Evaluation of effects of dietary carbohydrate on formation of struvite crystals in urine and macromineral balance in clinically normal cats

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Objective—To evaluate effects of dietary carbohydrate on urine volume; struvite crystal formation; and calcium, phosphorus, and magnesium balance in clinically normal cats.

Animals—21 healthy adult cats (15 sexually intact males and 6 sexually intact females).

Procedure—Diets containing no carbohydrate source (control diet), control plus starch, or control plus fiber were given in a 3 X 3 Latin-square design. The diets were available ad libitum in study 1 (n = 12) and given under restrictions in study 2 (9) to equalize daily intakes of crude protein among the 3 groups. Formation of struvite crystals and balance of calcium, phosphorus, and magnesium were measured.

Results—Urine volume was lower in the starch group and fiber group in study 1, whereas no differences were detected among the groups in study 2. Urinary pH and struvite activity product were higher in the starch group in both studies, and the fiber group also had higher struvite activity product in study 2. In both studies, urinary concentrations of HCl-insoluble sediment were higher in the starch group and fiber group. In the fiber group, a net loss of body calcium, phosphorus, and magnesium was detected in study 2.

Conclusions and Clinical Relevance—Starch and fiber in diets potentially stimulate formation of struvite crystals. Hence, reducing dietary carbohydrate is desirable to prevent struvite urolith formation. In addition, a net loss of body calcium, phosphorus, and magnesium during feeding of the fiber diet suggests that dietary inclusion of insoluble fiber could increase macromineral requirements of cats. (*Am J Vet Res* 2004;65:138–142)

Cats require high amounts of specific amino acids, essential fatty acids, and vitamins and basically do not require carbohydrates.[1-3] Commercial dry cat foods generally contain 40% to 60% carbohydrates as a source of starch needed for the extrusion process.[4] The effects of dietary carbohydrate on the nutritional status of cats have not been fully evaluated.

Our previous studies[5,6] reveal that high protein intake increases urine volume and decreases urinary pH and the **struvite activity product** (**SAP**; $[Mg^{2+} \times NH_4^+ \times PO_4^{3-}]$). Because the SAP is positively related to formation of struvite crystals,[7] a decrease in SAP suggests that high protein intake not only prevents formation of struvite crystals but also promotes solubility of preformed struvite crystals. In addition, high protein intake also decreases HCl-insoluble urinary sediment, which contains possible organic matrices for struvite crystals.[6] Those results suggest that a high-protein diet is beneficial for prevention of struvite uroliths.[5,6] In those studies, however, the carbohydrate content of diets decreased as the protein content increased. Thus, it is possible that the preventive effect of a high-protein diet on struvite crystal formation may be partly attributable to the lower content of carbohydrate in those diets. To clarify these relationships is important for preparation of an optimal cat food as well as for our knowledge of cat nutrition.

The purpose of the study reported here was to examine the effects of dietary carbohydrate on struvite crystal formation in clinically normal cats. In addition, the effects of dietary carbohydrate on the use of macrominerals Ca, P, and Mg were also evaluated because high protein intake decreases Ca and P retention in growing cats.[5]

Materials and Methods

Cats—Twenty-one mixed-breed cats considered to be clinically normal on the basis of physical examination (hemograms, serum biochemical profiles, and urinalyses) were used for 2 studies. Different cats were used in the 2 studies. All cats were individually housed in metabolic cages continuously throughout each study and cared for according to the principles outlined in the Institute for Laboratory Animal Research Guide for the Care and Use of Laboratory Animals.[8] They were kept in a temperature-controlled room (24 ± 2°C) with artificial light provided from 6 AM to 6 PM daily. The cats' health was monitored every day by evaluation of appearance, appetite, and condition of feces.

Diets—Three dry diets were prepared with a twin-screw extruder. The control diet mainly consisted of meat meal, fish meal, and corn gluten meal and did not contain any carbohydrate source as a dietary ingredient. In the starch diet, corn was substituted for a part of the meat meal, fish meal, and corn gluten meal, and in the fiber diet, beet pulp, cellulose powder, and wheat flour were substituted (**Appendix 1**).

