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CT Pneumocolonography In Normal Dogs

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Abstract

Objectives of this experimental study were to describe effects of varying technical components that may contribute to an optimal protocol for CT pneumocolonography (CTP) in dogs, and to develop a standardized methodology for CTP as a future potential diagnostic tool in canine clinical patients with large bowel disease. Eight purpose-bred intact male hound cross research dogs were enrolled and randomized to groups based on variables of pressure/body position (n=4) and insufflation time (n=4). For each segment of large bowel (rectum, colorectal junction, descending colon, transverse colon, ascending colon), the adequacy of bowel preparation, % of bowel lumen filled with fecal material, and bowel tortuosity or folding were assessed. Measurements of bowel wall thickness (cm), cross-sectional bowel lumen diameter (cm), and cross-sectional bowel luminal area (cm^2) were obtained at standardized locations within the large bowel. False discovery rates (FDR) were calculated to adjust for multiple testing. Values of FDR < 0.05 were considered significant. Differences in mean cross-sectional area and diameter and bowel wall thickness under increasing pressure were not significant after adjusting for multiple testing; some had raw p values <0.05. Ascending colon diameter and ascending colon area significantly increased with insufflation time (FDR<0.05). No other response variables showed a significant change with insufflation time. The optimal insufflation pressure for maintaining pneumocolon in this study was determined to be 20 mmHg. CTP is a feasible technique to provide consistent distension for imaging of the large bowel and further study on application of CTP in clinical patients is warranted.

Keywords

Computed tomography; pneumocolonography; large bowel; dog

Introduction

The colorectum can be a difficult anatomic region to image, and each of the currently commonly utilized imaging modalities such as ultrasound, radiography, and colonoscopy have limitations. Ultrasound does not interrogate structures within the pelvic canal well due to interference from surrounding bony structures, and standard radiographs alone do not differentiate soft tissue structures with precision. While optical colonoscopy provides an excellent view of the luminal aspect of the large bowel and identification of luminal mass

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lesions, it does not provide information about potential lesion extent within the wall itself or description of lesion location and extent relative to fixed structures that can be easily identified intraoperatively by a surgeon. A three dimensional image with relationships to other anatomic structures can provide an important context for surgical planning, especially in complicated cases. Computed tomography (CT) is not currently very commonly recommended for imaging assessment of the colorectum, because if the colorectum is not evaluated while empty, the presence of fecal material can seriously limit the ability to identify and accurately describe mass lesions. Conversely, when the bowel is empty, collapse of the gastrointestinal lumen and contraction of the muscular wall limits the information that can be derived about mass extent and wall invasion on standard unenhanced and contrast enhanced CT. A technique of CT imaging of the large bowel during luminal insufflation of gas (CT pneumocolonography, CTP) is utilized in the human medial field as an alternative to screening colonoscopy for polypoid lesions, and for surgical planning of larger mass lesions, and has been described using insufflation of room air or CO_2.[1,2,3,4,5] Assessment of colorectal neoplasia by CTP has shown very good correlation with visual assessments by optical colonoscopy with accurate detection of large (>10mm) polypoid lesions, moderate to good sensitivity in detection of small (6-9mm) polypoid lesions, and good sensitivity for identification of nonpolypoid (flat) lesions.[2] CTP could improve our ability to image the colorectum in veterinary patients compared to current techniques, especially from the perspective of surgical planning.

While there is a large body of human medical literature on the use of CTP,[1,2] important gaps in knowledge exist in order to translate this imaging technique to veterinary patients. Adequate distension is a prerequisite for CTP; a poorly distended colon can obscure polyps and masses and reduce the diagnostic yield of the examination.[3] In general, to reach optimal distension several choices have to be made concerning the distension methods used, including type of insufflation (automatic vs. manual), equilibration time, use of room air or CO_2, and the body positions to use during insufflation.[1] CTP is performed awake in human patients, who are verbally instructed to contract their anal sphincter and "hold in" the instilled air or CO_2 until such time that they experience and verbally express discomfort, and in general, the largest “tolerable” insufflation pressure is preferred to obtain images in human CTP studies, although this is rarely quantified. This is not possible in veterinary patients, who would be unable to verbally communicate differential levels of discomfort associated with gas distension of bowel, nor would we be able to communicate to them to retain the gas and not immediately expel it. CTP must be performed in anesthetized veterinary patients, and it is important to define a safe, but effective protocol that provides adequate colonic distension for image interpretation. Colonic distension pressures are rarely measured and reported in humans undergoing CTP, and total gas insufflation volumes can be affected by a myriad of factors including patient size, adequacy of the seal at the anus, and gas absorption from the colorectum, therefore it is difficult to directly extrapolate a CTP protocol to anesthetized dogs. To date, no studies have evaluated the optimal insufflation volumes or optimal intraluminal pressure for CTP for different large bowel conditions, however a target insufflation pressure of 25 mmHg has been recommended by one group for adequate CTP insufflation in humans.[1]

