Relationship between Electrolyte Apparent Absorption and Fecal Quality in Adult Dogs Differing in Body Size\textsuperscript{1,2}

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EXPANDED ABSTRACT

KEY WORDS: • dog size • electrolytes absorption • intestinal water absorption • fecal electrolytes • fecal quality

No other mammalian species presents such a wide diversity in body weight (BW)\textsuperscript{4} and size as the domestic dog. In view of this extreme variation, it is of interest to evaluate potential physiological consequences. Results of previous studies (1,2) indicate that large-breed dogs, such as Labrador Retrievers or Great Danes, have higher fecal water content and greater frequency of soft feces compared with small-breed dogs, independent of diet. Moreover, it was reported that colonic water absorption is a major determinant of fecal quality in dogs (3). From these observations it could be hypothesized that the poorer fecal quality in large dogs than in small dogs could be explained by a lower intestinal water-absorption capacity.

The diffusion of water from luminal content to form solid feces requires electrolyte absorption and, more specifically, sodium (4,5). In many studies a disruption of normal electrolyte transport is associated with a low water absorption in the small intestine (6) or the colon (5,7). Furthermore reduced electrolyte absorption is described as a primary mechanism of diarrhea (8), and in dogs (9).

The maintenance of the ionic gradient is closely dependent on the integrity of the intestinal mucosa. In this way, the overall apparent absorption of electrolytes could be related to the intestinal permeability. In fact, the intestinal epithelium usually retains, against their concentration gradient, the electrolytes absorbed by active route or by facilitated diffusion. In case of high intestinal permeability, electrolytes attracted by the concentration gradient return to the intestinal lumen where they accumulate (10), decreasing the osmotic gradient and water absorption. We recently reported (11) that Giant Schnauzers and Great Danes presented a greater permeability of the small intestine with a higher urinary lactulose:rhamnose ratio than Standard Schnauzers and Miniature Poodles.

The objectives of this study were: 1) to assess the absorption capacity of sodium and potassium in dogs of different sizes by measuring the apparent absorption of these electrolytes and their concentration in stools, 2) to correlate this overall net absorption of electrolytes with fecal osmolality and intestinal permeability previously measured in the same dogs, and 3) to study the relationship between these different variables and stool quality.

MATERIALS AND METHODS

Animals and diet

Twenty-four female adult dogs of four breeds, representative of the great diversity of weight and size in the canine species, were included in the study: six Miniature Poodles (MP) (3.3 ± 0.7 kg BW, 30.3 ± 2.0 cm height at the shoulder), six Standard Schnauzers (SS) (12.6 ± 0.9 kg, 43.9 ± 1.0 cm), six Giant Schnauzers (GS) (23.3 ± 1.3 kg, 58.5 ± 1.9 cm), and six Great Danes (GD) (46.3 ± 1.0 kg, 78.5 ± 0.5 cm). All dogs were given the same dry expanded diet\textsuperscript{5} containing 0.38% sodium and 0.70% potassium measured on dry matter (DM). Each dog received the amount of food necessary to cover its daily caloric needs (132 kcal/kg BW\textsuperscript{0.75}/d) and it was made sure that all food was ingested.

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\textsuperscript{4}Abbreviations used: BW, body weight; DM, dry matter; GD, great danes; GS, giant schnauzers; L/R, ratio of lactulose to rhamnose; MP, miniature poodles; SS, standard schnauzers.

\textsuperscript{5}Vet Size Maxi Junior (Royal Canin, Aimargues, France) containing 39.2% crude protein, 16.3% fat, and 7.3% crude fiber on a dry matter basis, with a metabolizable energy of 3900 kcal/kg.
Animals were housed at the National Veterinary School of Nantes in closed indoor/outdoor runs for the entire duration of the study. Clinical examinations, blood cell counts, and biochemistry were performed before the study to ensure that all animals were in good health. The experimental protocol adhered to European Union guidelines and was approved by the Animal Use and Care Advisory Committee of Nantes.

