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Gastrointestinal transit time is faster in Beagle dogs compared to cats

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OBJECTIVE
To characterize gastrointestinal transit times (GITTs) and pH in dogs, and to compare to data recently described for cats.

ANIMALS
7 healthy, colony-housed Beagles.

PROCEDURES
The GITTs and pH were measured using a continuous pH monitoring system. For the first period (prefeeding), food was withheld for 20 hours followed by pH capsule administration. Five hours after capsule administration, dogs were offered 75% of their historical daily caloric intake for 1 hour. For the second period (postfeeding), food was withheld for 24 hours. Dogs were allowed 1 hour to eat, followed by capsule administration. Both periods were repeated 3 times. The GITTs and pH were compared to published feline data.

RESULTS
The mean ± SD transit times in dogs for the pre- and postfeeding periods, respectively, were esophageal, 3 ± 5 minutes and 13 ± 37 minutes; gastric, 31 ± 60 minutes and 829 ± 249 minutes; and intestinal, 795 ± 444 minutes and 830 ± 368 minutes. The mean ± SD gastrointestinal pH in dogs for the pre- and postfeeding periods, respectively, were esophageal, 6.6 ± 0.6 and 5.7 ± 1.0; gastric, 3.0 ± 1.4 and 1.8 ± 0.3; intestinal, 7.9 ± 0.3 and 7.7 ± 0.6; first-hour small intestinal, 7.6 ± 0.5 and 7.1 ± 0.4; and last-hour large intestinal, 7.9 ± 0.6 and 7.7 ± 1.0. The first-hour small intestinal pH and total transit times varied between dogs and cats depending on feed period (P = .002 and P = .04, respectively). Post hoc analysis revealed significantly shorter total transit times in dogs prefeeding (P = .005; mean ± SD for cats, 2,441 ± 1,359 minutes; for dogs, 828 ± 439 minutes) and postfeeding (P = .03; mean ± SD for cats, 3,009 ± 1,220 minutes; for dogs, 1,671 ± 513 minutes). Total transit time for dogs was also shorter pre- versus postfeeding (P = .003).

CLINICAL RELEVANCE
GITT is faster in Beagles compared to cats, but gastrointestinal pH are similar when fed the same diet.

Gastrointestinal (GI) signs such as regurgitation, vomiting, diarrhea, and dysorexia are some of the most common clinical signs for which dogs and cats are presented to their veterinarian. The development of nutritional and pharmacologic strategies to better understand GI physiology is required, particularly in cats. A significant discrepancy in available GI physiologic data exists for cats compared to dogs, thereby limiting our ability to develop oral administration protocols further in this species. More data on GI physiology from dogs are available, largely because dogs are often used as a preclinical model to predict oral drug performance in people. Thus, we have rich data to compare dogs to people, but not to compare cats to dogs. The data available for dogs have facilitated development of many more oral medications for dogs compared to cats. Veterinarians may be tempted to treat cats as small dogs when drug data are not available. However, interspecies differences, including GI tract pH and transit time, could have a dramatic effect on oral drug performance. When comparing the data collected in canine studies to the

limited data collected from studies of cats describing GI pH and transit times, several notable interspecies differences are suspected, including a faster total transit time and decreased small intestinal pH in cats compared to dogs.[1-4] However, drawing meaningful conclusions from these studies is hampered by the presence of several potentially confounding variables, including differing housing environments and methodologies including different photoperiod durations, inconsistent restraint and sedation techniques, and dissimilar experimental methodology equipment to evaluate GI transit times and pH. Moreover, these comparisons are made despite differences in the diets fed, including major differences in the macronutrient composition of fed diets, which are known to have an effect on GI physiology and the luminal microenvironment.[5-7] Comparative studies controlling for these potentially confounding variables are needed so that true species differences can be identified and applied to nutritional and pharmacologic strategies. Accordingly, our objectives were to use a continuous pH monitoring system to record GI pH and transit times in dogs, and to compare these results to those recently published for cats[8] using the same methodology and being fed the same commercial diet.

