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23 Improving conspicuity of the canine gastrointestinal wall using dual phase
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25

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42 **Abstract**

43 Gastrointestinal (GI) disease is a common clinical complaint in small animal patients;
44 computed tomography (CT) examinations enable a global overview of the GI tract and
45 associated structures. Previously, the GI wall has been reportedly identified from serosa to
46 mucosa in 77% of standard postcontrast CT studies and wall layers seen in ultrasound have
47 not been distinguished. Inconsistent strong contrast enhancement of the inner layer of the
48 GI mucosal surface was noted on dual phase CT studies acquired in our institution, which
49 increased the visibility of the GI tract and disease processes. The aim of this retrospective,
50 observational, cross-sectional study was to determine the optimal portal vein attenuation
51 for maximizing GI wall conspicuity using dual phase contrast-enhanced CT. Patients with
52 abdominal CT for a non-GI related disease were included. In a pilot study, 175 GI segments
53 from 35 CT studies were graded for presence of mucosal surface enhancement (MSE). The
54 strongest mucosal surface enhancement grade correlated with portal vein attenuation of
55 43–150 HU; this value was used as inclusion criterion in the main study. A total of 441 GI
56 segments were evaluated in 42 CT studies postcontrast for GI wall conspicuity. The GI
57 wall was conspicuous in 56.7% precontrast, 84.5% at 30s, and 77.3% late postcontrast;
58 4.7% of segments were removed due to motion blur. At 30 s distinct mucosal surface
59 enhancement was seen in the small intestine and gastric mucosal surface enhancement was
60 poor. Findings supported the use of dual phase contrast-enhanced CT for improving
61 conspicuity of the GI wall. ©2016 *American College of Veterinary Radiology*.

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

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74 **Introduction**

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

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

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

113 **Material and Methods**

114 *Subject Selection*

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

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

130 As part of the inclusion criteria, all patients were scanned in sternal recumbency
131 from cranial to caudal using 16 multidetector row computed tomography unit
132 (MDCT) (Mx8000 IDT, Philips, Best, The Netherlands). The majority of patients
133 had both thoracic and abdominal CT. The following helical CT protocol was used:
134 16×1.5 mm collimation, 1.5 cm slice overlap, tube rotation time of 0.5 s, 150 mA
135 (nominal), 120 kVp, 3 mm slice thickness, and display field of view tailored to
136 patient size.

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

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

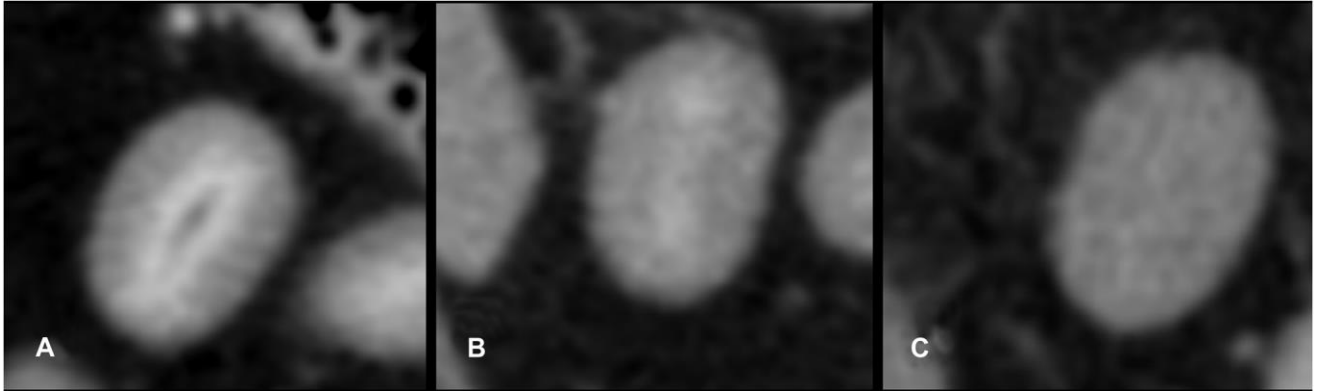
144 A single review of retrieved images was performed by the primary author (E.F.)
145 followed by consensus review with the last author (R.D.). For the image review
146 studies were reviewed in three batches; precontrast, 30 s postcontrast, and late
147 postcontrast. The patient's identification number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