**Fecal electrolytes and fecal osmolality**

Fresh stools collected for each dog were homogenized and 20 g were diluted to 1:10 (wt:wt) with a solution containing distilled water and mercuric chloride (HgCl₂; 1 g/L) (preservative) (Merck S.A., Fontenay-sous-Bois, France), then centrifuged at 10,000 g for 15 min to collect the supernatant. Sodium and potassium were then measured by flame photometry (model PFP7, Jenway, Essex, UK) according to AFNOR standards (1981). The osmolality of the supernatant was measured using an osmometer (Osmette A, Precision System, Natick, MA).

**Fecal variables and electrolytes apparent absorption**

Fecal scoring was recorded daily during 1 wk for each dog. 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. From a representative sample of the 7-d fecal period, water content of stools was calculated by weighing before and after lyophilization, and apparent absorption of electrolytes was calculated using the formula:

\[
\text{Apparent absorption (\%)} = \frac{\text{electrolyte ingested (g)} - \text{electrolyte excreted (g)}}{\text{electrolyte ingested (g)}} \times 100
\]

**Statistical analysis**

All the results of this study are expressed as mean ± SD. The statistical analysis was made using StatView 5.0 software (SAS Institute, Cary, NC). An analysis of variance test (ANOVA) was used to test the influence of breed on fecal variables, apparent absorption of electrolytes, concentration of fecal electrolytes, fecal osmolality, and on the ratio of urinary lactulose:rahamose. When significant (F-test, \( P < 0.05 \)), the differences between mean values were assessed by the Fisher’s protected least significant difference test (PLSD). Linear regression analyses were analyzed to reveal any possible correlation between the animals’ weight and size on the one hand, and the different variables tested on the other hand. A P-value <0.05 was considered significant for all analyses.

**RESULTS**

**Effect of body size on fecal quality**

Significantly poorer fecal scores and higher fecal moisture were found in Giant Schnauzers and Great Danes than in Miniature Poodles and Standard Schnauzers (Table 1). We found a significant (\( P < 0.0001 \)) correlation between fecal water content and height at the shoulder (\( r = 0.88 \)) or body weight (\( r = 0.89 \)) as well as between fecal score and height at the shoulder (\( r = 0.85 \)) or body weight (\( r = 0.84 \)).

**Effect of body size on fecal electrolytes**

Fecal sodium and potassium content (g/kg DM) were significantly higher in Giant Schnauzers and Great Danes than in the two small breeds. There was no effect of body size on potassium fecal concentration (mmol/L of fecal water) but the Na:K concentrations ratio (mmol/L) was significantly higher in large than in small breeds (Table 1).

Positive correlations were observed between fecal electrolytes content and the dogs’ weight (\( r = 0.69 ; P < 0.0002 \) and \( r = 0.51 ; P < 0.013 \), respectively, for sodium and potassium) or size (\( r = 0.75 ; P < 0.0001 \) and \( r = 0.55 ; P < 0.006 \), respectively, for sodium and potassium).

**Effect of body size on electrolyte apparent absorption**

Apparent absorption of sodium and potassium were significantly lower in the Giant Schnauzers and Great Danes than in the Standard Schnauzers and Miniature Poodles (Table 1). There were high (\( P < 0.001 \)) negative correlations between electrolyte apparent absorption and the dogs’ weights (\( r = -0.74 \) and \( -0.64 \), respectively, for sodium and potassium) or size (\( r = -0.77 \) and \( -0.74 \), respectively, for sodium and potassium).

**Effect of body size on osmolality of stool**

The osmolality of stools of Great Danes and Giant Schnauzers was higher than for Standard Schnauzers and Miniature Poodles (Table 1). Moreover, we found high positive correlations between fecal osmolality and the dogs' weights or size (\( r = 0.85 \) and 0.90 respectively, \( P < 0.0001 \)).