To remove the confounding effect of diet on comparison of GI pH and transit times between dogs and cats, the diet fed to cats in our previously published study[8] was also used for the dogs in the current study. Although this commercial diet is specifically formulated for cats, all nutrients met the recommended allowance or minimum requirement for canine adult maintenance per the National Research Council 2006[9] and Association of American Feed Controls 2020[10] profiles on an energy basis, respectively. In addition, none of the nutrients that have safe upper limits set by the National Research Council 2006[9] and the Association of American Feed Controls 2020[10] profiles were exceeded in this diet for canine adult maintenance. Last, the macronutrient composition of the feline diet and its ingredients are comparable to certain diets intended specifically for dogs. This provided us with the opportunity to compare the effect of the same diet on GI pH and transit times in both species.

Materials and Methods

Animals

Dogs were cared for according to the principles outlined in the National Institutes of Health Guide for the Care and Use of Laboratory Animals (approval No. IACUC 2020-0181). The number of dogs selected for this study was based on the desire to meet the number selected for our published cat study[8] (n = 6) to keep a balanced statistical model. An additional dog was included in the current study to ensure at least an equal number of dogs to cats in the event of subject dropout. Healthy purpose-bred Beagle dogs from a closed research colony at Texas A&M University were recruited for inclusion in our study. Healthy was defined as lacking a history of GI signs, including

vomiting, decreased appetite, weight loss, or diarrhea, and having a normal physical examination with no evidence of systemic or GI disease (including poor hair coat, a body condition score of ≤ 3/9, or abnormal muscle condition, abdominal palpation, or thoracic auscultation). Healthy was also defined as lacking biochemical or hematologic evidence of GI disease (eg, abnormal serum albumin, globulin, or cholesterol concentration; or abnormal hematocrit or platelet count) present on routine laboratory investigation consisting of a CBC, serum biochemistry profile, and urinalysis performed within 3 weeks of study entry.

In our study, we endeavored to duplicate the environmental and dietary conditions of our previously published study in cats[8] to allow direct comparison between the 2 species. To minimize the confounding effect of stress on GI transit times and pH, the dogs were maintained in their original colony housing throughout the study in stainless steel housing (approximately 8 feet 2 inches X 7 feet 10 inches) in a controlled environment with a 12-hour light and dark cycle, and access to natural light. Prior to the study, dogs were consuming Advanced Protocol High Density Canine Diet (Lab Diet; 3.3 kcal/g as fed; 27% protein on a metabolizable energy [ME] basis, 36% fat ME, and 37% carbohydrate ME). Two and a half weeks prior to study onset, dogs were transitioned to the same diet fed to the cats in our previously published study[8] (Purina Pro Plan Focus Adult Hairball Management Chicken and Rice formula dry cat food, Nestlé Purina PetCare; 3.7 kcal/g as fed; 38.8% protein ME, 39.8% fat ME, and 21.4% carbohydrate ME). During the study, dogs were meal-fed 75% of their historical daily caloric intake and allowed 1 hour to eat. They were fed less than their historical intake to mirror similar proportions consumed by the cats in the published comparison study.[8] Dogs were weighed before each feeding time at a consistent time of day across times and periods. The amount of urination or defecation prior to the weight evaluation was not recorded. The feed was also weighed before and after the 1-hour feeding time to calculate the actual energy intake. Dogs were provided water ad libitum, including during fasting periods. Dogs were monitored a minimum of twice daily for changes in attitude or fecal consistency using the Purina Fecal Scoring System (Nestlé Purina PetCare) in accordance with the IACUC protocol. Social interaction was provided by the caretakers and investigators in a similar manner to that provided to the previous study in cats[8] to minimize any confounding effect of exercise or stimulation on GI pH and transit.

Study protocol

A continuous pH monitoring system (Bravo pH monitoring system; Medtronic) was used to characterize GI transit times and pH as previously described for dogs[11,12] and as performed in our published study in cats.[8] The pH capsule was detached from its delivery device after calibration and administered orally to determine GI transit times and pH. The pH capsule was administered orally with a syringe-style pet piller

(Butler Sales Bullseye Pillgun) as described previously,[8] followed by syringe administration of up to 15 mL tap water to facilitate swallowing of the capsule. The procedure was repeated 3 times for each period (ie, prefeeding and postfeeding), with at least 1 week separating each repeated evaluation. For this study, individuals who were involved directly in pilling and feeding the dogs (NT, EG) spent 6 weeks prior to study onset helping the dogs acclimate to them because they were not involved in the care of the dogs before then.

