Influence of age and body size on gastrointestinal transit time of radiopaque markers in healthy dogs

Mickaël P. Weber, MS; Fouzia Stambouli, DVM; Lucile J. Martin, DVM, PhD; Henri J. Dumon, DVM; Vincent C. Biourge, DVM, PhD; Patrick G. Nguyen, DVM, MA

Objective—To compare gastric emptying time, small-intestinal transit time (SITT), and orocecal transit time (OCTT) of radiopaque markers in dogs varying in age and body size and to determine whether fecal variables (ie, consistency and moisture content) are related to gastrointestinal tract transit times in dogs.

Animals—24 eight-week-old female puppies, including 6 Miniature Poodles, 6 Standard Schnauzers, 6 Giant Schnauzers, and 6 Great Danes.

Procedure—Gastrointestinal tract transit time experiments were performed at 12, 22, 36, and 60 weeks of age. Dogs were fed 30 small radiopaque markers mixed with a meal. Abdominal radiographs were taken. The time at which 50% of the markers had left the stomach (T50) and the time at which the first marker reached the colon were calculated. Fecal moisture content and scoring on the basis of fecal consistency were recorded during the same periods.

Results—Puppies had a shorter mean T50 than adults, and mean OCTT decreased significantly only during growth of large-breed dogs. However mean fecal moisture content significantly increased with age, except in Giant Schnauzers. No effect of body size on T50 was found regardless of age, and no difference was observed between OCTT of small- and large-breed adult dogs. The effect of age on the mean SITT was not significant for any breed. However, a strong positive correlation was recorded between body size and fecal moisture content (r^2 = 0.77) or fecal scores (r^2 = 0.69) in adult dogs.

Conclusions and Clinical Relevance—Age affects T50 in small- and large-breed dogs and OCTT in large-breed dogs. However, body size does not affect T50 or OCTT. A relationship does not exist between gastrointestinal tract transit time and fecal variables in healthy dogs. (*Am J Vet Res* 2002;63:677–682)

No other mammalian species presents such a wide diversity in body size and shape as the domestic dog. In view of this extreme differentiation, it is of interest to evaluate potential physiologic consequences. A relatively lower mass of the gastrointestinal tract has been found in large breeds of dogs, compared with small breeds.[1,2] This finding was confirmed by Meyer et al[3] who reported that the weight of the emptied gastrointestinal tract in small breeds was 6 to 7% of their body weight but was only 3 to 4% in large and giant breeds. From these observations, it can be hypothesized that the gastrointestinal tract may be relatively shorter in large-breed dogs, compared with small-breed dogs. Results of previous studies[4,5] indicate that large-breed dogs, such as Labrador Retrievers or Great Danes, have higher fecal moisture content, increased frequency of soft feces, and increased number of defecations, compared with small-breed dogs. This might be the consequence of anatomic differences between small- and large-breed dogs and might be explained by a shorter gastrointestinal tract transit time in large-breed dogs, compared with small-breed dogs.

As growth is associated with many changes in morphologic characteristics and function of the gastrointestinal tract,[3] age could also influence the gastric emptying and **small-intestinal transit time (SITT)**. To the best of our knowledge, the effect of body size and age on gastrointestinal tract transit time has not been determined for dogs. Thus, the objectives of the study presented here were to compare gastric emptying time, SITT, and **orocecal transit time (OCTT)** of radiopaque markers in dogs varying in age and body size and to determine whether fecal variables are related to gastrointestinal tract transit times in dogs.

Materials and Methods

Dogs—Twenty-four female puppies were enrolled in our study when they were 8 weeks old. They had been chosen to represent the range of breed sizes in the canine species as follows: 6 Miniature Poodles, 6 Standard Schnauzers, 6 Giant Schnauzers, and 6 Great Danes. Dogs were treated in accordance with the French Ministry of Agriculture and Fisheries regulatory rules for animal welfare. Dogs were housed at the National Veterinary School of Nantes in closed indoor runs for the duration of our study. Dry diet allowance was calculated on the basis of ideal body weight gain during growth (< 1,200 g/wk for Great Danes, 800 g/wk for Giant Schnauzers, 400 g/wk for Standard Schnauzers, and 200 g/wk for Miniature Poodles). Dogs were exercised outdoors once daily for an hour. All dogs received regular vaccinations and were treated for endoparasites. They remained healthy throughout the duration of our study on the basis findings on routine physical examinations, serum biochemical analysis, and CBC.

