A lthough disorders of gastrointestinal tract motility are commonly encountered in canine medicine, the diagnosis of these disorders is hampered by a lack of data on gastrointestinal transit times in healthy dogs. To our knowledge, there are no reference ranges available for these measurements to which values for a particular patient could be compared. In particular, with the large range of body sizes in the canine species, there is a lack of undisputed evidence about the influence of body size on gastrointestinal transit times. Although large- and giant-breed dogs reportedly have prolonged GETs, inconsistent results have been reported in studies conducted to evaluate gastric emptying in dogs of various sizes. Moreover, there is only sparse data available on the relationship between body size and small

**Assessment of the relationship between body weight and gastrointestinal transit times measured by use of a wireless motility capsule system in dogs**

Carol S. Boillat, Dr med vet; Frédéric P. Gaschen, Dr med vet, Dr habil; Giselle L. Hosgood, BVSc, PhD

**Objective**—To assess the relationship between body weight and gastrointestinal transit times measured by use of a wireless motility capsule (WMC) system in healthy dogs.

**Animals**—31 healthy adult dogs that weighed between 19.6 and 81.2 kg.

**Procedures**—Food was withheld overnight. The following morning, a WMC was orally administered to each dog, and each dog was then fed a test meal that provided a fourth of the daily energy requirements. A vest was fitted on each dog to hold a receiver that collected and stored data from the WMC. Measurements were obtained with each dog in its home environment. Regression analysis was used to assess the relationship between body weight and gastrointestinal transit times.

**Results**—Gastric emptying time (GET) ranged from 405 to 897 minutes, small bowel transit time (SBTT) ranged from 96 to 224 minutes, large bowel transit time (LBTT) ranged from 427 to 2,573 minutes, and total transit time (TTT) ranged from 1,294 to 3,443 minutes. There was no positive relationship between body weight and gastrointestinal transit times. A nonlinear inverse relationship between body weight and GET and between body weight and SBTT best fit the data. The LBTT could not be explained by this model and likely influenced the poor fit for the TTT.

**Conclusions and Clinical Relevance**—A positive relationship did not exist between body weight and gastrointestinal transit times. Dogs with the lowest body weight of the cohort appeared to have longer gastric and small intestinal transit times than did large- and giant-breed dogs. (Am J Vet Res 2010;71:898–902)

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**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCS</td>
<td>Body condition score</td>
</tr>
<tr>
<td>GET</td>
<td>Gastric emptying time</td>
</tr>
<tr>
<td>LBTT</td>
<td>Large bowel transit time</td>
</tr>
<tr>
<td>MMC</td>
<td>Migrating motor complex</td>
</tr>
<tr>
<td>SBTT</td>
<td>Small bowel transit time</td>
</tr>
<tr>
<td>SLBTT</td>
<td>Small and large bowel transit time</td>
</tr>
<tr>
<td>TTT</td>
<td>Total transit time</td>
</tr>
<tr>
<td>WMC</td>
<td>Wireless motility capsule</td>
</tr>
</tbody>
</table>

or large intestinal transit times. Measurements of specific intestinal transit times have been hampered by the lack of techniques that are easy to use for obtaining this data. A WMC system is a noninvasive method for assessment of gastric and intestinal motility that has recently been approved for use in humans and validated for use in dogs. The GET measured by use of the WMC in dogs correlates with that obtained for other methods. The WMC is able to detect changes associated with administration of motility-modifying drugs. After ingestion and during its transit through the gastrointestinal tract, the nondigestible WMC records pH, temperature, and pressure and transmits these data to an external receiver; the information then is downloaded from the

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From the Department of Veterinary Clinical Sciences, School of Veterinary Medicine, Louisiana State University, Baton Rouge, LA 70803. Dr. Boillat’s present address is the Department of Clinical Veterinary Medicine, Vetsuisse Faculty, University of Bern, CH-3001 Bern, Switzerland. Dr. Hosgood’s present address is the Department of Small Animal Medicine and Surgery, School of Veterinary and Biomedical Sciences, Murdoch University, Murdoch, WA 6150, Australia. Supported in part by Nestlé-Purina.

Address correspondence to Dr. Gaschen (fgaschen@lsu.edu).
receiver and analyzed. The GET, SLBTT, SBTT, and TTT are calculated. The purpose of the study reported here was to assess the relationship between body weight and gastrointestinal transit times measured by use of a WMC in healthy dogs.