151 *Determining the Optimal Contrast Enhancement Time*

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

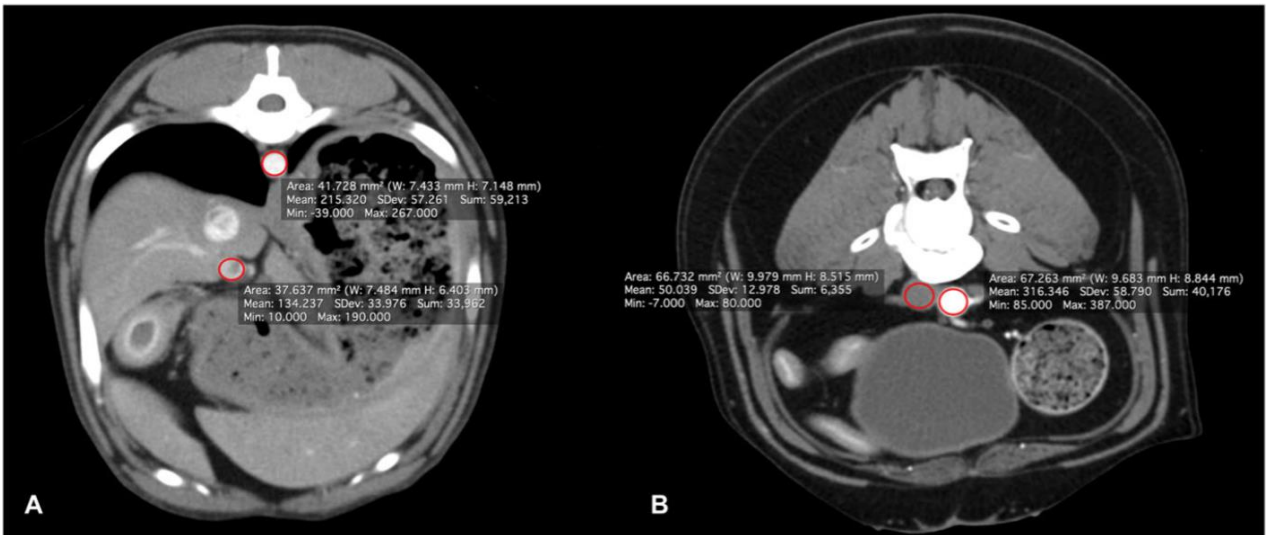
159 of mucosal surface enhancement with vessel attenuation. To grade the mucosal
160 surface enhancement, five representative gastrointestinal segments were selected
161 from each of these CT studies: gastric body, descending duodenum, jejunum, ileum,
162 and descending colon. A subjective three-tiered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