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Metabolizable energy, Ca content, and P content were made similar among the diets by adding appropriate amounts of tallow, $CaCO_3$, and $Ca(PO_4)_2$ to each diet. Crude protein content was higher in the control diet than in the other 2 diets with carbohydrate sources. The determined contents of nutrients were at or above the amounts recommended by the **Association of American Feed Control Officials (AAFCO)** for maintenance (**Appendix 2**).[9] Dietary base excess calculated according to Kienzle et al[10] was 199, 364, and 303 mmol/kg of dry matter for the control, starch, and fiber diets, respectively.

Study 1—To examine the effects of dietary carbohydrate on urine volume, struvite crystal formation, and use of Ca, P, and Mg, 12 adult cats (9 sexually intact males and 3 sexually intact females; mean body weight, 4.69 kg [range, 3.06 to 5.95 kg]) were used in a 3 × 3 Latin-square design for a 2-week period. The diets and water were available on an ad libitum basis throughout the study, and the diets were provided daily at 4 PM. Intakes of food and water were recorded daily. For the last 5 days of each 2-week period, pooled urine and feces and fresh urine were collected as described.[5,6,11]

Study 2—In study 2, struvite crystal formation, effects of carbohydrate intake on urine volume, and use of Ca, P, and Mg were examined at the same level of crude protein intake by use of 9 adult cats (6 sexually intact males and 3 sexually intact females; mean body weight, 3.81 kg [range, 2.58 to 4.90 kg]) in a 3 × 3 Latin-square design for a 2-week period. Experimental diets and sampling procedures were identical to those used in study 1. Daily intakes of crude protein were equalized among the 3 groups as follows. In a preliminary study, all cats were given free access to the fiber diet for the initial 5 days and access to the starch diet for the next 5 days. On the basis of mean daily intakes of the fiber diet and the starch diet, daily amounts of 3 experimental diets were determined to equalize the crude protein intake among the diets in each cat. Forty percent of the daily amount of the diet was given at 8 AM, and the remaining 60% of the diet was given at 4 PM. As a result, no food refusal was detected throughout the study. Water was available on an ad libitum basis.

Analyses—Chemical composition of the diets was determined by methods of the Association of Official Analytical Chemists.[12] Mineral contents of the diets (Na, K, Ca, P, Mg, and Cl), fecal minerals (Ca, P, and Mg), and concentrations of struvite constituents of urine were measured as described.[5] Briefly, the diets, air-dried feces, and urine (Mg, P, and total ammonia) were wet-washed, and mineral contents were measured; Ca and Mg were measured by use of atomic absorption spectrophotometry, Na and K by use of flame emission spectrophotometry, Cl by the Mohr method,[12] and P by use of the method of Gomori.[13] Urinary total **ammonia** (NH_4^+) concentration was determined by use of the Okuda and Fujii method.[14] For estimating SAP, Mg was assumed to be in ionic forms in urine. The NH_4^+ and PO_4^{3-} concentrations in the urine were estimated from the urinary pH, and concentrations of total ammonia and P in urine were determined as described.[5] For convenience, SAP is expressed as pSAP, the negative logarithm of SAP.[5-7,11] In contrast to SAP, pSAP is negatively related to struvite crystal formation.[7] Urinary concentrations of struvite crystals and sediment were measured as described.[6]

Statistical analyses—Data were analyzed by use of an ANOVA.[15,a] The model included diet, cat, and period. When the effect of diet was significant ($P < 0.05$), differences among the 3 groups (control, starch, and fiber) were evaluated by use of the Dunnett multiple-range test. Mean (± SEM) values are presented in tabular format, and results were considered significant at $P < 0.05$.

Results

All cats appeared to be healthy and did not develop any clinical abnormalities during either study. Changes in weight during each study period were minimal.

Study 1—Effects of dietary carbohydrate on daily intakes of food and water and urine volume under the ad libitum feeding condition were evaluated (**Table 1**). Daily food intake was not different among groups. As a result, daily intakes of nutrients were proportional to the dietary contents; daily intakes of crude protein, **nitrogen-free extract (NFE)**, and crude fiber were highest in the control, starch, and fiber groups, respectively. Compared with the control group, water intake was lower in the starch group and urine volume was lower in the starch group and fiber group.