Objectives of the current study were to describe effects of varying technical components that may contribute to an optimal protocol for CTP in dogs and to develop a standardized methodology for CTP that could be used in future studies of dogs with large bowel disease. We hypothesized that 1) CTP would be a safe and feasible technique for improving visual conspicuity of bowel wall thickness, 2) an optimal insufflation pressure could be identified that safely maximized large bowel distension without resulting in small bowel distension, 3) change in body position would result in differential distention of different regions of the large bowel, and 4) an optimal protocol time from the onset of insufflation to image acquisition could be identified.

Materials and Methods

This study was approved by and conducted in accordance with the Institutional Animal Care and Use Committee. Eight healthy, purpose-bred male hound-mix dogs were enrolled in this experimental study. Median weight of all dogs was 21.2 kg (range, 20.2-24.3 kg). Median age was 9 months (range, 8-10 months). Median body condition score was 4/9 (range, 3/9-5/9). All dogs were deemed to be systemically healthy based on the results of physical examination and hematologic evaluation of packed cell volume and serum total protein. Dogs were randomized to groups of pressure/position (n=4) and insufflation time (n=4) groups. Dogs were anesthetized according to a standardized protocol of premedication with morphine (0.3 mg/kg) and atropine (0.02 mg/kg) subcutaneously, induction with propofol intravenously (5 mg/kg to effect), and maintenance on inhalant isoflurane in oxygen to effect. All dogs were recovered from anesthesia. Subcutaneous buprenorphine (0.01 mg/kg q 6-8 hours as needed) and carprofen (2 mg/kg once) were administered for postoperative analgesia. All dogs received a standard commercial diet (Adult Maintenence Dog Food, Eukaneuba, Proctor & Gamble, Cincinnati, OH), and a standard bowel preparation protocol for all scans, consisting of no food for 36 hours (free access to water at all times) and 4 doses of a sodium phosphate monobasic monohydrate/sodium phosphate dibasic anhydrous tablet colonic cleansing agent (Osmoprep, Salix Pharmaceuticals, Raleigh, NC) at a dose of 6 grams PO q 8 hours, starting 36 hours prior to the scheduled CT pneumocolonography procedure. Carbon dioxide gas was used for large bowel insufflation in all dogs, and the insufflation pressures studied were 0, 15, 20, and 25 mmHg.

Cohort 1 - Pressure/Position (4 dogs)

The effects of insufflation pressure and body position on large bowel distention were evaluated in this cohort of dogs. All dogs in this cohort were anesthetized twice, in a randomized crossover design. Immediately following a pre-insufflation scan, the CT pneumocolonography was performed at one of two maximum CO_2 insufflation pressures (15 mmHg and 25 mmHg) under one anesthetic episode, and then each dog received the same imaging protocol at the alternate pressure under a separate anesthetic event on a separate day. Differences in CT imaged bowel distension associated with insufflation pressures of 0 mmHg (pre-insufflation), 15 mmHg, and 25 mmHg were evaluated. At each distension pressure, the dog was scanned initially in a supine body position (dorsal recumbency), followed by a prone body position (sternal recumbency) to evaluate effects of body position on visceral position and bowel distension in different regions of the colorectum.

Cohort 2: Insufflation Time (4 dogs)

The effects of duration of CO_2 insufflation on bowel distension were evaluated in this cohort of dogs. Under general anesthesia dogs were positioned in a sternal body position, and four separate non-contrast CT scans were performed, at 1, 5, 10, and 20 minutes after insufflation was initiated. Based on the data obtained from cohort 1, in which a large proportion of the dogs experienced retrograde insufflation of the small bowel at higher pressure, data in this group were obtained at a CO_2 insufflation pressure of 20mmHg.

CT Pneumocolon Procedure and Image Analysis

Prior to positioning in the CT scanner a purse string suture of 2-0 nylon was placed circumferentially in the anus at the mucocutaneous junction. Any fecal material palpated per rectum during catheter placement was digitally removed. A 10 French balloon-tipped Foley urinary catheter (SurgiVet, Smiths Medical ASD Inc.,St. Paul, MN) was passed into the rectum, the catheter balloon was inflated with 5 mL of room air, and the purse string suture was tightened and tied. The Foley catheter was withdrawn until the balloon seated against the anus. An unenhanced scan of the abdomen and pelvis, from the diaphragm to the anus, was performed during a positive-pressure breath-hold. Following the initial scan, CO_2 pneumocolon was established and maintained at the determined insufflation pressure using a mechanical insufflator (Endoflator, Karl Storz Veterinary Endoscopy, Goleta, CA) to the predetermined pressure according to the dog's assigned experimental cohort. Additional scans were performed according to the dog's assigned experimental cohort.