For the prefeeding period of the study, during which the capsule was administered prior to feeding, food was withheld from the dogs for approximately 20 hours and the pH capsule was administered orally. Five hours after capsule administration, the dogs were meal-fed 75% of their historical daily intake for 1 hour. For the postfeeding period of the study, during which the capsule was administered after feeding, food was withheld from the dogs for 24 hours prior to being meal-fed 75% of their historical daily intake for 1 hour, after which point the food was removed and the capsule administered orally to the dogs. For both periods, feed was weighed before and after the 1-hour feeding period to calculate absolute food intake. In between study days, dogs were fed 100% of their historical daily intake every 24 hours.

pH Telemetry system

All pH capsules and receivers were calibrated as described previously[8] according to the manufacturer's instructions. The pH capsule (6 X 5 X 25 mm) records GI pH readings from 0 to 9 every 6 seconds. GI pH readings were initiated immediately after oral administration and continuously acquired until the capsule was eliminated from the dog's body via the feces. The corresponding data receivers were kept on the side of each dog's cage, out of the dog's reach, during the data acquisition phase. The pH data were uploaded to a computer using a software package provided by the manufacturer (Reflux Software version 6.1; Medtronic) every 96 hours, or sooner if capsule passage occurred before 96 hours, for each monitoring period. The same receiver was used to obtain data from the same dogs for the next monitoring period. The pH was used to determine the location of the capsule within the GI tract as described previously. Esophageal residence time was defined by the time of pilling to the time of entry into the stomach.[4,8] Entry into the stomach from the esophagus was defined by a sharp and persistent decrease to pH < 4. Gastric transit time was defined as the time of entry into the stomach to the time of entry into the small intestine, denoted by a rapid and persistent increase to a pH > 4. Intestinal transit time was defined as the time of entry into the small intestine followed by exit from the body, detected as a sharp decrease in pH. The Bravo pH capsule does not measure pressure; therefore, because the transition from the small intestine to the large intestine could not be determined as a result of a similar pH, small and large intestinal transit times and pH are described together as intestinal transit time and intestinal pH.

As a representation of proximal (likely small intestine) intestinal pH, data for 1 hour after gastric transit were recorded and labeled as first-hour small intestinal pH. As a representation of distal (likely large intestine) intestinal pH, data for 1 hour prior to capsule elimination were recorded and labeled as last-hour large intestinal pH.

Statistical analysis

A 3-way, repeated-measures, mixed-model ANOVA was performed to evaluate esophageal, gastric, intestinal, first-hour small intestinal, and last-hour large intestinal pH and esophageal, gastric, intestinal, and total transit time (with and without esophageal transit) measures for differences between species (dog and cat), feed period (before and after post), and time (time 1, 2, or 3). Species was treated as a between-subject factor whereas feed period and time were treated as within-subject repeated measures. All main effects, and 2-way and 3-way interactions were included in each analysis. Unstructured Kronecker product variance and covariance structures were incorporated into each model.[13] Tukey–Kramer P-value adjustments were applied to post hoc tests. A Shapiro–Wilk test and QQ plots were used to evaluate the normality of ANOVA residuals for each outcome. Levene's equality of variances test was used to evaluate the equality of variances between species, feed period, and time (time 1, 2, or 3). Box-and-whisker plots and "Studentized" residual diagnostics were performed to evaluate each mixed model for the presence of outliers. A log transformation was required for esophageal, gastric, and total transit time (with and without esophageal retention time) as well as gastric pH. After transformations were applied as necessary, all statistical assumptions were met. Statistical significance was defined as P < .05. Statistical analysis was performed using a commercial software package (SAS software version 9.4, release TS1M7; SAS Institute, Inc).

Results

Animals

Seven Beagle dogs (4 spayed females, 3 castrated males) met the inclusion criteria and were enrolled into the study. All dogs completed the study. Dogs were approximately 3.5 years old with a median body condition score of 5 points (range, 4 to 6 points) using a 9-point scale (World Small Animal Veterinary Association Canine Body Condition Scoring system) and a median body weight of 11.6 kg (range, 10.2 to 13.4 kg).