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



177

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



180

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

182

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

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

185 * CVC attenuation values were censored from further analysis

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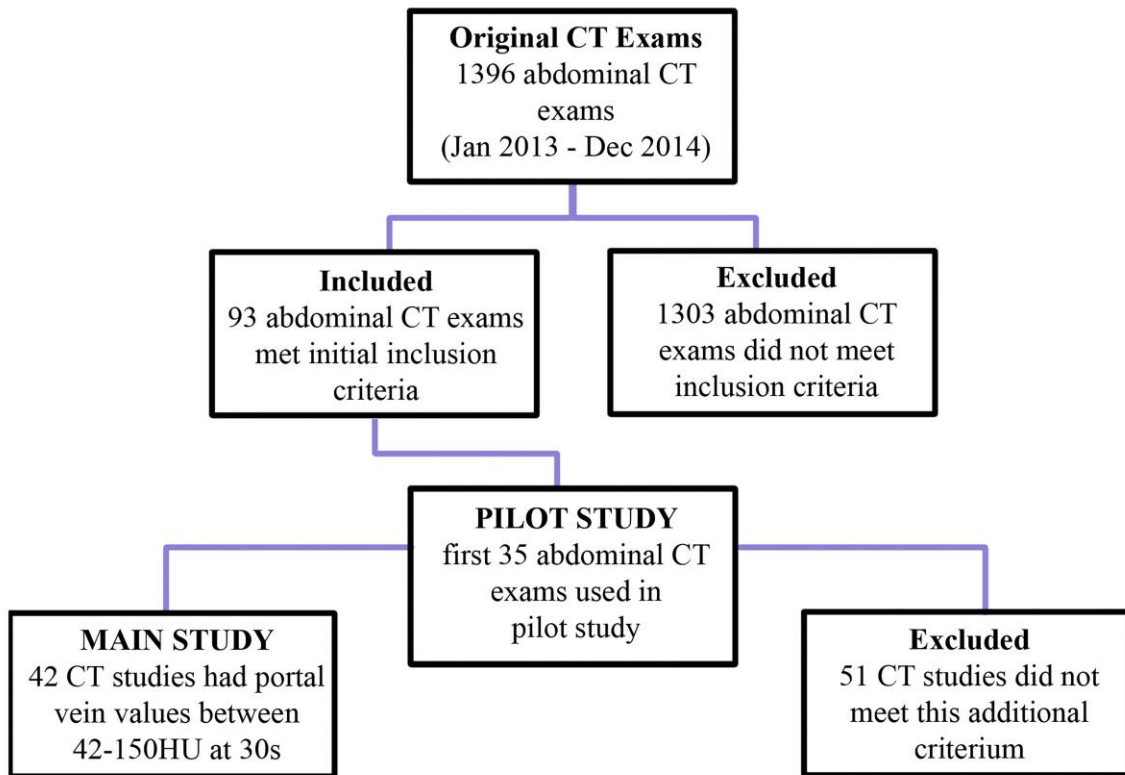
187 *Determining Whether Dual Phase Contrast CT Improved Gastrointestinal Wall*
188 *Conspicuity*

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

206 conspicuity were performed by the first author (E.F.) using commercial software
207 (SPSS version 19, SPSS Inc., Chicago, IL).

208 **Results**

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



214

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

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

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

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

237 normally distributed (P -value > 0.05). The portal vein attenuation values for grade
238 1 colonic mucosal surface enhancement were not normally distributed; thus a
239 median portal vein attenuation value was calculated for the colon.

240 Mean and median portal vein attenuation values for the grade 1 mucosal surface
241 enhancement of the duodenum, jejunum, ileum, and descending colon were 94, 87,
242 81, and 64 HU, respectively (Table 2); hence the range of 43–150 HU portal vein
243 attenuation in the 30 s postcontrast examinations was used as an additional criterion
244 for patient selection. This criterion standardized portal vascular enhancement
245 between studies in the absence of patient-specific bolus timing based on grade 1
246 mucosal surface enhancement of the duodenum, jejunum, ileum, and colon.

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

	Mean PV*	SD PV	Range PV
	attenuation	attenuation	attenuation
	(HU)	(HU)	(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
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249 *Portal vein, †median value

250

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

254 The 39 dogs included in the main study had a me- dian age of 10 years (range 2.5–
 255 14 years). Of the dogs included there were 19 neutered males, 14 neutered females,
 256 and six entire male dogs. The study population consisted of 12 crossbreeds, five
 257 Labradors, three English Springer Spaniels, two Dobermans, and one each of 16
 258 other breeds (Basset Hound, Beagle, Boxer, Cavalier King Charles Spaniel, Cocker
 259 Spaniel, Chow Chow, Golden Retriever, Hungarian Vizsla, Irish setter, Irish Terrier,
 260 Jack Russell Terrier, Lurcher, Poodle, Rottweiler, Tibetan Terrier, West Highland
 261 White Terrier). The median weight of the dogs was 24 kg (range 10–47 kg).