Images were acquired with a helical 16-slice CT scanner (Lightspeed 16 helical scanner, General Electric Co., Milwaukee, US) with a pitch of 1.375 and 2.5mm and 0.625mm collimation. Acquisition parameters were 120 kV and 150 mA with 1s tube rotation and contiguous reconstruction. Contrast medium was administered intravenously by hand with a dose of 880 mg/kg (Isovue 370, Bracco Diagnostics Inc., Princeton, US), and contrast enhanced images were obtained 2 minutes after administration. Images were viewed in a soft tissue algorithm and soft tissue window, with manual adjustments to maximize conspicuity of the colon wall. Multiplanar reformatting was used to measure colon wall thickness, diameter, area, and volume perpendicular to the long axis of the lumen (Osirix 64 bit v. 5.8.2, Pixmeo, Bernex, Switzerland; GE Advantage Workstation, 4.4, Milwaukee, WI.)

CT measurements/parameters evaluated

For each segment of large bowel (rectum, colorectal junction, descending colon, transverse colon, ascending colon) the following subjective assessments were performed: adequacy of bowel preparation, % of bowel lumen filled with fecal material, and bowel tortuosity or folding. Measurements of bowel wall thickness (cm), cross-sectional bowel lumen diameter (cm), cross-sectional bowel luminal area (cm^2) were obtained from transverse slices at each of the following anatomic locations: rectum at the level of the mid-acetabulum, rectum at the level of the caudal aspect of the sacroiliac joint, descending colon-rectal junction, mid-descending colon, mid-transverse colon, mid-ascending colon. A single board-certified veterinary radiologist (AZ) performed all measurements. An optimal insufflation pressure for cohort 2 was defined from cohort 1 data, as the largest insufflation pressure that could be

administered without observed physiologic complications (bowel perforation, cardiorespiratory dysfunction) or likely retrograde passage of gas into the small bowel.

Statistical Analysis

Study data were collected and managed using REDCap electronic data capture tools[6] hosted at the University of California-Davis. Statistical analysis was performed by two authors (ST and RC) using R 2.15.2.[7] For assessment of the effect of insufflation pressure, results from images taken with no pressure were compared to those with 15, 20, or 25 mmHg insufflation. Using cohort 1 dogs, paired Wilcoxon tests or paired t-tests were used to test for median or mean differences between insufflation pressures of 0, 15, and 25 mm Hg for continuous variables, depending on whether the data were normally distributed. McNemar's test was used for categorical variables to test for differences in proportions. Categorical variables with more than two response categories were converted to binary variables. Insufflation pressures of 0 mmHg and 15 mmHg versus 20 mmHg were compared using two-sample Wilcoxon tests, or t-tests or Fisher's exact tests because images at 20 mmHg were from cohort 2 dogs. For each pressure FDRs were computed to adjust for multiple testing of numerous variables.

The effect of body position (dorsal versus sternal positions) in dogs 1-4 was evaluated using paired t-tests/Wilcoxon tests and McNemar's tests at insufflation pressures of 15 mmHg and 25 mmHg. For the time of insufflation analyses, linear and logistic regression with a random dog effect was used to investigate if each response variable was significantly related to the insufflation duration. False discovery rates were calculated to adjust for multiple testing. Values of FDR < 0.05 were considered significant.

Results

No dogs experienced clinical problems associated with the bowel cleansing protocol. No dogs experienced pneumoperitoneum suggestive of intestinal perforation at any of the insufflation pressures studied. Minor positional systemic hypotension (in dorsal recumbency only) was experienced by one dog in the pressure/position cohort (dog #2) under both anesthetic episodes. This observed hypotension responded to body position change, intravenous fluid administration, and reduction in inhalant anesthesia dose.

Pressure/Position

In experiment 1 (dogs 1-4), pneumocolon of the large intestine but not the small intestine was established and maintained well at 15mmHg. At 25 mmHg the pressure was also well maintained, but 3/4 dogs experienced gas distension of the small intestine after initiation of colorectal insufflation. Summary data are provided for measurements obtained at insufflation pressures of 0mmHg, 15mmHg, and 25mmHg (Table 1). While only a few variables differed significantly, the mean areas and diameters in the large bowel were generally larger under pressure than with no insufflation, and bowel wall thickness tended to be smaller under pressure. Many of the area and diameter measurements were significant based on raw p-values, but did not remain significant after adjusting for multiple testing. Body position did not significantly affect any variable measured.