**TABLE 1**

<table>
<thead>
<tr>
<th>Variables studied</th>
<th>Miniature Poodles</th>
<th>Standard Schnauzers</th>
<th>Giant Schnauzers</th>
<th>Great Danes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stool quality</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scores</td>
<td>2.4 ± 0.1(^a)</td>
<td>2.6 ± 0.1(^a)</td>
<td>2.9 ± 0.1(^b)</td>
<td>3.4 ± 0.4(^c)</td>
</tr>
<tr>
<td>Moisture</td>
<td>64.3 ± 2.0(^a)</td>
<td>69.7 ± 2.1(^b)</td>
<td>71.2 ± 2.0(^b)</td>
<td>74.5 ± 1.8(^c)</td>
</tr>
<tr>
<td>Fecal electrolyte content</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium (g/kg DM)</td>
<td>2.1 ± 0.7(^a)</td>
<td>3.2 ± 0.7(^a)</td>
<td>5.6 ± 1.7(^b)</td>
<td>6.1 ± 1.3(^c)</td>
</tr>
<tr>
<td>Potassium (g/kg DM)</td>
<td>34.9 ± 16(^a)</td>
<td>47.3 ± 9.8(^a)</td>
<td>100.4 ± 22(^b)</td>
<td>114.6 ± 7.4(^c)</td>
</tr>
<tr>
<td>Na/K ratio each in mmol/L</td>
<td>2.7 ± 0.5(^a)</td>
<td>2.9 ± 0.6(^ab)</td>
<td>3.6 ± 0.6(^b)</td>
<td>3.5 ± 0.5(^c)</td>
</tr>
<tr>
<td>Apparent digestibility</td>
<td>38.3 ± 7.8(^b)</td>
<td>27.3 ± 7.8(^b)</td>
<td>37.0 ± 5.1(^a)</td>
<td>31.1 ± 5.9(^ab)</td>
</tr>
<tr>
<td>Osmolarity (mOsm/L)</td>
<td>1.0 ± 0.5(^a)</td>
<td>1.8 ± 0.3(^a)</td>
<td>2.7 ± 0.6(^c)</td>
<td>3.8 ± 0.8(^b)</td>
</tr>
</tbody>
</table>

Values (mean ± sd) with different letters on the same line are significantly different at \( P < 0.05 \) (ANOVA and Fisher’s PLSD (\( n = 6 \) for each breed).
Correlation between the different variables studied and stool quality

Fecal quality was closely related to fecal sodium content ($r < 0.0001, r = 0.79$ and $0.78$, respectively, for fecal scores and moisture) and fecal osmolality ($r = 0.76$ and $P = 0.001$, $r = 0.82$ for fecal scores and moisture) whereas a lesser significant correlation was observed between stool quality and fecal potassium content ($r = 0.46$; $P = 0.03$ and $r = 0.40$; $P = 0.05$, respectively, for fecal scores and moisture). Moreover, fecal water content and stool scores were negatively correlated with apparent absorption of sodium or potassium (Table 2).

There were high correlations between urinary L:R and sodium fecal content and apparent absorption ($P > 0.76$ and $r = 0.47$, respectively). We found lower correlations of potassium content ($P = 0.02$, $r = 0.47$) and apparent absorption ($P = 0.002, r = 0.60$) with L:R ratio. Moreover, L:R ratio was highly correlated to fecal osmolality ($P < 0.0001, r = 0.73$).

DISCUSSION

Electrolyte absorption in the small and large intestine has generally been evaluated directly, in fistulated dogs, by calculating net flow through the mucosa after electrolyte perfusion proximally to the segment to be studied (12). A less-invasive alternative involves endoscopically placing a dialysis bag containing a known amount of electrolytes in the segment to be studied for a given amount of time (3). Furthermore, many studies have preferred indirect assessment of overall electrolyte absorption by measuring either their apparent absorption (2,13) or their concentration in stools (2,14). Although they provide no information on the rate of electrolyte absorption in the different segments of the digestive tract, these methods seem to give good indications of possible disruption of hydroelectrolytic exchanges in the small intestine and colon.

Concerning our study, the high negative correlations found between fecal content of sodium and potassium and their respective apparent absorption ($P < 0.0001, r = -0.78$ and $-0.71$, respectively) suggest that in itself measuring electrolytes in stools provides a good indication of overall net electrolyte absorption in the digestive tract.