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

266 TABLE 3. Results of Main Study: Number (%) of Gastrointestinal Segments Identified in Each
 267 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%)

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

270

271 *Gastric Wall Conspicuity*

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

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

284 *Pyloric Antrum Wall Conspicuity*

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

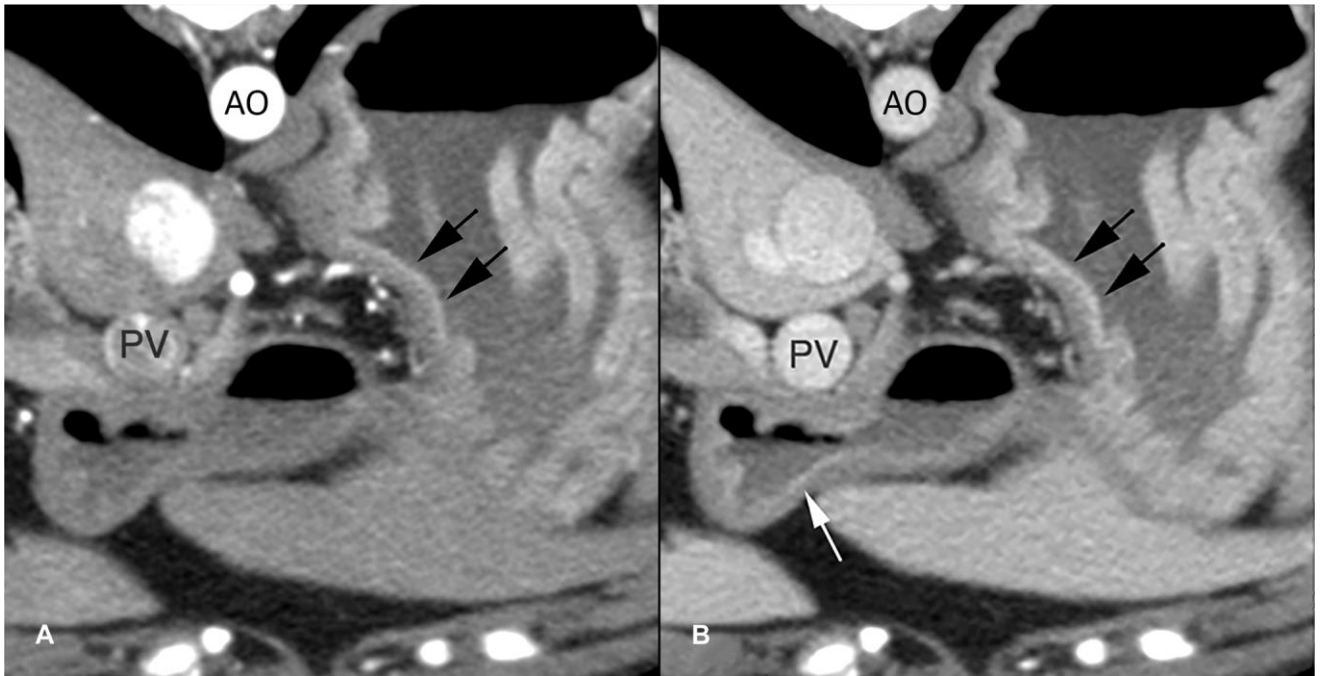
294 *Pylorus Wall Conspicuity*

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

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



306
307 FIG. 4. Gastric body, pyloric antrum and pylorus (white arrow) precontrast (A), at 30 s (B) and late (C) postcontrast in
308 the main study population. Contrast enhancement of the mucosal surface of the gastric body and pyloric antrum is poor
309 at 30 s. Enhancement of the gastric body mucosal surface (white arrowheads) improves in the late postcontrast
310 examination. AO, aorta; PV, portal vein.



311

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

314

315 *Descending and Transverse Duodenum Wall Conspicuity*

316 In the 42 examinations the descending duodenal wall was delineated in 28/42
 317 (66.6%) precontrast, 42/42 (100%) at 30 s and 36/42 (85.7%) late postcontrast.

318 Two transverse duodenal segments were removed due to motion. Of the remaining
 319 40 examinations the transverse duodenal wall was clearly defined in 22/40 (55%)
 320 precontrast, 40/40 (100%) at 30 s and 32/40 (80%) late post-contrast. Precontrast,
 321 14/42 (33.3%) descending duodenal wall segments and 8/40 (20%) transverse
 322 duodenal wall segments were not identified. In all descending and transverse
 323 duodenal segments not identified, the lumen was collapsed devoid of either

324 intraluminal gas or fluid.