Time of Insufflation

There were no significant differences in bowel wall thickness, cross-sectional bowel lumen diameter, or cross-sectional bowel luminal area measured in the second cohort of dogs in dorsal and sternal positions at an insufflation pressure of 20 mmHg, compared to the first cohort of dogs at 15 mmHg and 25 mmHg. Ascending colon diameter and ascending colon area significantly increased with insufflation time (FDR <0.05). No other response variables showed a significant change with insufflation time. No dogs experienced retrograde gas distension of the small intestine at 20mmHg insufflation pressure at any insufflation time point.

Computed Tomographic Interpretation

Bowel preparation was subjectively considered to be adequate with a small amount of residual fecal material in 4/8 dogs, and moderate or multifocal feces present in 2-3 regions in 4/8 dogs. The amount of feces was small when the colon was insufflated, and did not hinder assessment of the colon wall. The colonic wall was best seen on contrast enhanced images, and when surrounded by fat. On unenhanced images conspicuity was generally poor, and excellent conspicuity was obtained most frequently at 2 minutes post contrast administration (Table 2). Contrast enhancement did not affect the thickness measurements of any colonic wall segments (FDR >0.05), however both insufflation and contrast administration were required for excellent wall conspicuity (Figure 1). Folding of the colon was assessed at all insufflation pressures (15, 20, and 25 mm Hg). The rectum, transverse, and ascending colon tended to be straight, with folding occurring in the colorectal junction and junctions between transverse and ascending, and transverse and descending colon (Table 3, Figure 2).

Discussion

Findings from the current study indicated that pneumocolonography can be safely and effectively applied to normal dogs using a pressure range of 15-25 mmHg for the purposes of colonic distension during CT imaging. This technique holds promise for application to clinical canine patients with focal colorectal disease in which precise anatomic localization can be crucial to successful surgical planning. While conventional optical colonoscopy is regarded as the diagnostic gold standard for evaluation of the colonic lumen, there is evidence that colonoscopic localization of colorectal neoplasia may be inaccurate and does not translate easily to operative decision-making, and in particular reliance on distance measurements may be misleading.[2] Historically, standard CT has not been widely used for the diagnosis and localization of focal colorectal lesions, however a recent report on CT evaluation of the gastrointestinal tract evaluated gastrointestinal segments of normal dogs for conspicuity, contrast enhancement, and wall-layering after contrast administration, and additionally reported on the same measurements in two dogs diagnosed with gastrointestinal neoplasia.[8] CTP is non-invasive, quick, and accurate in detection of large colorectal lesions in humans; it enables evaluation of the entire colon even in case of obstructive lesions; it allows an accurate location of the lesion and precise measurement of the distance from the anus; provides important data on depth of mass invasion into the colorectal wall, and last, but not least, offers a complete staging including extra-colonic findings.[2]

Because the colon is a highly compliant organ, insufflation is associated with a relative increase in volume that is greater than the relative increase in pressure.[4] In general, the largest "tolerable" insufflation volumes are preferred to obtain images in human CTP studies,[1] but large bowel distension pressures are not commonly measured and reported matched with the underlying large bowel pathology in humans undergoing CTP. The colon has a high compliance up to 80mmHg; most air insufflated into the colon contributes to expansion of colonic volume with little increase in pressure, although it has been reported that the pressures needed for perforation of the right colon and cecum are lower than those needed for perforation of the sigmoid and descending colon.[4,9,10,11] The upper limit of safe intraluminal human colonic pressure is estimated to be 80 mm Hg, because perforation can occur at pressures greater than 140 mm Hg.[12] Older studies have demonstrated that distention of the bowel and elevation of intraluminal pressure beyond 30 mm Hg diminishes intestinal, and especially mucosal, blood flow, and that intraluminal pressures greater than 30 mm Hg may be generated during routine colonoscopy.[13] Sustained intraluminal colonic pressure with a maximum of 58 mmHg was recorded in 34 human patients in one study of conventional colonoscopy.[9] One group has recommended a clinical target luminal pressure of 25 mmHg for CTP in humans[1] and in the clinical setting, peak pressures for CTP rarely exceed 40 mm Hg.[14] However, an experimental study in dogs found that at lower levels of transient (40 mmHg) and constant (60-70 mmHg) intraluminal pressure elevation, colonic blood flow was actually increased.[13] The colon was insufflated to intraluminal pressures of up to 105 mmHg in these normal dogs without perforation or other complications described.[13] Automatic insufflation, in which pressure sensors measure the pressure continuously and gas is insufflated when the measured pressure drops below the target pressure, produces a controlled intracolonic pressure in which gas loss is replaced during scan acquisition, and safety is enhanced by an alarm that alerts to colonic pressures that exceed preset values, allowing excess pressure to be released. Studies have shown an improved distension using automatic insufflation compared to manual insufflation, with very few perforations recorded since the introduction of automatic insufflation and the use of flexible catheters.[1] Other methods of optimizing colonic distention include supine and prone positioning to redistribute gas to different bowel segments as needed.[4]