Urinary pH, urinary concentrations of struvite constituents, pSAP, urinary struvite crystals, and urinary concentrations of sediment were examined (**Table 2**). In the starch group, urinary pH was higher in the control group. As a result, the pSAP was lower, which indicated increased possibility of struvite crystal formation. In fact, urinary concentrations of struvite crystals were significantly higher in this group, compared with the control group. In addition, urinary concentrations of HCl-insoluble sediment were higher in the starch group. In contrast to the starch group, urinary pH, pSAP, and urinary concentrations of struvite crystals were not significantly different between the control

Table 1—Mean ± SEM values of daily food and water intakes and urine volume in 12 cats fed (ad libitum) a dry diet without any carbohydrate source (control) or the same diet containing ingredients rich in starch or fiber

Variable	Control	Starch	Fiber
Food intake (g/kg/d)	13.8 ± 1.1	14.8 ± 0.8	15.4 ± 0.5
Crude protein	9.36 ± 0.72[a]	7.25 ± 0.38[b]	7.52 ± 0.26[b]
Acid ether extract	0.97 ± 0.08[c]	1.24 ± 0.06[b]	2.02 ± 0.07[a]
Crude fiber	0.05 ± 0.003[c]	0.11 ± 0.01[b]	0.49 ± 0.02[a]
Nitrogen-free extract	1.78 ± 0.14[c]	4.43 ± 0.23[a]	3.59 ± 0.12[b]
Water intake (ml/kg/d)	45.6 ± 2.8[a]	36.7 ± 2.6[b]	42.0 ± 2.0[a]
Urine volume (ml/kg/d)	27.2 ± 2.3[a]	20.4 ± 1.5[b]	18.9 ± 1.2[b]

[a,b,c]Within rows, values with different superscript letters are significantly ($P < 0.05$) different.

Table 2—Mean ± SEM values of urinary variables in 12 cats fed a dry diet (ad libitum) without any carbohydrate source (control) or the same diet containing dietary ingredients rich in starch or fiber

Variable	Control	Starch	Fiber
pH	6.95 ± 0.08[b]	7.24 ± 0.10[a]	7.08 ± 0.09[a,b]
Magnesium (mM)	6.03 ± 0.90	6.41 ± 0.73	6.20 ± 0.93
Ammonium ion (mM)	109.9 ± 4.9	104.8 ± 5.8	110.6 ± 4.3
Total phosphorus (mM)	38.3 ± 2.8	37.5 ± 2.8	39.0 ± 3.6
Phosphoric acid ion ($\times 10^{-3}$ mM)	0.92 ± 0.26	2.56 ± 1.01	1.46 ± 0.50
pSAP	9.45 ± 0.11[a]	9.04 ± 0.16[b]	9.29 ± 0.12[a]
Struvite crystals (No./µL of urine)	21.8 ± 14.1[b]	69.0 ± 25.2[a]	36.1 ± 17.1[b]
Sediment (mg/mL of urine)			
HCl-soluble	9.12 ± 1.23	12.04 ± 1.041	2.50 ± 2.26
HCl-insoluble	1.33 ± 0.20[b]	2.01 ± 0.16[a]	1.92 ± 0.21[a]
Total	**10.44 ± 1.39***	**14.05 ± 1.04**	**14.42 ± 2.42**

*Total does not equal 100% because of rounding of values. pSAP = Negative logarithm of the struvite activity product.
See Table 1 for remainder of key.