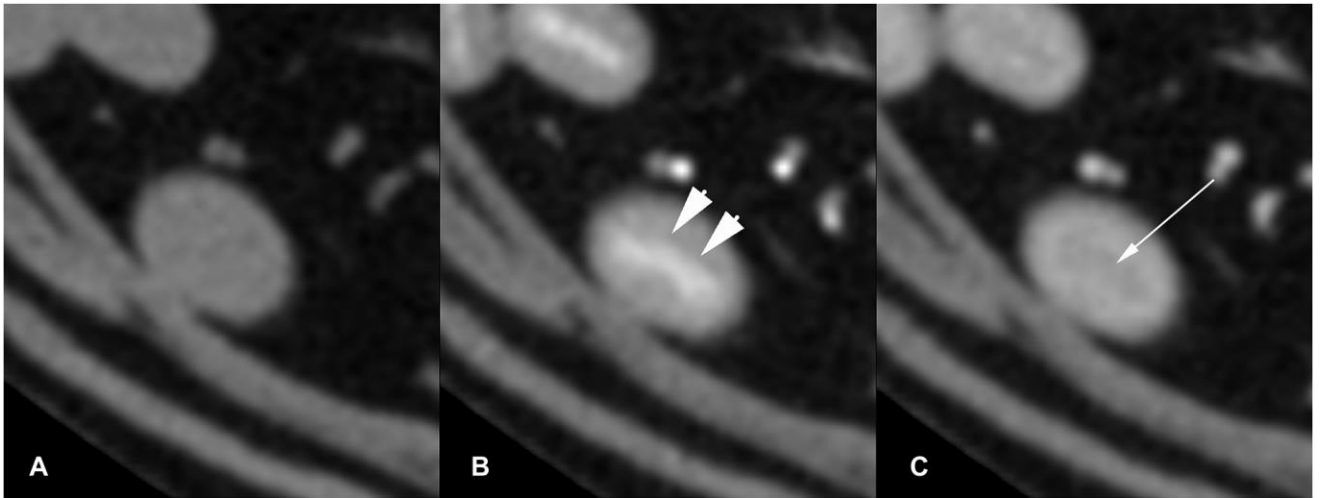
325 In the late postcontrast images, 6/42(14%) descending duodenum and 8/40(20%)
326 transverse duodenum wall segments were not defined. The absence of a fluid/gas
327 filled lumen prevented differentiation of the mucosal surface of opposite intestinal
328 walls. The mucosal surface enhancement identified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

330 *Jejunum Wall Conspicuity*

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

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

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



347
348 FIG. 6. Images of a jejunal segment precontrast (A), at 30 s (B) and late (C) postcontrast in the main study population.
349 Note the intense enhancement of the mucosal surface at 30 s (white arrow heads). Late postcontrast, there is washout of
350 contrast from the luminal surface (single white arrow) and enhancement is seen more in the depth of the wall.