In our study, only the ascending colon diameter and area significantly increased with insufflation time, although we found trends of greater mean bowel luminal area and diameter at insufflation of any pressure compared to no insufflation, and an inverse correlation of bowel wall thickness with insufflation pressure compared to no insufflation. No CT images were obtained prior to placement of the insufflation catheter, and any fecal material palpated per rectum during catheter placement was digitally removed. Some gas and fecal distension observed in the CT images obtained prior to initiation of insufflation was subjectively more prevalent in the more caudal large bowel segments. This could have contributed to the lack of statistically significant differences, and may have been associated with the cleansing protocol or placement of the insufflation catheter. The lack of statistical difference between these variables at no insufflation and any of the insufflation pressures studied may additionally be associated with the relatively low number of dogs in each study group, and it is possible that with additional animals, statistically significant differences between variables studied may have been reached. Colorectal distension was well-

maintained in all bowel segments in these normal dogs, but with an insufflation pressure of 25 mmHg, 3/4 of these dogs experienced gas distension of the small intestine. This small intestinal distension was present after initiation of colorectal insufflation, but not before, indicating over-riding of the ileocecocolic sphincter pressure and retrograde insufflation of CO_2 into the small bowel. The space occupying effect secondary to the insufflation of the small intestine could have limited further colorectal distension at the 25 mmHg insufflation pressure, and was felt to be visibly undesirable, with the potential to negatively impact CT interpretation of wall thickness and mass extent in a clinical patient.

Body position can be important in the administration of CTP in humans.[1] Bowel wall compliance associated with focal infiltrative disease and/or the weight of a focal mass lesion could inhibit distribution of gas within the bowel lumen and regional large bowel distension. Even though there were no differences in the parameters measured in the young normal dogs in our study, changes in body position during imaging may be needed to optimally image a clinical patient. The sternal position may help to better delineate the terminal rectum and sphincter as the tail is not compressed against this region and can be positioned away from the region of interest. Additionally, sustained pressure in the gas-insufflated colon was higher in the prone position than in the supine position in a study of human CTP patients, and was presumed to be related to compression and flattening of the abdomen against the CT table.[4] While a positional difference was not observed in our cohort of young, thin experimental dogs, this could be important in CTP performed in clinical patients at lower insufflation target pressures in which pressure on the abdomen could result in the insufflation of lower volumes of gas before reaching the target insufflation pressure, limiting large bowel distension and potentially altering interpretation of wall thickness.

The bowel cleansing protocol utilized in this study was well tolerated by all dogs. The amount of residual feces was small, and there was minimal solid or liquid fecal material in widely dispersed regions of the lumen. In regions where feces were present, it is possible that silhouetting with a wall lesion could occur and hinder imaging evaluation. Additional studies on the impacts of bowel preparation techniques on the interpretation of images generated by CTP are needed. The insufflation catheter was visible on CT images but was not felt to negatively impact the ability to adequately interpret regional soft tissue structures. Filling the balloon of the Foley catheter with air rather than saline or contrast minimizes the chance that it will obscure a rectal lesion and improves interpretation in the caudal portion of the rectum/region of the anal sphincter.

Adverse effects of CTP were minimal in this cohort of dogs. The observed minor positional systemic hypotension experienced by one dog did not appear to be directly related to insufflation but rather the effects of general anesthesia. Adverse effects that have been described in human patients and may potentially be associated with the CO_2-CTP procedure in clinical canine patients could include cramping/discomfort, systemic hypotension, hypercapnia, vasovagal responses, colonic pneumatosis, or colonic rupture/pneumoperitoneum from overdistension.[14,15] CO_2 is a highly soluble gas that is rapidly absorbed, and it is possible that colonic insufflation of CO_2 may be associated with transient hypotension or hypercarbia. However, with careful monitoring and ventilatory compensation, absorption of CO_2 is expected to be clinically well tolerated, and with a rapid

return to baseline values when insufflation is terminated, similar to patients undergoing CO_2 insufflation for laparoscopy.[16] Mechanical ventilation is necessary to perform a breath-hold for CTP-imaging purposes, and would be recommended for management of systemic CO_2 levels during insufflation. Vasovagal responses associated with colonic distension have been described in one case report of 2 human patients.[17] In general, insufflation times for CTP should be short and any physiologic changes will resolve as soon as the insufflation is completed, but it would be recommended to monitor heart rate, indirect blood pressure, end-tidal CO_2 of dogs while undergoing the CTP in order to identify any clinically significant bradycardia associated with vasovagal responses, hypercapnia, or hypotension. Subjectively, these experimental dogs did not experience any ongoing discomfort or distress associated with this procedure as they were able to evacuate their bowels immediately after the purse string was removed. An experimental study in dogs demonstrated that once the CO_2 insufflation is discontinued, intraluminal colonic pressures return to normal in less than 10 min,[13] therefore by the time the animals have recovered from anesthesia they should no longer be experiencing any discomfort or distress associated with introduction of pneumocolon.