Diet—Several batches of a dry expanded diet, complete and balanced for growing dogs,[6] were given to the dogs from weaning to the end of our study (**Appendix**). This diet was free of radiopaque material that could interfere with radiographic interpretation. During gastrointestinal tract transit

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From the Laboratory of Nutrition and Endocrinology, National Veterinary School of Nantes, BP 40706, 44307 Nantes Cedex 3, France (Weber, Stambouli, Martin, Dumon, Nguyen); and the Royal Canine Research Center, BP 4, 30470 Aimargues, France (Biourge).

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Address correspondence to Dr. Nguyen.

experiments, each dog was fed a sufficient amount of food to meet half of its daily caloric intake. Water was available ad libitum.

Experimental method—The experimental protocols adhered to European Union guidelines and were approved by the Animal Use and Care Advisory Committee of Nantes Veterinary School. Gastrointestinal tract transit time experiments were performed on each dog at 12, 22, 36, and 60 weeks of age. Each dog was conditioned to the experimental procedure from 8 weeks of age to minimize stress and avoid the use of sedation, which could modify gastric emptying kinetics.[7,8] Body weight and height at the shoulder (ie, body size) of each dog were recorded before each radiographic study.

Dogs were food-deprived for at least 20 hours prior to experiments, but water was always available ad libitum. In all experiments, food was moistened in a 1:2 ratio of water to dry food (wt/wt) to facilitate ingestion of markers. Thirty barium impregnated polyethylene spheres[a] of 1.5 mm diameter were mixed thoroughly with food. Most of the dogs ate markers mixed with the meal readily, but sometimes some markers had to be administered orally after the dogs had completed their meal. Dogs were manually restrained by 2 people in left lateral and ventrodorsal positions, and abdominal radiographs were taken every 30 minutes for 4 hours then hourly until 12 hours after feeding.

Radiographic interpretation—Both radiographic views were interpreted by a radiologist who localized the markers either in the stomach or in the gastrointestinal tract. The percentage of markers that had left the stomach at each time point was determined, and the **time at which 50% of the markers had left the stomach (T50)** was calculated for each dog. When these times fell between 2 of the hourly time points, the longer time was taken to represent the T50. The OCTT was defined as the time at which the first marker reached the colon. The SITT equaled the OCTT minus the time at which the first marker was observed to have left the stomach.

Predictive total gastric emptying time—The gastric emptying data for each dog at each age were fitted[b] by a nonlinear mathematic model:

$$y = 120/(1+be^{-kt})$$

where y represents the percentage of markers that had left the stomach at a given time (t), b is the integrative constant, k is a gastric emptying speed variable, and t is the time in hours.[9] This model allowed the calculation of the **predictive total gastric emptying time (pTGET)** for each dog, defined as the time at which no marker (< 3%) remained in the stomach.

Fecal variables—Fecal scoring was recorded daily during 1 week for each dog at each study period. Feces grades ranged from 1 to 5, with 1 representing hard and dry feces and 5 indicating liquid diarrhea. A 2.5 score was considered as optimum, representing a well-formed feces easy to collect but not too dry. Fecal moisture content was measured the week before the radiographic study. Fresh fecal samples were collected and pooled, and water content was assessed by weighing them before and after freeze drying.[c]

Statistical analysis—Results are expressed as mean (± SE) values. An ANOVA was used[d] to test the influence of breed and age on food intake, gastrointestinal tract transit times, and fecal variables. When significant (F test, $P < 0.05$), the differences between mean values were assessed by the Fisher least significant difference test (matrix of pairwise comparison probabilities). Linear regression analyses were performed to compare the effect of body weight and height at the shoulder (ie, body size) on the fecal variables as well as the effect of body weight, height at the shoulder, food intake, and fecal variables on the gastrointestinal tract transit times. A value of $P \le 0.05$ was considered significant in all analyses.