351

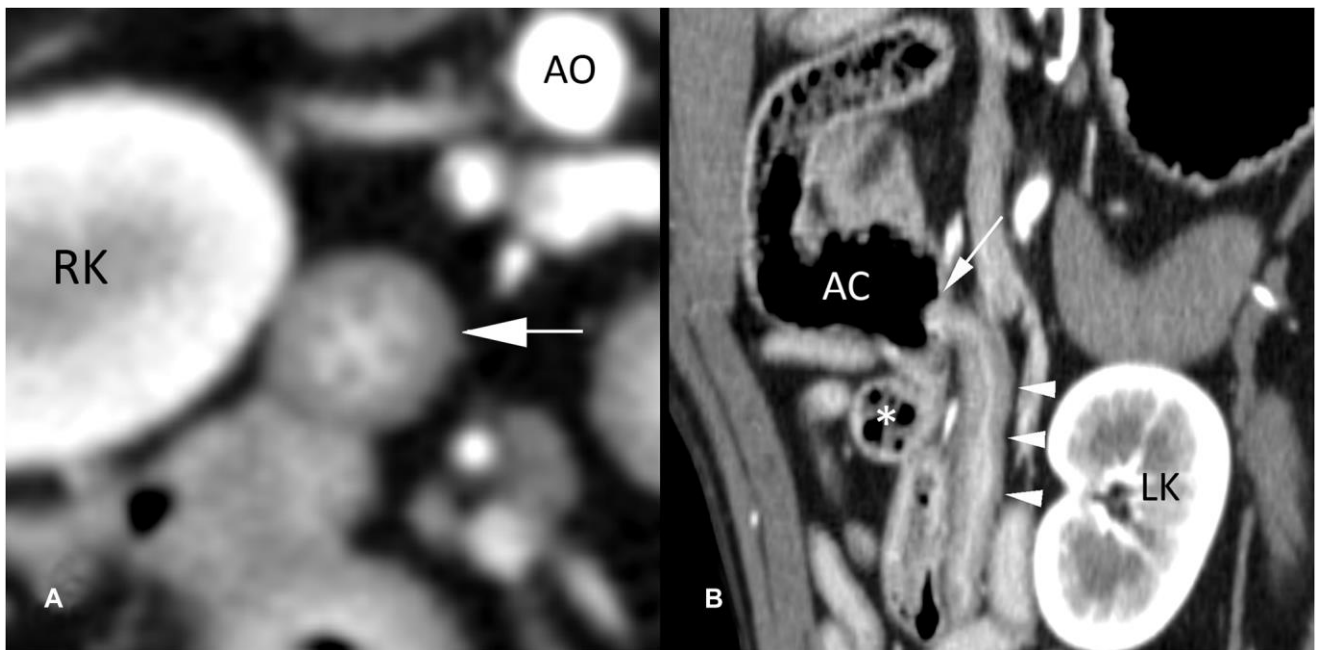
352 *Ileal Wall Conspicuity*

353 Of all segments evaluated, the ileum was most frequently affected by motion blur;
354 6/42(14%) cases were removed from calculations. The ileal wall was clearly defined
355 pre- contrast images in 19/36 (52.5%) segments, 34/36 (94.4%) at 30 s and 28/36
356 (77.7%) late postcontrast (Fig. 7). In pre- contrast images, the ileal wall not
357 identified in 17/36 (47%) cases due to luminal collapse. Poor mucosal surface
358 enhancement in 2/36 (5.5%) segments prevented delineation of the ileal wall at 30
359 s. The wall of the ileum could not be defined in 8/36 (22.2%) segments due to a

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

362 *Ileocolic Junction Wall Conspicuity*

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

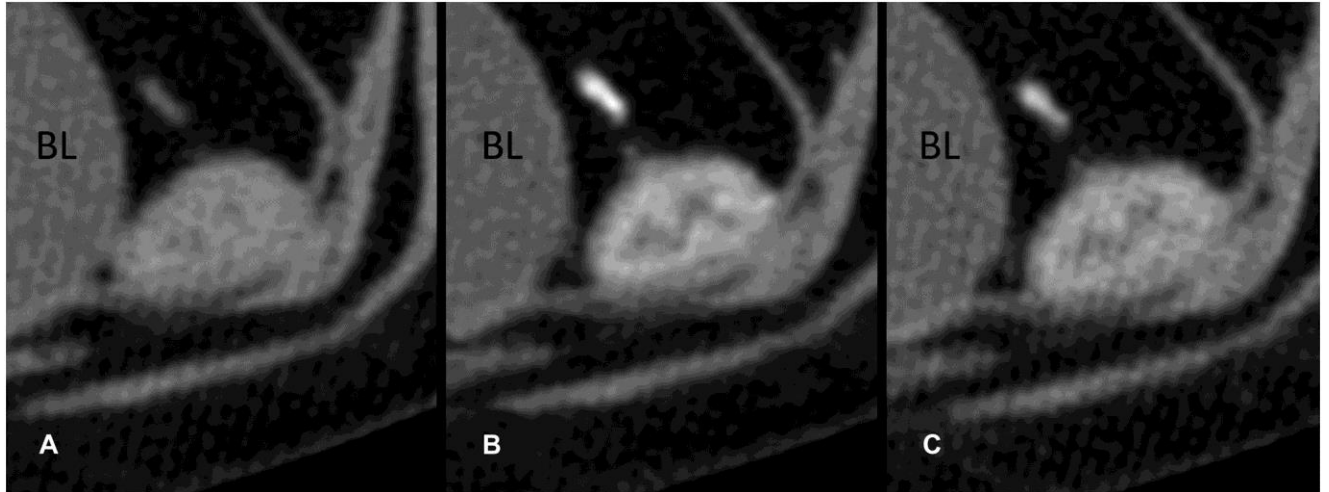


371
372 FIG. 7. Transverse image of the ileum at 30 s postcontrast (A) and a dorsal reconstructed image of the ileocolic junction