Colonic rupture/pneumoperitoneum was not observed in our small cohorts of normal dogs, and the incidence of colonic rupture associated with CTP in humans is very rare with a reported incidence of 0.02-0.059%.[14,15,18,19] Insufflation pressures higher than 25 mmHg have been utilized and described without complication in CTP in humans.[4] Nearly all known cases of perforation have occurred with the use of manual insufflation of room air rather than the use of automated CO_2 insufflation, and in recent years, automated CO_2 delivery has become the standard first-line colonic distension technique for many institutions.[14,15] A recent study in humans demonstrated that greater volumes of gas were delivered to patients when room air was administered by hand pump to tolerance compared to continuous low-pressure automated infusion of CO_2.[20] Risks of colonic perforation with CTP in humans are additionally thought to be increased if there is an obstructing or partially obstructing lesion, known hernia, recent colon biopsy or polypectomy, underlying colonic disease, or the patient is elderly.[21] Pneumoperitoneum associated with colonic rupture secondary to CTP in human patients was easily identifiable on the CT scans.[15] In humans, while total insufflation volumes vary due to differences in colonic volume, loss of air around the rectal catheter, and continuous colonic resorption, the typical human patient requires a total volume of 4-6 liters of insufflated CO_2 to achieve an intraluminal equilibrium pressure of 25 mmHg during a CTP procedure.[15] This volume is recorded in an attempt to monitor for potential perforation.[15] While total insufflated volumes needed are likely to be much less in canine patients due to their smaller body size, this range is currently unknown in dogs. For implementation of CTP in clinical veterinary patients, owners should be counseled regarding the risk of colonic perforation with CTP, but we would expect the risk of over-distension and colonic rupture at the relatively low pressures that we evaluated in this study to be extremely low. In humans, if pneumoperitoneum suggestive of colonic perforation is found during a CTP procedure, immediate colonic decompression is performed and a surgical consultation is obtained, although asymptomatic patients may be conservatively managed with antibiotics and careful monitoring.[15]

In conclusion, CTP is a feasible technique to provide consistent distension for imaging of the large bowel and further study on application of CTP in clinical patients is warranted. Data on the safety and optimal parameters for CTP in cats is lacking. Based on the results of this study, the authors recommend a clinical protocol for CTP in clinical canine patients with an initial insufflation pressure of 20 mmHg, with CT imaging initiated 2 minutes after initiation of insufflation and 2 minutes after contrast administration, unless the region of interest is in the ascending colon, in which case a longer interval between initiation of insufflation and imaging may be desirable. Body position did not appear to be important in generating adequate insufflation in this cohort. However, these data were obtained in young healthy dogs without signs of colorectal disease, and may not represent the CT appearance of the organ in older adult dogs with clinical signs attributed to the colorectum, potentially leading to problems of over-or under-interpretation. Additionally, if diffuse or regional colorectal distension does not appear to be adequate at the recommended protocol in older clinical patients that may have different colorectal wall compliance or partial obstructions due to mass lesions, this protocol may need to be altered with higher insufflation pressures, longer insufflation times, or positional changes (including lateral recumbencies) to promote gas migration into specific regions of interest of the colorectum.