Materials and Methods

Dogs—Thirty-one adult dogs of various body weights were recruited for inclusion in the study. Dogs were owned by students and staff of the School of Veterinary Medicine at Louisiana State University. Consent was obtained from each owner for participation of their dog in the study. The study was approved by the Louisiana State University School of Veterinary Medicine Clinical Protocol Review Committee.

For inclusion in the study, each dog had to be between 1 and 10 years old, be healthy, weigh ≥ 19 kg, and be current with regard to vaccinations and heartworm preventative. A BCS was recorded for each dog by use of a scale of 1 to 9 (1 = extremely thin, 5 = optimal, and 9 = extremely obese), and only dogs with a BCS between 4 and 6 were included. Assessment of health status was based on results of physical examination, a CBC, and a serum biochemical analysis. All results had to be within the respective reference ranges for a dog to be included in the study. Prior to entering the study, all dogs were treated for gastrointestinal parasites by use of a broad-spectrum parasiticide.

Diet—Test meals were prepared for each dog. Each test meal consisted of a dog’s regular dry kibble diet and was designed to provide a fourth of its calculated daily energy requirement, as determined by use of the following equation: $y = (S \cdot e^{-K \cdot x}) + P$, where $y$ is the transit time, $S$ is the span (ie, range) over which $y$ is expressed, $e$ is the natural logarithm, $K$ is the rate constant of decay, $x$ is body weight, and $P$ is the plateau (ie, baseline) of $y$. The 95% confidence range was used to analyze the data retrieved from the receiver, and GET, SLBTT, and TTT were calculated. All emptying and transit times were also calculated on the basis of the pH data and compared with those recorded by the software. The SBTT was graphically defined as the interval between an increase in pH of ≥ 3 U and a change in the pressure pattern from continuously high (MMC phase III) to isolated, segmented contractions (colonic motor complexes). This time point coincided with a decrease in pH of > 1 U associated with passage through the ileocolic valve. The LBTT was calculated as SLBTT minus SBTT.

Statistical analysis—Graphs of transit times versus body weight were created and evaluated. On the basis of visual inspection and biological plausibility, nonlinear regression curves were fitted by use of a 1-phase exponential decay model to the data with the following equation: $y = (S \cdot e^{-K \cdot x}) + P$, where $y$ is the transit time, $S$ is the span (ie, range) over which $y$ is expressed, $e$ is the natural logarithm, $K$ is the rate constant of decay, $x$ is body weight, and $P$ is the plateau (ie, baseline) of $y$. The 95% confidence and prediction bands of the model were calculated and plotted. Fit of the model was examined by use of the runs test, the coefficient of determination (ie, $R^2$), and evaluation of residuals (ie, $S_x$) and was compared with the fit of a simple linear regression (default) model. The runs test, which examines the runs of data points above or below the estimated curve, was considered evident of a good fit for $P > 0.5$ (the highest $P$ value possible was preferred). A value of $P > 0.5$ suggests that fewer runs than expected

Table 1—Mean ± SE values of parameters in a 1-phase exponential decay model for various transit times determined for 31 healthy adult dogs by use of a WMC system.

<table>
<thead>
<tr>
<th>Transit time</th>
<th>$K$</th>
<th>$S$</th>
<th>$P$</th>
<th>Half-life (min)</th>
<th>$R^2$</th>
<th>Runs test ($P$ value)</th>
<th>$S_x$</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>0.094 ± 0.069</td>
<td>1,436 ± 2,074</td>
<td>561.4 ± 48.8</td>
<td>7.4</td>
<td>0.24</td>
<td>0.936</td>
<td>107.8</td>
</tr>
<tr>
<td>SBTT</td>
<td>0.054 ± 0.099</td>
<td>79.4 ± 127.5</td>
<td>152.8 ± 30.2</td>
<td>15.8</td>
<td>0.07</td>
<td>0.884</td>
<td>31.6</td>
</tr>
<tr>
<td>LBTB</td>
<td>0.002 ± 0.206</td>
<td>1,586 ± 101,859</td>
<td>−101.8 ± 102,716</td>
<td>248.7</td>
<td>0.01</td>
<td>0.275</td>
<td>566.3</td>
</tr>
<tr>
<td>SLBTT*</td>
<td>0.020 ± 0.121</td>
<td>1,557 ± 21,736</td>
<td>962.3 ± 22,753</td>
<td>110.6</td>
<td>0.03</td>
<td>0.275</td>
<td>622.9</td>
</tr>
</tbody>
</table>