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

376 *Transverse and Descending Colon Wall Conspicuity*

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

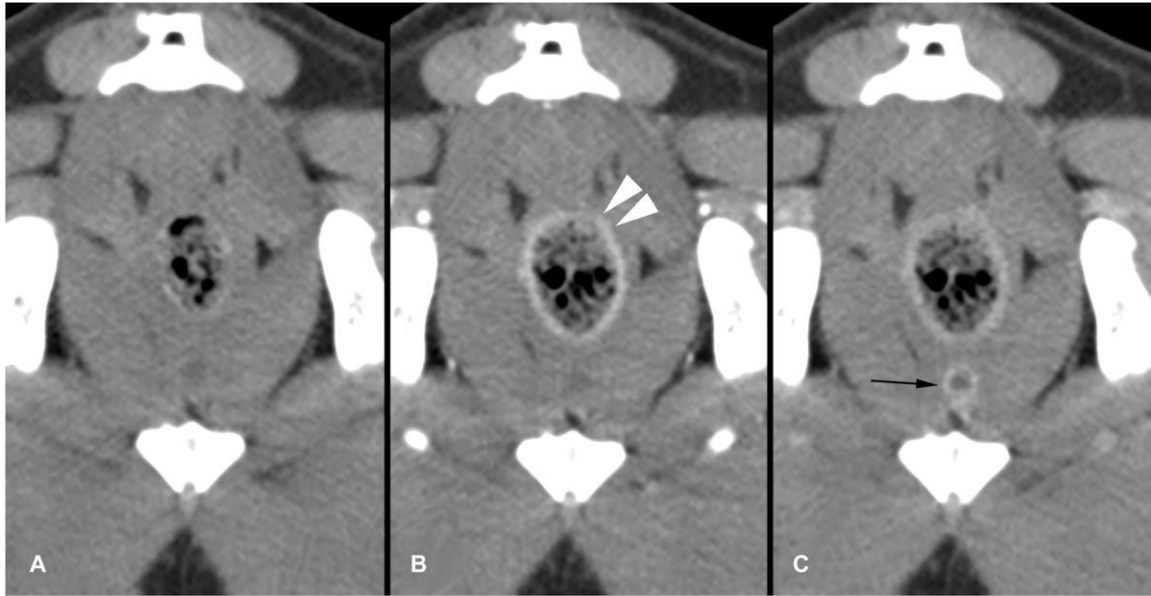


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391 FIG. 8. Transverse images of the descending colon with a collapsed lumen precontrast (A), at 30 s (B), and late (C)
392 postcontrast in the main study population. In precontrast images the opposing luminal surfaces are indistinguishable.
393 Postcontrast,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

394 *Rectum Wall Conspicuity*

395 In the 42 examinations, the rectal wall was conspicuous in 29/42 (69%) precontrast,
396 41/42 (97.6%) at 30 s and 39/42 (92.8%) in the late postcontrast examination.
397 Precontrast luminal collapse or presence of isoattenuating feces with a similar
398 attenuation to rectal wall prevented delineation of the luminal/mucosal interface
399 (Fig. 9). Poor mucosal surface enhancement was identified in 1/42 cases at 30 s and
400 3/42 in the late examination in which the luminal/mucosal interface could not be
401 defined.



402

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

408

409 In summary, the wall conspicuity of the eleven gastrointestinal wall segments was
410 56.7% precontrast, 84.5% at 30 s and 77.3% in the late postcontrast examinations.

411 **Discussion**

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

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

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

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

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

458 mucosal surface enhancement defined 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 intraluminal gas or hyperattenuating feces. In
461 the absence of rectal lumen dilatation, mucosal surface enhancement increased 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

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

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

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

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

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

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

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

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

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

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

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

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

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