neo- plastic intestinal lesions was previously compared using ultrasound.[24] A multivariate analysis of the ultrasound findings in these dogs identified loss of intestinal wall layering alone to be an excellent predictive factor in differentiating neoplastic from nonspecific enteropathy. In the human literature, different CT enhancement patterns have been associated with various types of intestinal neoplasia; however, there remains considerable overlap between benign and malignant conditions.[25] Excluding

sporadic case reports, very little information is available on the CT appearance of gastrointestinal masses in veterinary patients.

There are a number of limitations for the current study. First, although the timing of image acquisition postcontrast was fixed at 30 s from the beginning of injection, the bolus infusion rates were variable between patients. The pilot study endeavored to standardize the stage of contrast enhancement by selecting cases with similar attenuation values in the portal vein. This may have introduced a se- lection bias in the cases used for the conspicuity analyses. The second limitation of this study was that histologic confirmation of normal gastrointestinal wall status was not obtained. It is therefore possible that animals with subclinical gastrointestinal wall disease could have been included. In this selection of clinical patients without gastrointestinal disease, obtaining full thickness biopsies to correlate the degree of mucosal surface enhancement with the histologic location and absence of disease would neither be ethical, as this is not a benign procedure, nor was there a clinical indication. Obtaining partial thickness biopsies, although arguably safer, would also not be without risk and was also not clinically indicated.[26]

In conclusion, findings of the current study indicated that, for a complete evaluation of the gastrointestinal tract, dual phase contrast-enhanced CT offers advantages over standard postcontrast CT. An early postcontrast examination is recommended to evaluate small and large intestine. Specific portal vein values of 43–150 HU were correlated with good mucosal surface enhancement. Bolus tracking techniques or

time attenuation curves may be used to achieve these portal vein attenuations. When using bolus-tracking techniques the time taken for the scan to begin must be taken into account. The timing of peak gastric body and pyloric antral mucosal surface enhancement has not been specifically identified. However, a late postcontrast examination (>60 s postcontrast) was found to be most useful when evaluating the gastric wall. In addition, the introduction of air into the gastric lumen may aid evaluation of the gastric wall. Further research is needed to define a repeatable protocol for optimizing gastrointestinal tract mucosal surface enhancement. Further studies are also needed to determine whether any change in the presumed normal enhancement patterns of gastrointestinal wall segments as described in this study occurs with diffuse gastrointestinal disease such as inflammatory bowel disease or infiltrative neoplasia such as lymphoma. Additionally, research is needed to evaluate the accuracy, sensitivity, and specificity of dual phase contrast- enhanced CT for detecting other common gastrointestinal diseases such as gastrointestinal ulceration and mechanical obstruction.

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