Results

Dogs remained healthy throughout the duration of our study. They had a steady and normal growth and reached standard adult body size and body weight at a standard age.

Food allowance—The dry diet allowance determined on the basis of metabolic body weight (gram/kilogramBW$^{0.75}$) significantly decreased ($P < 0.001$) from 12 to 60 weeks of age for each breed (from 32 ± 2 to 21 ± 1 g/kgBW$^{0.75}$ for Miniature Poodles; from 30 ± 1 to 24 ± 1 g/kgBW$^{0.75}$ for Standard Schnauzers; from 28 ± 0.5 to 25 ± 0.5 g/kgBW$^{0.75}$ for Giant Schnauzers; and from 28 ± 0.5 to 25 ± 0.5 g/kgBW$^{0.75}$ for Great Danes). No correlation was observed between meal size and T50, pTGET, OCTT, or SITT from 12 to 60 weeks of age for each breed.

Fecal variables—The mean fecal moisture content significantly increased with age in Miniature Poodles, Standard Schnauzers, and Great Danes but not in Giant Schnauzers. No effect of age on fecal scores was found in the 4 breeds.

Significantly poorer fecal quality was recorded for large-breed dogs during our study (**Fig 1**). A strong positive correlation was observed in adult dogs between height at the shoulder or body weight and fecal water content ($r^2 = 0.77$ and 0.80, respectively; $P < 0.001$) or fecal scoring ($r^2 = 0.69$ and 0.71, respectively; $P < 0.001$).

The T50—The effect of age on T50 was significant ($P < 0.001$). The mean T50 increased significantly between 12 and 22 weeks of age in Miniature Poodles, Standard Schnauzers, and Giant Schnauzers and between 22 and 36 weeks in Great Danes and then remained constant **(Table 1)**.

No correlation of body size or body weight with T50 was found regardless of age. The mean T50 was

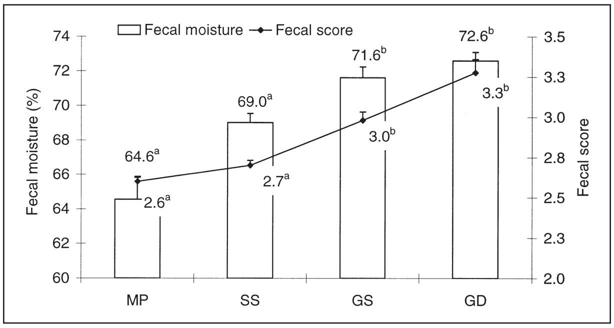

Figure 1—Effect of body size on mean (± SE) fecal moisture content (%) and fecal scoring in Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes (mean of the 4 ages for each breed). Fecal scoring ranged from grade 1 (hard and dry feces) to grade 5 (liquid diarrhea). A well-formed feces was represented by the 2.5 grade. Notice a lower fecal quality was recorded in large-breed dogs, compared with small-breed dogs.[a,b]Different superscript letters for the same variable (ie, fecal moisture content or fecal score) are significantly different ($P < 0.05$). MP = Miniature Poodles. SS = Standard Schnauzers. GS = Giant Schnauzers. GD = Great Danes.

significantly higher in Giant Schnauzers than in Miniature Poodles at 12 and 22 weeks of age and in Great Danes at 22 weeks of age. This effect of breed on T50 was not significant at 36 and 60 weeks of age. Mean T50 of Great Danes, Standard Schnauzers, and Miniature Poodles was not significantly different throughout our study (Table 1).