GI times

There were no episodes of vomiting or diarrhea (Purina fecal score ≥ 5) throughout the study. The GI transit times and pH in the pre- and postfeeding periods for dogs are summarized in **Table 1**. Esophageal transit times differed between animal species depending on the feeding period (P = .034). Post hoc tests revealed that cats have significantly increased prefeeding esophageal transit times (P = .019; mean ± SD, 81 ± 127 minutes) compared to

Table 1—Descriptive statistics of gastrointestinal (GI) physiological factors by pre and postfeeding period in 7 healthy Beagle dogs.

GI measurement	Mean	SD	Median	Minimum	Maximum	Period
TT (min)						
ERT	3[a]	5	1	1	24	A
	13	37	2	1	172	B
Gastric TT	31	60	1	1	197	A
	829	249	842	1	1,248	B
Intestinal TT	795	444	1,039	188	1,428	A
	830	368	778	323	1,731	B
Total TT	828[b,c]	439	1,070	244	1,430	A
	1,671[a]	513	1,708	539	2,743	B
Total TT (ERT removed)	825[b,c]	439	1,069	243	1,429	A
	1,659[a]	518	1,704	538	2,722	B
pH						
Esophageal	6.6	0.6	6.6	5.8	7.2	A
	5.7	1.0	5.9	3.8	6.8	B
Gastric	3.0	1.4	2.5	1.4	5.7	A
	1.8	0.3	1.7	1.4	2.7	B
Intestinal	7.9	0.3	7.9	7.2	8.4	A
	7.7	0.6	7.7	6.5	8.7	B
Assumed small intestinal	7.6[b]	0.5	7.6	6.4	8.3	A
	7.1[d]	0.4	7.0	6.1	7.9	B
Assumed large intestinal	7.9	0.6	7.9	6.8	8.9	A
	7.7	1.0	7.9	4.4	9.0	B

A = Prefeeding period. B = Postfeeding period. ERT = Esophageal retention time. TT = transit time.

[a]Post hoc tests comparing dogs to cats under the same feeding conditions: .01 < P < .05. [b]Post hoc tests comparing fasted to fed period in dogs: .001 < P < .01. [c]Post hoc tests comparing dogs to cats under the same feeding conditions: .001 < P < .01. [d]Post hoc tests comparing dogs to cats under the same feeding conditions: P < .001.

dogs prefeeding esophageal transit times (3 ± 5 minutes) but not postfeeding esophageal transit times (P = .85; cats, 31 ± 88 minutes; dogs, 13 ± 37 minutes). Only 3 dogs had 1 episode each of prolonged (≥ 15 minutes) esophageal retention of the capsule. All of these events occurred during the postfeeding period. None of the dogs had exaggerated swallowing or showed overt evidence of discomfort with capsule retention. In contrast, 5/6 cats had prolonged esophageal retention of the capsules during the prefeeding period (5 cats, 8/17 times) and 4 of 6 cats had prolonged retention during the postfeeding period (4 cats, 6/18 times). Gastric transit times increased from the prefeeding to postfeeding periods (P = .003) regardless of species. A significant difference between species for gastric transit time was not observed (P = .07); however, no dogs had a dramatically delayed gastric emptying time (> 5 hours) of the capsule prefeeding, whereas 4 cats had at least 1 episode of delayed gastric emptying during the prefeeding period. Total transit times differed between animal species depending on the feeding period (P = .04). Post hoc tests revealed a significant increase in total transit time for cats compared to dogs both prefeeding (P = .005; cats, 2,441 ± 1,359 minutes; dogs, 828 ± 439 minutes) and postfeeding (P = .03; cats, 3,009 ± 1,220 minutes; dogs, 1,671 ± 513 minutes). This was a consistent finding regardless of whether esophageal transit time was included in the total transit time calculation. The total transit time for dogs (Table 1) also significantly

increased between the pre- and postfeeding periods (P = .003), but not for cats (P = .54).