$*$Values did not converge; estimates are based on initial values (ie, based on the data obtained). $K$ = Rate constant of decay; $P$ = Plateau (ie, baseline) of $y$. $S$ = Span (ie, range) over which $y$ is expressed. $S_x$ = Root mean square.
Table 2—Mean ± SE values of parameters in a linear regression model for various transit times determined for 31 healthy adult dogs by use of a WMC system.

<table>
<thead>
<tr>
<th>Transit time</th>
<th>Slope</th>
<th>$R^2$</th>
<th>Runs test (P value)</th>
<th>$S_y$</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>GET</td>
<td>-2.83 ± 1.38</td>
<td>0.14</td>
<td>0.936</td>
<td>112.9</td>
<td>0.049</td>
</tr>
<tr>
<td>SBTT</td>
<td>-5.63 ± 0.36</td>
<td>0.09</td>
<td>0.985</td>
<td>313.3</td>
<td>0.132</td>
</tr>
<tr>
<td>LBTT</td>
<td>-3.97 ± 0.51</td>
<td>0.01</td>
<td>0.275</td>
<td>556.5</td>
<td>0.557</td>
</tr>
<tr>
<td>SBLTT</td>
<td>-5.70 ± 0.26</td>
<td>0.02</td>
<td>0.249</td>
<td>594.8</td>
<td>0.419</td>
</tr>
<tr>
<td>TTT</td>
<td>-7.24 ± 0.36</td>
<td>0.03</td>
<td>0.275</td>
<td>612.1</td>
<td>0.320</td>
</tr>
</tbody>
</table>

*Probability that the slope of the regression line does not equal zero. Values did not converge; estimates are based on initial values (i.e., based on the data obtained).

$S_y$ = Root mean square.

are observed, whereas a value of $P < 0.5$ suggests that the data do not fit the equation. For $R^2$, which quantifies the goodness of fit of the model and reflects the fraction of the total variance of y that can be explained by x, a model with the highest $R^2$ was preferred. For $S_y$ (root mean square = $\sqrt{SS/[N – P]}$, where SS is the sum of squares of the vertical distances of the points from the curve, N is the number of data points, and P is the number of parameters), the model with the smallest $S_y$ was preferred. The estimated parameters and their SE were reported. Models were fitted by use of commercially available software.13

Results

Body weight of the 31 dogs ranged from 19.6 to 81.2 kg (mean, 41.2 kg), and dogs had a mean BCS of 5.2. There were 14 females and 17 males. Dogs were between 1.5 and 9 years of age. Ten were crossbred dogs, and 21 were purebred dogs (6 Great Danes, 5 Rottweilers, 2 Labrador Retrievers, and 1 each of Alaskan Malamute, Australian Cattle Dog, Chesapeake Bay Retriever, Golden Retriever, Husky, Mastiff, Poodle, and Rhodesian Ridgeback).

Transit times ranged from 405 to 897 minutes for GET, 96 to 224 minutes for SBTT, 427 to 2,573 minutes for LBTT, 579 to 2,765 minutes for SLBTT, and 1,294 to 4,443 minutes for TTT.

Visual inspection of the data suggested a negative relationship between increasing body weight and transit times. Use of a 1-phase exponential decay model appeared to yield a better fit of the data than did use of simple linear regression for all transit times, although the GET did have a significant but moderate negative linear association (Tables 1 and 2). The data best fit by use of the 1-phase exponential model were for GET and SBTT (Figure 1). Data for LBTT could not be fit by use of the model and likely influenced the poor fit of the model for SLBTT and TTT data. Data for SLBTT could not be fit by use of the exponential model. The model was evaluated with and without 2 suspected outliers (52.4 kg, which yielded a GET of 883 minutes, and 61.6 kg, which yielded a GET of 867 minutes). The residual for these 2 points was the highest. The GET for these 2 outliers was > 3 SDs of the predicted outcome for the model without these points (565 + [3 X 79] = 802, 571 + [3 X 64] = 763, respectively) and outside the predicted range, which were considered sufficient criteria to remove them from the model analysis.13 Although the GET and SBTT could be explained by the decay model, which results of the runs test indicated were a reasonable fit ($P = 0.94$ for GET and $P = 0.86$ for SBTT), the fit was not precise, with substantial SEs in the estimated parameters and a low $R^2$ ($R^2 = 0.24$ for GET and $R^2 = 0.07$ for SBTT). The 95% confidence interval of the nonlinear regression line and the 95% prediction band were extremely wide.