The pTGET—The pattern of gastric emptying for all dogs fit well with the exponential logistic function as indicated by the strong correlations obtained for all dogs ($r^2 \geq 0.98$). A slowing down of gastric emptying time was observed between 12 and 60 weeks of age when results were combined for the 4 breeds (**Fig 2**). A significant effect of age on pTGET ($P < 0.001$) was found with an increase between 12 and 60 weeks of age in each of the 4 breeds (**Fig 3**).

Body size or body weight did not correlate with pTGET regardless of age. Except at 22 weeks of age when the mean pTGET of Giant Schnauzers was significantly higher than in Miniature Poodles, Standard Schnauzers, and Great Danes (18.7 ± 0.19 hours vs 14.7 ± 1.4, 14.4 ± 1.5, and 11.9 ± 0.6 hours, respectively), the mean pTGET was not significantly different among the 4 breeds at 12, 36, and 60 weeks of age. A significant correlation was obtained between pTGET and T50 ($r^2 = 0.66$; n = 96; $P < 0.001$).

The OCTT and SITT—The mean OCTT decreased significantly between 12 and 60 weeks of age in Giant Schnauzers and Great Danes (from 4.4 ± 0.5 to 2.9 ± 0.6 hours and from 3.8 ± 0.4 to 3.0 ± 0.2 hours at 12 and 60 weeks, respectively) but remained constant during growth for Miniature Poodles and Standard Schnauzers. The effect of age on the mean SITT was not significant for any breed.

Table 1—Mean (± SE) T50 in hours of Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes from 12 to 60 weeks of age

Age (wk)	Mean T50 values (h)			
	Miniature Poodles (n = 6)	Standard Schnauzers (6)	Giant Schnauzers (6)	Great Danes (6)
12	3.4 ± 0.4[a,c]	4.4 ± 0.3[a,c,d]	5.2 ± 0.9[a,d]	4.3 ± 0.6[a,c,d]
22	5.7 ± 0.5[b,c]	6.1 ± 0.7[b,c,d]	8.2 ± 1.2[b,d]	4.7 ± 0.4[a,b,c]
36	6.8 ± 0.7[b,c]	6.3 ± 0.7[b,c]	8.3 ± 1.2[b,c]	6.5 ± 1.0[b,c]
60	6.4 ± 0.5[b,c]	6.5 ± 1.2[b,c]	7.8 ± 0.7[b,c]	6.4 ± 1.1[b,c]

[a,b]Different superscript letters in the same column are significantly different ($P < 0.05$). [c,d]Different superscript letters in the same row are significantly different ($P < 0.05$).
T50 = The time at which 50% of ingested radiopaque markers had left the stomach.

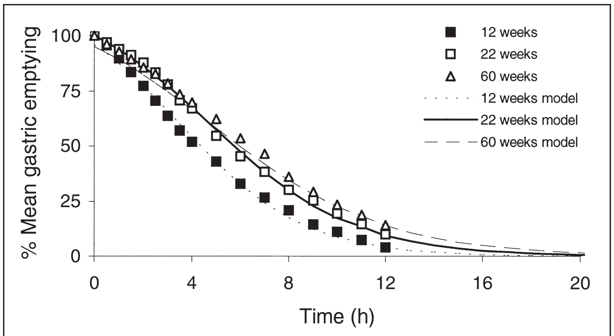

Figure 2—Effect of age (12, 22, and 60 weeks of age) on the gastric emptying curves (mean of the 4 breeds at each age) and similarity of the nonlinear model-predicted curves with observed mean data. Notice that the kinetics of gastric emptying of radiopaque markers shift toward the right during growth.