Table 3—Mean ± SEM values of mineral balance in 12 cats fed (ad libitum) a dry diet without any carbohydrate source (control) or the same diet containing dietary ingredients rich in starch or fiber

	Calcium balance			Phosphorus balance			Magnesium balance		
Variable	**Control**	**Starch**	**Fiber**	**Control**	**Starch**	**Fiber**	**Control**	**Starch**	**Fiber**
Intake (mg/kg/d)	155.4 ± 12.0[c]	187.8 ± 9.7[b]	213.7 ± 7.4[a]	130.6 ± 10.1[b]	149.3 ± 7.8[a,b]	156.9 ± 5.4[a]	8.5 ± 0.8[c]	12.2 ± 0.6[a]	10.7 ± 0.4[b]
Feces (mg/kg/d)	133.6 ± 10.1[b]	122.2 ± 12.0[b]	271.3 ± 25.3[a]	82.0 ± 9.4	81.2 ± 8.0	95.6 ± 8.6	7.4 ± 0.9[b]	7.2 ± 0.8[b]	14.3 ± 1.0[a]
Urine (mg/kg/d)	2.56 ± 0.96	1.52 ± 0.61	1.62 ± 0.55	31.6 ± 2.9[a]	22.7 ± 1.3[b]	22.4 ± 2.0[b]	4.2 ± 0.9[a]	3.2 ± 0.6[b]	2.8 ± 0.5[b]
Retained (mg/kg/d)	19.2 ± 8.1[b]	64.1 ± 11.1[a]	–59.2 ± 28.2[c]	17.0 ± 9.1[b]	45.5 ± 9.4[a]	38.9 ± 9.8[a]	–3.0 ± 1.2[b]	0.3 ± 0.8[a]	–5.0 ± 1.1[c]
Feces (% of intake)	90.0 ± 7.2[b]	65.0 ± 5.9[c]	129.8 ± 13.4[a]	64.9 ± 6.7	55.0 ± 5.7	61.7 ± 5.7	94.9 ± 13.2[b]	65.8 ± 5.9[c]	118.9 ± 8.1[a]
Urine (% of intake)	1.52 ± 0.54[a]	0.75 ± 0.27[b]	0.74 ± 0.25[b]	24.8 ± 1.7[a]	15.5 ± 0.8[b]	14.1 ± 1.0[b]	49.3 ± 8.4[a]	30.3 ± 5.6[b]	23.4 ± 4.5[b]
Retained (% of intake)	8.5 ± 7.0[b]	34.3 ± 5.9[a]	–30.5 ± 13.4[c]	10.3 ± 7.9	29.6 ± 5.8	24.2 ± 6.0	–44.2 ± 18.5[b]	3.9 ± 7.7[a]	–42.3 ± 9.3[b]

See Table 1 for key.

group and fiber group. Urinary concentrations of HCl-insoluble sediment were also higher in the fiber group, compared with the control group.

Effects of dietary carbohydrate on the balance of Ca, P, and Mg were tabulated (**Table 3**). It was intended that the Ca and P contents would be identical among the diets by adding Ca and P salts (Appendix 1), although the contents were slightly different (Appendix 2). Small differences of dietary mineral contents and daily food intake among the groups resulted in significant differences for Ca, P, and Mg intakes. Therefore, results were expressed not only as milligrams per kilogram of body weight per day but also as percentage of intake. The major excretion route of Ca was via feces. Compared with the control group, the percentage of fecal Ca, compared with Ca intake, was lower in the starch group and higher in the fiber group; this led to highest and lowest Ca retention in the starch group and fiber group, respectively. Compared with the control group, fecal excretion of Mg was also lower in the starch group and higher in the fiber group. Urinary excretion of Mg was lower in the starch group and the fiber group. As a result, Mg retention was highest in the starch group. Although dietary Mg contents met the AAFCO nutrient requirements for maintenance of adult cats,[9] Mg retention in the control group and fiber group had negative values. Fecal excretion of P was comparable in all the groups. Because urinary excretion of P was lower in the starch group and fiber group than in the control group, P retention was higher in these groups.

Study 2—Effects of dietary carbohydrate on daily intakes of food and water and urine volume were evaluated for similar amounts of crude protein intake under the restricted feeding conditions (**Table 4**). Crude protein intake was comparable among the groups, and compared with the control group, intakes of NFE and crude fiber were higher in the starch group and fiber group, respectively. Unlike study 1, water intake and urine volume were not different among the groups.