Discussion

Results of the study reported here did not support the hypothesis that gastric emptying is slower in large- and giant-breed dogs. On the contrary, GETs may be shorter in giant-breed dogs than they are in dogs of smaller size and body weight. Because of the size of the WMC, we elected to include only dogs that weighed > 19 kg in this study, with the largest dog weighing 81.2 kg. Inconsistent results have been detected for evaluation of gastric emptying in dogs of various sizes. In 1 study, investigators found a significant positive linear correlation between body weight and gastric emptying rate (measured by use of the $^{13}$C-octanoic acid breath test) in 24 healthy adult dogs that weighed between 3.5
and 59.1 kg. A weak but significant positive correlation between body weight and 50% emptying was also reported in a second study conducted by use of barium-impregnated polyethylene spheres in 20 dogs with body weight between 13.3 and 37.0 kg. However, there was no significant association between body weight and 25% or 75% emptying in that study. Comparatively, in humans (body weight between 59 and 93 kg), heavy subjects have a slower emptying rate and hence a longer GET. In contrast, GET of radiopaque markers was measured in 24 dogs, and no effect of body size on GET was detected, regardless of age of the dogs. Also, in another study that included 55 dogs with body weight between 6 and 39 kg, no association was detected between the rate of gastric emptying and body surface area or body mass. Similarly, we did not detect a positive association between body weight and GET in dogs of the study reported here. On the contrary, the best fit of the data suggested a nonlinear inverse relationship. An inverse relationship between GET and body weight was reported in 1 study. In that study, investigators compared GET in growing Giant Schnauzers and Great Danes between the ages of 12 and 36 weeks by use of barium-impregnated polyethylene spheres and found that Great Danes had a shorter gastric transit time at all ages. However, the number of dogs of each breed was small, and the same laboratory group could not reproduce these results in a study of adult dogs of the same breeds.

Gastric emptying is a highly regulated process that is controlled by many physiologic, pharmacologic, and dietary factors. In the study reported here, several procedures were used to prevent undesirable interferences, including the fact that all test meals were of equal caloric content in relation to the body weight of the dogs. Moreover, although meal volume was not standardized, the caloric density of the various diets fed to the dogs was maintained within a narrow range. Finally, all test meals were administered in the morning. In addition, the entire monitoring period was when each dog was in its familiar home setting in an attempt to offset effects because age can affect gastric emptying in growing dogs. Moreover, most dogs (24/31 [77.4%]) enrolled in our study were neutered. However, only adult dogs were selected for our study population because age can affect gastric emptying in growing dogs.

After a meal has been broken up in the stomach of a dog, only particles ≤ 1 mm in diameter will empty into the proximal portion of the duodenum, whereas large indigestible particles remain in the stomach and are later moved into the duodenum by a burst of peristaltic contractions (phase III MMC) during the interdigestive period. Because of its size, the nondigestible WMC exited the stomach during the phase III MMC, which was after the digestible part of the solid meal had already passed into the duodenum. Therefore, the WMC measures the total GET, and other methods such as the 14C-octanoic breath test or scintigraphy measure the half-time of gastric emptying. Although GET measured by use of the WMC is consistent with the times obtained by use of scintigraphy in healthy dogs, it is possible that the use of different methods for measuring different variables could make it more arduous to reliably assess the relationship between body weight and GET. In the present study, it required between 405 and 897 minutes for the WMC to exit the stomach. Those values are in the same range as findings from a study in which total GET of a dry kibble test meal (evaluated by use of a contrast radiographic technique) ranged from 7.0 to 15.0 hours. In another study, radiography was performed in 5 dogs with a body weight between 25 and 30 kg that were fed a dry-fod meal; gastric emptying was completed between 14 and 16 hours after eating.