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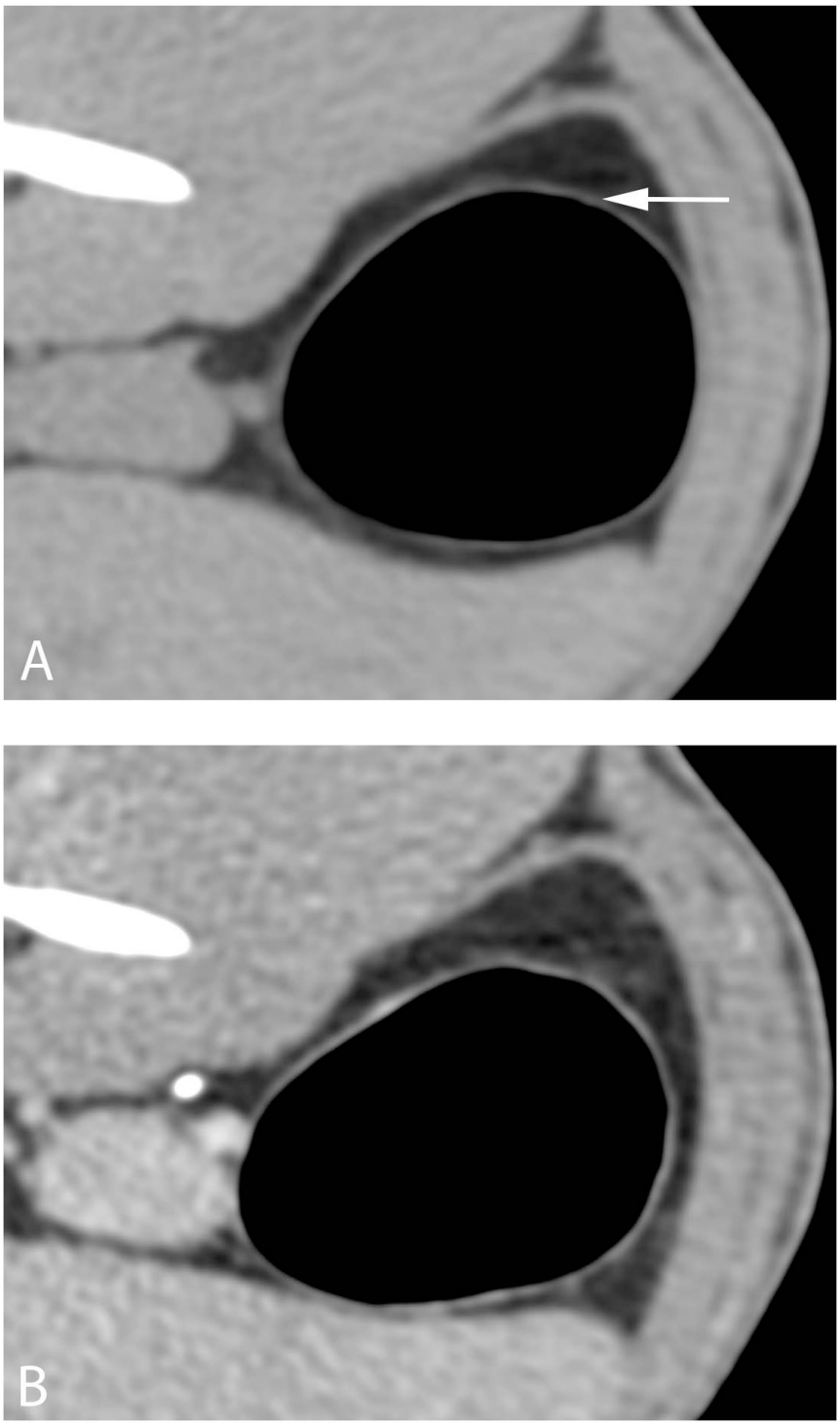

Figure 1.
Unenhanced (A) and contrast enhanced (B) images of the descending colon insufflated to 15 mm Hg. The colon wall is visible between the gas-filled lumen and the surrounding fat (A, arrow). Conspicuity is increased with contrast administration (B).

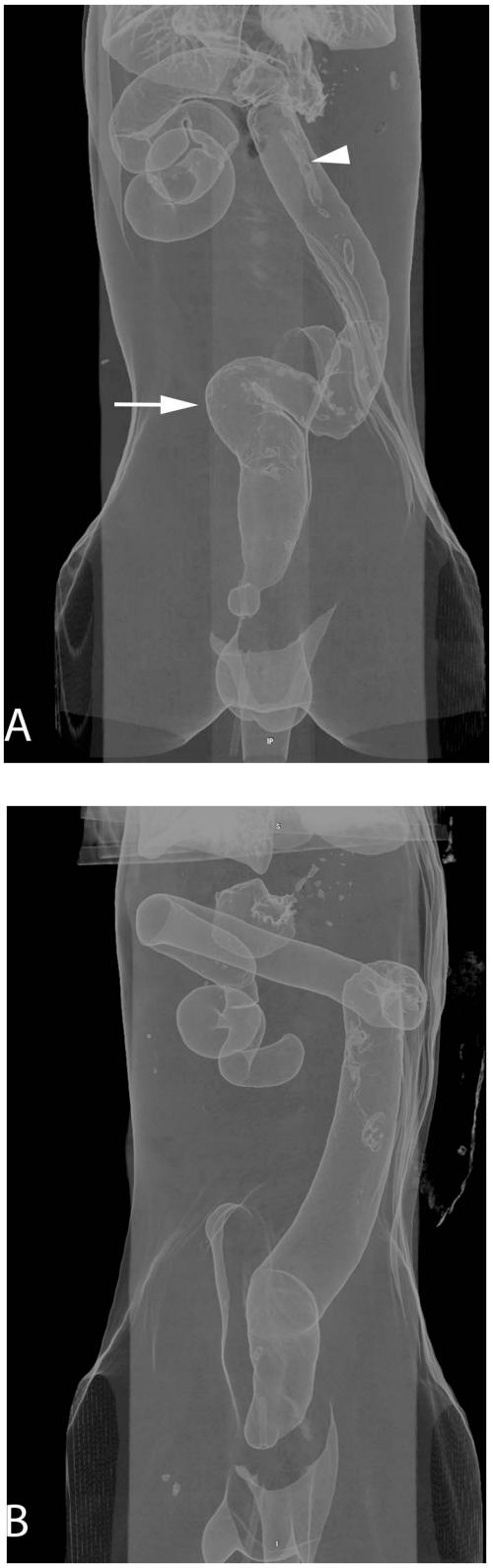

Figure 2.