Our results indicate a lower overall net absorption of electrolytes in large dogs compared to small dogs, as shown by the lower apparent absorption of sodium and potassium as well as higher fecal content of these electrolytes (g/kg DM) in large compared to small dogs. These results are in agreement with those reported by Zentek and Meyer (2), who showed poorer net absorption rate of these minerals and higher fecal content of sodium and, to a lesser degree, of potassium in Great Danes compared to Beagles. However, the lower significant differences in potassium fecal concentration (mmol/L) and the higher Na:K concentrations ratio found in large dogs indicate that it is the sodium that is mainly affected by body size.

These results are not the consequence of a larger amount of electrolytes ingested by large dogs, because Miniature Poodles ingested amounts of electrolytes that were either greater, according to their body weight (124 mg Na/kg BW or 248 mg K/kg BW) for MP and 68 mg Na/kg BW or 136 mg K/kg BW for GD), or similar to large dogs, according to their metabolic body weight. Finally, all dogs were given 174 ± 10 mg Na/kg BW and 348 ± 15 mg K/kg BW.

This lower apparent absorption of electrolytes in large dogs could be explained by several mechanisms, including differences in motility, mucosa state, or intestinal permeability. Changes in motility reduce the mixing of luminal content and the time available for electrolyte absorption, whereas differences in mucosa state alter the efficiency of absorption mechanisms like the Na+/H+ exchange or Na+/K+/ATPase pumps. Finally, increased intestinal permeability disrupts the ionic gradient and net balance of electrolytes absorption (10).

In a previous study (11), intestinal permeability was measured in the same 24 dogs by the dual-sugar test using the ratio of urinary lactulose:rhamnose. A significant effect of size on intestinal permeability was found, as indicated by the correlation between urinary L:R and size or body weight ($r = 0.77 ; P < 0.0001$; and $r = 0.78$; $P < 0.0001$, respectively). In adult dogs, the urinary L:R was twice as high in Great Danes as in Miniature Poodles (0.16 ± 0.04 for MP and 0.31 ± 0.08 for GD).

Water absorption is closely related to electrolyte absorption, more specifically sodium (4,5). Increased permeability could cause backflow of absorbed electrolytes into the lumen (11), which would decrease osmotic gradient, drawing back water from the bloodstream to the intestinal lumen by simple diffusion and increasing fecal water excretion. We found significant higher fecal osmolality in large dogs than in small dogs and significant relationships between osmolality and fecal quality. The higher intestinal permeability found in large dogs compared to small ones is consistent with the higher fecal osmolality, the lower net electrolyte absorption, and the poorer fecal quality observed in large dogs, and is supported by the high correlations between sodium parameters or urinary L:R and fecal scores or water content (Table 2).

We found high correlation between urinary L:R and sodium fecal content, sodium apparent absorption, and fecal osmolality but only a lower correlation between urinary L:R and potassium variables. Moreover, the significant difference in Na:K concentrations ratio between dogs’ sizes well suggests that intestinal permeability modifications would mainly affect the sodium and then water absorption.

In this study we found strong correlation between intestinal permeability and sodium apparent absorption. These data suggest that a lower apparent absorption of sodium could be the result of a higher intestinal permeability and explain the higher fecal moisture and the lower fecal scores observed in large compared to small breed dogs. More invasive studies would be necessary to investigate this hypothesis.

<table>
<thead>
<tr>
<th>TABLE 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Values of the coefficients of correlation ($r$) and significance ($P$) of correlations between the different variables studied and stool quality (scores and moisture)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables studied</th>
<th>Scores</th>
<th>Moisture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fecal sodium content (g/kg DM)</td>
<td>0.79 &lt;0.0001</td>
<td>0.78 &lt;0.0001</td>
</tr>
<tr>
<td>Fecal potassium content (g/kg DM)</td>
<td>0.46 0.03</td>
<td>0.40 0.05</td>
</tr>
<tr>
<td>Digestibility of sodium (%)</td>
<td>-0.77 &lt;0.0001</td>
<td>-0.70 0.0002</td>
</tr>
<tr>
<td>Digestibility of potassium (%)</td>
<td>-0.81 &lt;0.0019</td>
<td>-0.53 &lt;0.01</td>
</tr>
<tr>
<td>Osmolality (mOsm/L)</td>
<td>0.82 &lt;0.0001</td>
<td>0.82 &lt;0.0001</td>
</tr>
</tbody>
</table>

LITERATURE CITED