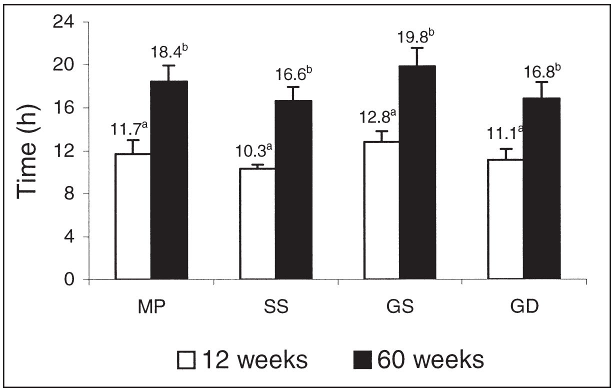

Figure 3—Effect of age on predictive mean (± SE) total gastric emptying time (pTGET) in Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes at 12 and 60 weeks of age. Notice that the mean pTGET increased in the 4 dog breeds between 12 and 60 weeks of age. [a,b]Different superscript letters for the same breed are significantly different ($P < 0.05$). *See* Figure 1 for key.

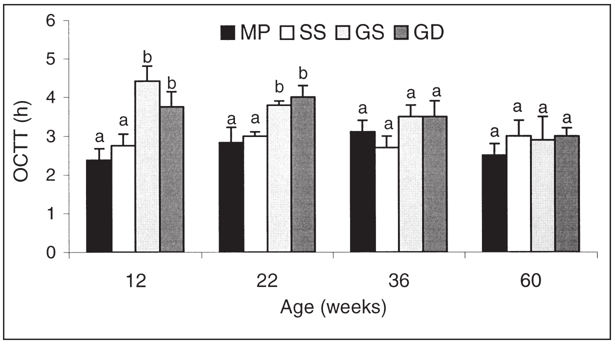

Figure 4—Effect of body size on mean (± SE) orocecal transit time (OCTT) at 12 to 60 weeks of age in Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes. Notice that the mean OCTT of small-breed dogs were shorter at 12 and 22 weeks of age. [a,b]Different superscript letters at the same age (growth period) are significantly different ($P < 0.05$). *See* Figure 1 for key.

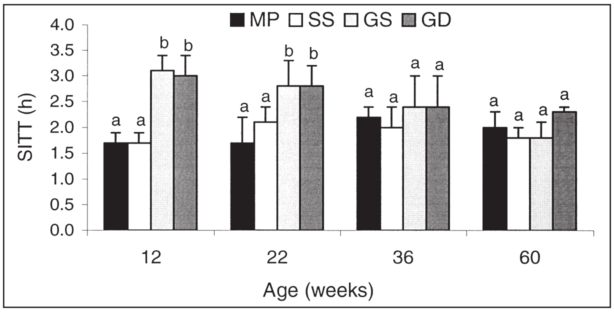

Figure 5— Effect of body size on mean (± SE) small-intestinal transit time (SITT) at 12 to 60 weeks of age in Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes. Notice that the mean SITT were shorter in the Miniature Poodles and Standard Schnauzers at 12 and 22 weeks of age. [a,b]Different superscript letters at the same age (growth period) are significantly different ($P < 0.05$). *See* Figure 1 for key.

Body size and body weight affected OCTT and SITT at 12 and 22 weeks of age, with a mean OCTT and SITT significantly shorter in small-breed dogs than in the large-breed dogs. After 22 weeks of age, the effect of body size and body weight on OCTT and SITT was not significant (**Fig 4 and 5**).

Effect of gastrointestinal tract transit times on fecal variables—The mean T50 or pTGET were not correlated with fecal moisture content or with fecal scoring regardless of breed and age. Moreover, no relationship was found between mean OCTT or SITT and the fecal variables.