Urinary pH, urinary concentrations of struvite constituents, pSAP, urinary struvite crystals, and urinary concentrations of sediment were examined (**Table 5**). Consistent with study 1, urinary pH was higher in the starch group than in the control group. Urinary Mg^{2+} concentration was also higher in the starch group than in the control group, resulting in lower pSAP. Compared with the control group, urinary concentration of Mg^{2+} was higher in the fiber group, leading to lower pSAP. Similar to study 1, urinary concentration of the HCl-insoluble sediment was also higher in both the starch group and fiber group, compared with the control group.

Effects of dietary carbohydrate on the balance of Ca, P, and Mg were evaluated (**Table 6**). When mineral balance was expressed as a percentage of the intake to eliminate differences in mineral intakes among the groups, fecal excretion of Ca, P, and Mg was higher in the fiber group than in the control group, leading to the lower and negative retention of these macrominerals. Unlike study 1, no significant differences were detected in the retention of Ca, P, and Mg between the control group and starch group.

Table 4—Mean ± SEM values of daily food and water intakes and urine volume in 9 cats fed a dry diet without any carbohydrate source (control) or the same diet containing dietary ingredients rich in starch or fiber under restricted feeding conditions

Variable	Control	Starch	Fiber
Food intake (g/kg/d)	10.3 ± 1.2[b]	12.6 ± 0.9[a]	12.7 ± 0.7[a]
Crude protein	6.99 ± 0.79	6.18 ± 0.46	6.19 ± 0.34
Acid ether extract	0.73 ± 0.08[c]	1.06 ± 0.12[b]	1.67 ± 0.06[a]
Crude fiber	0.03 ± 0.004[c]	0.10 ± 0.03[b]	0.40 ± 0.01[a]
Nitrogen-free extract	1.33 ± 0.15[c]	3.78 ± 0.22[a]	2.95 ± 0.21[b]
Water intake (mL/kg/d)	30.1 ± 3.5	28.0 ± 2.5	31.1 ± 2.4
Urine volume (mL/kg/d)	20.1 ± 2.3	17.0 ± 1.2	17.2 ± 0.9

See Table 1 for key.

Table 5—Mean ± SEM values of urinary variables in 9 cats fed a dry diet without any carbohydrate source (control) or the same diet containing dietary ingredients rich in starch or fiber under restricted feeding conditions

Variable	Control	Starch	Fiber
pH	7.06 ± 0.10[b]	7.35 ± 0.14[a]	7.18 ± 0.10[a,b]
Magnesium (mM)	2.75 ± 0.50[b]	3.96 ± 0.68[a]	4.37 ± 0.52[a]
Ammonium ion (mM)	180.3 ± 12.4	168.8 ± 19.7	201.0 ± 35.9
Total phosphorous (mM)	34.3 ± 4.3[b]	32.7 ± 4.1[b]	41.3 ± 3.5[a]
Phosphoric acid ion ($\times 10^{-3}$mM)	1.00 ± 0.28	2.52 ± 1.08	1.67 ± 0.30
pSAP	9.48 ± 0.13[a]	9.05 ± 0.15[b]	8.99 ± 0.13[b]
Struvite crystals (No./µL of urine)	18.0 ± 8.5	39.1 ± 15.1	32.5 ± 8.3
Sediment (mg/mL of urine)			
HCl-soluble	2.27 ± 0.31[b]	2.87 ± 0.30[a,b]	3.20 ± 0.34[a]
HCl-insoluble	0.45 ± 0.05[b]	0.67 ± 0.06[a]	0.62 ± 0.08[a]
Total	**2.72 ± 0.35[b]**	**3.54 ± 0.32[a]**	**3.82 ± 0.40[a]**

See Table 1 for key.