3D reconstructed images of the colon insufflated at 15 mm Hg (A) and 25 mm Hg (B). The dog is in dorsal recumbency with a Foley catheter placed in the rectum. On the 15 mm Hg images, there is folding of the rectum at the colorectal junction (A, arrow). This improves with increased insufflation pressure at 25 mm Hg (B), however additional folding occurs at the junctions of the descending and transverse, and transverse and ascending colon. Small amounts of residual fecal material are visible in the colon lumen (A, arrowhead).

Table 1

Summary statistics for continuous variables for each pressure group (mean ± SD).*

	Dogs 1-4 0 mmHg	Dogs 1-4 15 mmHg	Dogs 1-4 25 mmHg
Rectum - Mid Acetabulum			
Transverse Luminal Diameter (cm)	1.60 +/-0.33	3.77 +/-0.15	3.55 +/- 0.33
Wall Thickness (cm)	0.32 +/- 0.17	0.13 +/- 0.03	0.11 +/- 0.01
Luminal Cross Sectional Area (cm^2)	2.28 +/- 0.32	10.66 +/- 0.77	10.85 +/- 1.1
Rectum - Caudal Sacroiliac			
Transverse Luminal Diameter (cm)	2.70 +/- 0.39	4.36 +/- 0.26	4.00 +/- 0.56
Wall Thickness (cm)	0.25 +/- 0.06	0.12 +/- 0.01	0.1 +/- 0.02
Luminal Cross Sectional Area (cm^2)	4.84 +/- 3.03	12.65 +/- 0.87	12.84 +/- 1.37
Colorectal Junction			
Transverse Luminal Diameter (cm)	3.54 +/- 0.44	4.14 +/- 0.33	4.01 +/- 0.44
Wall Thickness (cm)	0.2 +/- 0.04	0.12 +/- 0.04	0.08 +/- 0.02
Luminal Cross Sectional Area (cm^2)	6.82 +/- 3.95	12.20 +/- 1.81	12.86 +/- 1.75
Descending Colon			
Transverse Luminal Diameter (cm)	2.59 +/- 0.56	3.83 +/- 0.38	3.97 +/- 0.43
Wall Thickness (cm)	0.12 +/- 0.09	0.12 +/- 0.01	0.1 +/- 0.02
Luminal Cross Sectional Area (cm^2)	3.49 +/- 1.75	9.13 +/- 1.45	11.41 +/- 2.16
Transverse Colon			
Transverse Luminal Diameter (cm)	1.83 +/- 0.93	3.43 +/- 0.5	3.24 +/- 0.65
Wall Thickness (cm)	0.11 +/- 0.03	0.15 +/- 0.04	0.07 +/- 0
Luminal Cross Sectional Area (cm^2)	2.47 +/- 2.18	8.35 +/- 2.35	8.45 +/- 2.44
Ascending Colon			
Transverse Luminal Diameter (cm)	1.37 +/- 0.25*	2.80 +/- 0.16*	3.01 +/- 0.55
Wall Thickness (cm)	0.23 +/- 0.06	0.13 +/- 0.03	0.08 +/- 0.02
Luminal Cross Sectional Area (cm^2)	1.06 +/- 0.42*	5.96 +/- 0.88*	7.11 +/- 2.48

*Asterisk indicates significant difference (FDR < 0.05), cm centimeter, mmHg millimeter mercury

Table 2

Bowel wall conspicuity according to insufflation status and contrast administration.

Scan Type	Poor	Good	Excellent
Non-insufflated (N=8)	7	1	0
Insufflated, precontrast (N=8)	5	3	0
Insufflated, postcontrast (N=8)	1	3	4
Insufflated, late contrast (N=8)	3	5	0
Total	16	12	4

Table 3

Severity of folding of the colonic regions with any insufflation (15, 20, or 25 mm Hg, N=8).

Region	Straight	Mild	Moderate	Severe
Rectum	8	0	0	0
Colorectal junction	3	4	1	0
Descending colon	3	2	2	1
Junction descending/transverse	2	2	2	2
Transverse	5	1	0	2
Junction transverse/ascending	5	0	3	0
Ascending colon	5	1	1	1