Gastrointestinal pH

Esophageal, gastric, intestinal, and last-hour large intestinal pH differed between the pre- and postfeeding periods (P ≤ .025, for each) regardless of species or time, with the prefeeding values being greater than the postfeeding values (Table 1), such that no buffering effect of feeding was detected. Assumed small intestinal pH values differed between animal species depending on feeding period (P = .002). Post hoc tests revealed that during the prefeeding period, the assumed small intestinal pH of cats was slightly increased (P = .054; mean ± SD, 8.1 ± 0.3) than in dogs (7.6 ± 0.5). However, postfeeding, dogs had significantly decreased mean pH (P < .001, 7.1 ± 0.4) compared to cats (8.3 ± 0.2). The assumed small intestinal pH for dogs decreased from prefeeding to postfeeding (P = .004), but this was not observed in cats (P = .51). The assumed small intestinal pH differed over time, regardless of species or feeding period (P = .02). No additional species differences were documented for esophageal, gastric, intestinal, or assumed large intestinal pH.

Discussion

To our knowledge, this is the first study to evaluate the transit times and pH of the entire length of the gastrointestinal tract in dogs, and to compare

to that previously published in cats[8] using the same methodology. A number of factors can influence GI physiology, including body size, dietary composition, host microbiota, and disease state.[5,6,14-16] We chose to minimize the variability induced by these factors through the use of Beagle dogs that were homogenized with regard to genetic background, size, and health. We also used the same staff and monitoring methodology to perform both studies, as well as the same commercial diet for both species. In each study, animals were maintained in their original colony housing, with monitoring performed in the conscious state using fear-free techniques to minimize the effect of stress on GI physiology. Under these controlled conditions, we determined transit time in dogs to be faster compared to cats in each anatomic segment, resulting in a significantly decreased total transit time in dogs compared to cats despite the dogs' body weight (median, 11.6 kg; range, 10.2 to 13.4 kg) being approximately 3 times greater than that of cats (median, 3.9 kg; 3.4 to 5.4 kg).

In the esophagus, prolonged retention of the capsule was not observed in any of the dogs during the prefeeding period, yet was a frequent finding in cats. The size of the capsule was relatively large (6 X 5 X 25 mm), especially in comparison to the size of the kibble fed (4 X 7 to 11 mm). Thus, these differences may be attributable to the larger potential space of the esophageal lumen in Beagle dogs. Alternatively, these differences, which were observed despite oral administration of water, may be a result of relatively decreased esophageal motility in the cat, as has been reported previously.[17,18] The reason for prolonged retention occurring solely during the postfeeding period in dogs is unknown, but could be related to lack of a consistently effective bolus with the kibble to propel motility in some dogs. In our colony of dogs, the esophageal pH mean ± SD (6.6 ± 0.6) was less than previously described using catheter-based techniques.[19,20] Because the pH of the tap water administered to dogs to facilitate capsule swallowing was alkaline (pH ~ 8.6), our lower results are not considered to be a result of water administration. These differences are more likely related to differences in methodology because our study used a freely administered capsule and the referenced studies used an intraluminal pH catheter.

Although a significant difference was not observed, the capsule underwent faster gastric passage in dogs compared to cats, as has been reported previously using radioscintigraphy, which is considered to be the gold standard for evaluating gastric emptying.[21,22] Slower gastric emptying in cats may be attributable to their smaller body size. In a previous study[23] of dogs evaluating the effect of body size on GI transit using a wireless motility capsule, there was an inverse relationship of gastric emptying time and body size. In a 2015 review by Oswald et al,[15] these differences were proposed to be the result of the restrictive nature of the pylorus in smaller animals. In a recent study of cats of similar body weight (median, 3.8 kg; range, 3.2 to 4.5 kg) to our previously published study in cats,[8] the internal pyloric diameter

of the majority of cats in the fasted state as estimated by endoscopy was measured as 9 ± 1 mm,[24] which is smaller than that reported for Beagles (approximately ≤ 12.8 mm).[25] Thus, the faster gastric emptying of the capsule may be explained by these differences in pyloric size. In both groups of animals, delayed gastric transit time was observed during the postfeeding period. These findings are consistent with previous reports whereby feeding delays gastric emptying of nondigestible solid items, such as the pH capsule used in the current study, which are retained until the onset of the interdigestive phase.[26,27]