Table 6—Mean ± SEM values of mineral balance in 9 cats fed a dry diet without any carbohydrate source (control) or the same diet containing dietary ingredients rich in starch or fiber under restricted feeding condition

	Calcium balance			Phosphorus balance			Magnesium balance		
Variable	**Control**	**Starch**	**Fiber**	**Control**	**Starch**	**Fiber**	**Control**	**Starch**	**Fiber**
Intake (mg/kg/d)	150.2 ± 17.0^{b}	208.2 ± 11.4^{a}	194.7 ± 14.4^{a}	92.9 ± 10.5^{b}	114.4 ± 6.3^{a}	113.7 ± 8.4^{a}	7.7 ± 0.9^{c}	12.3 ± 0.7^{a}	10.9 ± 0.8^{b}
Feces (mg/kg/d)	123.0 ± 11.3^{b}	194.1 ± 16.8^{a}	203.4 ± 13.6^{a}	66.4 ± 6.8^{b}	100.7 ± 9.6^{a}	102.9 ± 8.3^{a}	5.8 ± 0.7^{c}	9.4 ± 1.0^{b}	12.5 ± 0.9^{a}
Urine (mg/kg/d)	0.62 ± 0.18	0.57 ± 0.12	0.40 ± 0.12	20.2 ± 2.6^{a}	16.7 ± 1.9^{b}	21.3 ± 1.3^{a}	1.2 ± 0.1^{b}	1.6 ± 0.3^{a}	1.7 ± 0.2^{a}
Retained (mg/kg/d)	26.5 ± 8.0	13.6 ± 14.1	-9.0 ± 6.2	6.2 ± 3.9^{a}	$-3.0 \pm 7.6^{a,b}$	-10.5 ± 4.0^{b}	0.7 ± 0.5^{a}	1.3 ± 1.0^{a}	-3.4 ± 0.4^{b}
Feces (% of intake)	83.6 ± 3.6^{b}	$93.8 \pm 7.0^{a,b}$	105.6 ± 4.3^{a}	72.5 ± 3.0^{b}	88.5 ± 7.3^{a}	91.0 ± 4.1^{a}	76.1 ± 5.5^{b}	77.2 ± 7.4^{b}	116.0 ± 4.2^{a}
Urine (% of intake)	0.42 ± 0.12	0.26 ± 0.05	0.20 ± 0.07	22.0 ± 1.6^{a}	14.9 ± 1.7^{c}	19.2 ± 1.3^{b}	16.6 ± 2.4^{a}	13.2 ± 2.2^{b}	16.6 ± 1.8^{a}
Retained (% of intake)	16.0 ± 3.6^{a}	5.9 ± 7.0^{a}	-5.8 ± 4.3^{b}	5.4 ± 3.9^{a}	$-3.4 \pm 7.0^{a,b}$	-10.2 ± 4.4^{b}	7.3 ± 6.7^{a}	9.6 ± 7.8^{a}	-32.6 ± 5.2^{b}

See Table 1 for key.

Discussion

Many factors affect crystallization of struvite.[16] One of the factors is urine volume; increasing urine volume causes dilution and accelerated excretion of struvite constituents, which are beneficial for the prevention of struvite crystallization. In study 1, urine volume was lower in the starch group and fiber group. However, lower urine volume of the higher carbohydrate groups did not result from increased intake of carbohydrate but from decreased intake of protein because urine volume was comparable among the groups in study 2. Protein-induced increase in urine volume, which is attributable to urea diuresis,[17] is well-known in cats,[5] rats,[18,19] and sheep.[20] In fact, urine volume is positively related with daily nitrogen intake in adult cats.[5]

Dietary starch caused an increase in urinary pH. Both dietary starch and dietary fiber resulted in an increase in urinary concentration of Mg^{2+} and HCl-insoluble sediment, which possibly contains organic matrices for struvite crystals.[6] These changes led to a significant decrease in pSAP. Our results suggest that dietary carbohydrate potentially has a stimulating effect on the formation of struvite crystals in clinically normal cats and that reducing dietary carbohydrate is desirable to prevent struvite urolith formation.

The increase in urinary pH in the starch group was related to the dietary base excess, which was especially greater in the starch diet. A positive relationship between dietary base excess and urinary pH in cats has been reported.[10,21,22] In humans, metabolic fecal nitrogen is known to increase with increasing amounts of dietary fiber,[23,24] leading to a deterioration of nitrogen balance. In addition to the lower protein content of the fiber diet, increased metabolic fecal nitrogen may lead to an insufficient supply of arginine, a rate-limiting constituent of the urea cycle that disposes of ammonia.