Discussion

Several noninvasive techniques have been proposed to evaluate stomach emptying and gastrointestinal tract transit of solid food in dogs. Barium sulfate suspension mixed with food is a simple and inexpensive method often used by clinicians to make these assessments.[10-12] Unfortunately, this method is not quantitative, and barium may rapidly dissociate from the food producing misleading results.[12] Recently, [^{13}C]octanoic acid test has been developed to measure gastric emptying of solids.[13] This medium chain fatty acid is rapidly absorbed from the duodenum after gastric emptying of the test meal and carried to the liver where it is quickly and completely oxidized to carbon dioxide, then exhaled in breath. The appearance rate of the $^{13}CO_2$ in the expired air after ingestion of ^{13}C-labelled octanoic acid therefore reflects the rate of the gastric emptying. This test has a high degree of reproducibility within individuals[14]; nevertheless, it requires expensive equipment and only measures gastric emptying. Nuclear scintigraphy has been considered as the technique of choice to evaluate the gastrointestinal tract transit time in cats and dogs.[15-17] However, cost of equipment and use of radioelements limit its use. Barium-impregnated polyethylene spheres, radiopaque markers of density similar to that of food particles, have recently been developed to assess solid-phase gastrointestinal tract transit time in dogs and cats.[18-20] This technique is quantitative, noninvasive, and easier to perform and interpret than scintigraphy. On the basis of findings in previous studies,[21,22] 1.5-mm-diameter radiopaque markers were of a size likely to pass through the pylorus in a similar manner as food particles. This has been confirmed by a close correlation between gastric emptying and OCTT of the diet and radiopaque markers.[23] Differences in the rate and pattern of solid-phase gastric emptying of a radiolabeled meal as assessed simultaneously by scintigraphy and radiopaque markers in dogs have nevertheless been reported.[24] Thus, the use of radiopaque markers to assess gastric emptying remains controversial.[25] However, the purpose of our study was not to determine absolute values but rather to evaluate the relative effect of body size and age on radiopaque markers transit. Reference intervals for the gastrointestinal tract transit times of these markers have been established in dogs,[18,26] but neither age, breed, nor body size were taken into account in these studies.

It is noteworthy that all dogs used in our study were females and that results could have been influenced by sex and phase of the estrous cycle. Sex-related differences in gastrointestinal tract transit time are nevertheless still controversial in humans. A study reported a slower gastric emptying in premenopausal women[27] that could be explained by the inhibitory effects of estrogen or progesterone on gastric emptying.[28] In other studies, however, sex did not appear to have any effect on gastric emptying[29] nor gastrointestinal tract transit time[30] in humans. Moreover, no significant difference has been found between males and females on gastric emptying assessed by radiopaque markers in dogs[18] and by scintigraphy in cats.[15]

In our study, the gastric emptying data for each dog were fitted with a mathematic model to calculate the pTGET. A sigmoid nonlinear model was used. Gastric emptying has been shown to present 3 phases: a lag phase (for trituration), a relatively linear phase that reflects most of the gastric emptying, and a delayed phase that reflects the interdigestive period.[24,31] Among sigmoid models commonly used for the representation of gastric emptying curves,[15,24,32] none gave significant correlations with all gastric emptying curves (n = 96). Only the logistic function used in our study gave strong correlations ($r^2 \geq 0.98$) between all predicted and observed curves regardless of breed and age. This mathematic model was therefore used to determine the pTGET of each dog at each age.

In our study, age significantly affected gastric emptying as indicated by the increase of the T50 ($P < 0.001$) and pTGET ($P < 0.001$) during growth. This was in agreement with findings of a previous study[12] that reported a shorter gastric emptying time of food mixed with barium for puppies (from 9 to 14 weeks of age) than in adult dogs. In our study, meal size or stress is unlikely to explain faster gastric emptying of puppies as larger meals, and stress would be expected to slow rather than to accelerate gastric emptying.[15,33,34] Nevertheless, faster gastric emptying in puppies was not associated with poorer fecal quality.

Despite large differences in fecal consistency between small- and large-breed dogs, no effect of body size or body weight was observed on gastric emptying regardless of age. Only a weak correlation ($r^2 = 0.07$) was previously reported between T50 and body weight in dogs weighing between 13.5 and 37 kg.[18] These results contrast with a study[35] in humans where a strong inverse linear relationship was found between gastric emptying rates and body weight ranging from 59 to 93 kg. Significantly longer T50 and pTGET were found in Giant Schnauzers at the beginning of their growth. Giant Schnauzers puppies seemed nervous, and their prolonged gastric emptying times might be the result of stress despite every effort to accommodate them to the imaging procedures.