The absolute GI tract length of the average dog is expected to be approximately 2.3 times that of the average cat, with a ratio of body length to intestinal length of 1:6 in dogs and 1:4 in cats.[28] Based on these anatomic differences, we hypothesized that the intestinal transit time in dogs would be slower compared to cats. However, we observed a faster intestinal transit time in dogs compared to cats. It is possible that the delayed intestinal transit time in cats, along with increased small intestinal permeability that has been reported,[29] helps promote nutrient absorption in the face of a shortened intestinal length and decreased surface area. This theory is supported by previous studies in dogs in which smaller dogs had prolonged small intestinal transit times compared to larger dogs.[23]

Regarding GI pH, we observed very little difference in GI pH values between cats and dogs. Neither species had a buffering effect of food. Indeed, the pH of each anatomic segment decreased postfeeding regardless of species. A lack of buffering effect has been reported previously in the canine and feline stomachs.[30,31] However, this is the first study in which a decreased pH was detected postfeeding in all segments along the gastrointestinal tract.

One notable interspecies difference was with the first-hour small intestinal pH, which was decreased significantly in dogs postfeeding compared to cats. However, when evaluating the intestinal pH in the dogs, we observed that it matched more closely the intestinal pH of cats than previously reported.[2,28,32] This was particularly true when comparing what was presumed to be the large intestinal pH, which was approximately 1 U greater in dogs compared to what has previously been reported in other studies.[2,28] This may be a result of controlling for diet between studies, whereby dogs in our study were fed a diet intended for maintenance of adult cats and therefore contained a greater amount of protein than many commercial diets intended for adult dogs. High-protein diets have been demonstrated previously to alter intestinal microbiota, resulting in decreased fecal short-chain fatty acid production, increased fecal branched-chain fatty acids, and a higher fecal pH compared to cats and dogs fed a lower protein diet.[33] Because we did not evaluate the intestinal pH of dogs prior to transitioning to the diet intended for cats, nor did we evaluate the intestinal microbiota or metabolic products, we cannot establish a causal relationship between the higher protein diet and the increased intestinal pH in our study dogs.

There are several limitations in our study. We studied adult dogs and cats of similar size and genetic background within their own colony. All animals were also fed the same commercial diet intended for adult cats. Thus, our findings may not be applicable to dogs and cats of different ages, breeds, backgrounds, environments (colony vs client owned), or those fed diets with different dietary compositions or feeding practices (free feeding vs meal feeding). Moreover, our studies used healthy dogs and cats, and thus our findings cannot be applied to those with disease states. In addition, we used a nondigestible capsule, which may not accurately represent digestible and absorbable feed or pharmaceuticals. More studies addressing these limitations are warranted. Last, we controlled for calories fed according to historical daily intakes, similar to the cats in our published study. Although the cats were offered 100% of their daily historical caloric intake, the actual amount consumed was less than this. Therefore, the dogs in our study were offered 75% of their historical caloric intake, but this still resulted in the dogs being fed comparatively more volume than the study cats. However, despite this difference, the increased volume consumed by the dogs would have been expected to delay gastric emptying, rather than the faster gastric emptying observed in our study.

In conclusion, when healthy, colony Beagle dogs are fed a diet intended for maintenance of adult cats, GI transit times as assessed by a pH monitoring device are more rapid in dogs compared to colony cats, but the gastrointestinal pH is remarkably similar throughout the GI tract. Additional studies are now warranted to explore the effects of varying dietary macronutrient composition, disease states, feeding methodologies, and environments on GI pH and transit times to help provide objective data for both species. This will advance our ability to compare data between species, and therefore facilitate development of new oral drugs for cats.

Acknowledgments

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DID YOU KNOW?

Fun facts about veterinary medicine from veterinary medical students.

JAVMA AJVR

Veterinary Medicine
Washington State University

Brett Elliott Thompson from the Washington State University College of Veterinary Medicine, Class of 2025, was wondering if you knew:

Most water in the gastrointestinal tract is from secretions. Only about **20%** is from ingestion.

Zhang J, Li S, Deng F, Baikeli B, Yu W, Liu G. Distribution of aquaporins and sodium transporters in the gastrointestinal tract of a desert hare, *Lepus yarkandensis*. *Sci Rep.* 2019;9(1):1–14. doi:10.1038/s41598-019-53291-2