The fiber diet also caused retention of Ca, P, and Mg. In fact, when dietary intakes of crude protein were adjusted to be equal among the groups in study 2, retention of Ca, P, and Mg in the fiber group was negative, indicating a net loss of body minerals. Therefore, it is possible that mineral requirements increased in cats fed the high-fiber diet. Our previous study[5] revealed that feeding a high-protein diet also resulted in lower retention of minerals in growing cats. Consistent with the previous results, in study 1, in which intakes of crude protein were higher in the control group than in the starch group, the percentage retention of Ca and Mg relative to intake was lower in the control group than in the starch group, suggesting an increase in mineral requirements of cats fed the high-protein diet.

A high-fiber diet is often given to obese cats for reducing body weight. Because feeding a high-fiber diet increases fecal excretion of metabolic nitrogen, a diet with high fiber and protein content is preferable.[25] However, when the weight-reducing diet containing both high protein and fiber is prepared, it would be especially important to pay attention to mineral contents in the diet, in view of the effects of a high-fiber, high-protein diet on mineral retention.

[a]PROC GLM, SAS Institute Inc, Cary, NC.

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Appendix 1

Dietary ingredients of 3 dry diets (control [no carbohydrate], control plus starch, and control plus fiber) used to evaluate effects of dietary carbohydrate on formation of struvite crystals and use of macrominerals in clinically normal cats

	Diet		
Ingredients (g/kg of diet)*	**Control**	**Starch**	**Fiber**
Meat meal	420	250	250
Fish meal	90	80	80
Corn gluten meal	420	290	290
Corn	0	270	0
Wheat flour	0	0	100
Beet pulp	0	0	102
Cellulose powder	0	0	50
Beef tallow	20	50	70
Taurine	1	1	1
Vitamins and minerals†	20	20	20
NaCl	0	1	1
$Ca(PO_4)_2$	0	8	10
$CaCO_3$	10	11	7
Flavor‡	15	15	15
Cr_2O_3	4	4	4

*Determined on an as-fed basis. †One kilogram of the vitamin and mineral mixture contained 22,500 U of vitamin A, 35 g of vitamin E, 2.2 g of vitamin B_1, 2.3 g of vitamin B_2, 1.6 g of vitamin B_6, 8.5 mg of vitamin B_{12}, 20 g of nicotinic acid, 5 g of pantothenic acid, 22 mg of biotin, 185 g of chlorine, 10 g of inositol, 450 mg of folic acid, 600 mg of manganese, 6.5 g of iron, 33 mg of cobalt, 420 mg of copper, 500 mg of iodine, and 500 mg of taurine. ‡Spray-dried fish extract.

Appendix 2

Composition of 3 dry diets (control [no carbohydrate], control plus starch, and control plus fiber) used to evaluate effects of dietary carbohydrate on formation of struvite crystals and use of macrominerals in clinically normal cats

	Diet		
Component	**Control**	**Starch**	**Fiber**
Metabolizable energy (kcal/100 g)	374	371	366
Crude protein (% of dry matter)	71.9	52.1	51.6
Acid ether extract (% of dry matter)	7.5	8.9	13.9
Crude fiber (% of dry matter)	0.4	0.8	3.3
Nitrogen-free extract (% of dry matter)	13.6	31.8	24.6
Sodium (% of dry matter)	0.36	0.38	0.38
Potassium (% of dry matter)	0.23	0.24	0.21
Calcium (% of dry matter)	1.54	1.74	1.63
Phosphorus (% of dry matter)	0.96	0.96	0.95
Magnesium (% of dry matter)	0.08	0.10	0.09
Chloride (% of dry matter)	0.48	0.44	0.43
Methionine (% of dry matter)	1.43	1.04	1.02
Base excess (mmol/kg of dry matter)*	199	364	303

*Base excess was calculated as 2[Ca] + 2[Mg] + [Na] + [K] – 2[P] – 2[methionine] – [Cl].