In the present study, SBTT was the fastest gastrointestinal transit time, which ranged from 96 to 224 minutes among dogs of various body weights. Although this may be surprising considering the length of the small intestine, it corresponds to the propagation speed of phase III MMCs through the small bowel. Similar to the finding for GET, a nonlinear inverse relationship between SBTT and body weight appeared to be the best fit for the data. To our knowledge, no other data on SBTT in dogs have been published.

Only a few reports exist on the evaluation of the relationship between body size and other gastrointestinal transit times in dogs. No association between body size and orocecal transit time was detected in 2 studies performed in 24 dogs by use of the sulfasalazine-sulfapyridine method and in another study performed by use of small radiopaque markers. In a study performed by use of colored plastic beads in 50 dogs, a positive correlation was detected between body size and mean TTT. Another study performed by the same laboratory group via the same method in 24 dogs confirmed this positive correlation between body size and mean TTT, as mean LBTT increased significantly with body size. These findings are in contrast with our results, which indicated that body weight and TTT as well as LBTT varied independently. In the present study, variability in LBTT (range, 427 to 2,573 minutes) did not allow the data to be fit to any model and likely affected the SLBTT and TTT similarly. Extreme variability in LBTT in dogs has been reported in another study. Defecation, the final step of large bowel emptying, is voluntarily regulated and depends on environmental factors (such as being allowed outdoors), which can vary greatly, especially in pet dogs kept in a home environment. Considerable intraindividual and interindividual variations in colonic transit have also been reported in humans.

The GET and SBTT data were best fit by use of the decay model. These 2 variables had less variation (GET ranged from 405 to 897 minutes and SBTT ranged from 96 to 224 minutes) than did the other transit times. Although the data fit was not precise, visual inspection of the data revealed an apparent negative relationship between increasing body weight and GET or SBTT.

Giant-breed dogs have a lower digestive capacity. This may be attributed to several factors, including the smaller relative weight of the gastrointestinal tract in Giant-breed dogs.
giant-breed dogs, abnormal gastrointestinal transit times, impaired absorption of nutrients in the small intestines, or decreased absorption of water in the colon. A low overall absorption of electrolytes in the large intestine and an increase in colonic fermentative activity were suggested to explain the poor quality of feces observed in large dogs. However, decreased gastric and small intestinal transit times, such as was suggested by our results, may also be involved by partially impairing efficiency of digestion and absorption. This may cause intestinal content that reaches the ileocolic valve to be richer in unabsorbed nutrients, thereby contributing to increased fermentation by colonic bacteria and poor fecal quality, which is likely to be complex in origin.

Results from the study reported here indicated that in this population of medium- to giant-breed dogs, GET and SBTT were not positively associated with body weight. On the contrary, GET and SBTT appeared to have a nonlinear inverse relationship with body weight. Variations in LBTT were erratic and independent of body weight.

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e. Purina ProPlan, adult dog large breed formula, Nestle-Purina PetCare Co, St Louis, Mo.
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g. SmartPill pH p wireless capsule system, SmartPill Corp, Buffalo, NY.
h. Doglegs, Reston, Va.
i. MotiliGI, SmartPill Corp, Buffalo, NY.
j. GraphPad Software Inc, San Diego, Calif.

References

30. Meyer H, Kienzle E, Zentek J. Body size and relative weight of giant-breed dogs, abnormal gastrointestinal transit times, impaired absorption of nutrients in the small intestines, or decreased absorption of water in the colon. A low overall absorption of electrolytes in the large intestine and an increase in colonic fermentative activity were suggested to explain the poor quality of feces observed in large dogs. However, decreased gastric and small intestinal transit times, such as was suggested by our results, may also be involved by partially impairing efficiency of digestion and absorption. This may cause intestinal content that reaches the ileocolic valve to be richer in unabsorbed nutrients, thereby contributing to increased fermentation by colonic bacteria and poor fecal quality, which is likely to be complex in origin. Results from the study reported here indicated that in this population of medium- to giant-breed dogs, GET and SBTT were not positively associated with body weight. On the contrary, GET and SBTT appeared to have a nonlinear inverse relationship with body weight. Variations in LBTT were erratic and independent of body weight.

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