Even if the nature and the amount of diet fed in our study were different from previous studies, mean T50 of adult Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes (6.4 ± 0.5, 6.5 ± 1.2, 7.8 ± 0.7, and 6.4 ± 1.1 hours, respectively) were in the range of previously reported values for healthy adult dogs fed a canned (6.5 ± 3.2 and 6.9 ± 1.3

hours)[18,24] or a dry (7.5 ± 0.7 hours) diet.[e] In addition, mean pTGET of adult Miniature Poodles, Standard Schnauzers, Giant Schnauzers, and Great Danes (18.4 ± 1.5, 16.6 ± 1.3, 19.8 ± 1.7, and 16.8 ± 1.5 hours, respectively) was in agreement with previous data of > 16 hours in healthy adult dogs.[18,24] In our study, T50 correlated significantly with pTGET ($r^2 = 0.66$; n = 96; $P < 0.001$), suggesting that T50 could be a good predictor of accelerated or delayed total gastric emptying of solid phase in dogs.

Little information is available on the effect of age or body size on OCTT and SITT in dogs. In our study, a significant decrease of OCTT was found during growth of Giant Schnauzers and Great Danes, whereas it remained constant during growth of Miniature Poodles and Standard Schnauzers. However, no change in fecal moisture content or fecal scores was observed during the growth of Giant Schnauzers despite the reduction of their OCTT. Moreover, the increase in fecal moisture content during the growth of Miniature Poodles and Standard Schnauzers was not associated with a decrease of OCTT.

The OCTT and SITT were significantly longer in large-breed dogs, compared with small-breed dogs at the beginning of growth (12 and 22 weeks of age), but this effect of body was not observed for adult dogs. The lack of effect of body size in adult large-breed dogs and age in small-breed dogs could be the result of the method used to assess OCTT. This variable, defined as the time at which the first marker could be observed in the colon, might not be sensitive enough to detect differences. Other methods used to assess OCTT, such as breath hydrogen or sulphasalazine/sulphapyridine test, need to be performed to confirm our observations. Mean OCTT values found in our adult dogs (2.5 ± 0.2 hours, n = 24) were, however, similar to those measured in adult Beagles (mean ± SD) by breath hydrogen test (2.4 ± 0.5 hours)[36,f] and slightly shorter than those obtained by the sulphasalazine/sulphapyridine method (3.0 ± 0.4 and 3.0 ± 1.4 hours).[36,37]

In our study, neither the low fecal quality in large-breed dogs nor the increase of fecal moisture content during growth was associated with a faster gastric emptying or a shorter OCTT. These results indicate a lack of relationship in healthy dogs between gastrointestinal tract transit time and fecal variables. This agrees with results of a previous study[38] that indicated that feces form was not related to gastric emptying or SITT in healthy humans.

[a]BIPS, Chemstock Animal Health Ltd, Christchurch, New Zealand.
[b]Systat 5.0, SPSS Inc, Chicago, Ill.
[c]Flexi-Dry MP, FTS Systems Inc, New York, NY.
[d]Statview 5.0, SAS Institute Inc, Cary, NC.
[e]Nelson OL, Jergens AE, Miles KG. Using barium-impregnated polyethylene spheres (BIPS) to assess drug-induced gastrokinesis in healthy dogs (abstr). *Vet Radiol* 1995;36:359.
[f]Papasouliotis K, Gruffydd-Jones TJ, Rigby S, et al. The effect of dietary fibre on orocaecal transit time in dogs (abstr). *J Vet Intern Med* 1992;6:142.

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Appendix

Mean (± SE) nutrient composition determined from 5 batches of the diet used throughout the duration of our study for all dogs

Nutrients	Units	Composition
DM	g/100g	92.7 ± 0.2
Crude protein	g/100g DM	39.2 ± 0.4
Fat	g/100g DM	16.3 ± 0.2
Ash	g/100g DM	6.9 ± 0.7
Total dietary fiber	g/100g DM	9.8 ± 0.5
Estimated ME	Kcal/100g DM	381 ± 3

DM = Dry matter. ME = Metabolic energy.