# The Prediction of Urine pH Using Dietary Cations and Anions in Dogs Fed Dry and Wet Foods

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## ABSTRACT

The objective of the study was to predict urine pH using the nutrient components of canine foods. Ninety-nine foods (66 dry foods and 33 can foods) were fed to groups of 10 adult (mean ± SD = 4.7 ± 2.4 years of age) dogs in order to determine the urine pH of dogs fed each food. The food was fed for a period of 7 days and pH was determined on freshly voided urine on Days 5 through 7 of the test. Through stepwise regression it was determined which cations, anions, and sulfur-containing amino acids were important to predict urine pH. Three models were developed for urine pH prediction, including: 1) wet and dry foods, 2) wet-only foods, and 3) dry-only foods. The results of this study suggested that urine pH of adult dogs can be predicted from the nutrient components of the food, thus reducing the number of animal studies in order to optimize urine pH (for struvite and/or oxalate prevention) for specific products. Separate equations must be used for dry and wet foods to maintain accuracy.

## INTRODUCTION

Urolithiasis is a common cause of urinary tract disease in companion animals.[1,2] Of the uroliths identified, struvite and calcium oxalate uroliths have been studied extensively in dogs.[3] The research investigating the formation of these stone types has found a direct link with the type of foods and nutrients consumed.[2,4,5] Successful management of struvite in dogs includes lowering urine pH and restricting the food protein, phosphorus, and magnesium content.[2] Though this may be an effective strategy in struvite prevention, this approach would likely cause the formation of calcium oxalate stones.

Recent epidemiological studies[4,5] have linked increased levels of dietary protein, calcium, phosphorus, magnesium, sodium, potassium, chloride, or moisture with decreased risk of calcium oxalate formation in dogs fed wet or dry foods. In addition, it was speculated that reducing the amount of carbohydrate in wet foods may lower the risk of calcium oxalate formation.[4]

Even though the data from recent epidemiological studies may be anecdotal, it was evident that canine stone formation is linked with nutrition. Other predisposing factors include urine alkalinity and acidity, which aids or prevents in the formation of mineral precipitates and bacterial infection.[2] Thus, knowledge of how to control and/or manipulate urine pH through nutrition would be an advantageous tool for anyone trying to treat or prevent stone formation.

Recently, Yamka et al[6] investigated the effects of total dietary cations and anions on feline urine pH. Their study demonstrated

**Table 1.** Analyzed Nutrients and Observed Urine pH of the 66 Dry Foods Used in Canine Urine pH Studies.

| Nutrient, 100% Dry Matter Basis | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| Sodium | 0.069 | 1.386 | 0.300 | 0.167 |
| Potassium | 0.500 | 1.260 | 0.785 | 0.159 |
| Chloride | 0.205 | 3.016 | 0.685 | 0.383 |
| Sulfur | 0.087 | 1.071 | 0.363 | 0.180 |
| Calcium | 0.334 | 1.602 | 0.851 | 0.254 |
| Magnesium | 0.043 | 0.195 | 0.111 | 0.029 |
| Phosphorus | 0.205 | 1.273 | 0.662 | 0.192 |
| Methionine | 0.280 | 2.207 | 0.538 | 0.294 |
| Cystine | 0.183 | 0.509 | 0.301 | 0.059 |
| Observed urine pH | 5.917 | 8.311 | 7.251 | 0.455 |

SD = standard deviation.

**Table 2.** Analyzed Nutrients and Observed Urine pH of the 33 Wet Foods Used in Canine Urine pH Studies.

| Nutrient, 100% Dry Matter Basis | Minimum | Maximum | Average | SD |
|---|---|---|---|---|
| Sodium | 0.106 | 1.140 | 0.358 | 0.247 |
| Potassium | 0.484 | 1.182 | 0.767 | 0.152 |
| Chloride | 0.247 | 2.039 | 0.771 | 0.409 |
| Sulfur | 0.137 | 0.605 | 0.306 | 0.094 |
| Calcium | 0.350 | 1.625 | 0.811 | 0.317 |
| Magnesium | 0.017 | 1.182 | 0.125 | 0.193 |
| Phosphorus | 0.138 | 1.194 | 0.610 | 0.267 |
| Methionine | 0.299 | 1.123 | 0.491 | 0.165 |
| Cystine | 0.081 | 0.346 | 0.238 | 0.060 |
| Observed urine pH | 6.318 | 7.820 | 7.087 | 0.386 |

SD = standard deviation.

that urine pH of adult cats can be predicted accurately from the nutrient components of the food. The nutrients used to derive their predictive equations for feline urine pH were calcium, sodium, magnesium, potassium, sulfur, phosphorus, chloride, methionine, and cystine. To date, no published studies have investigated the effects of total dietary cations and anions, including sulfur, in relation to canine urine pH. It is hypothesized that the same dietary cations and anions can lead the prediction of urine pH of dogs.

## MATERIALS AND METHODS

### Animals and Foods

Forty adult dogs were used (mean ± SD = 4.7 ± 2.4 years of age) to determine the effect of nutrition on urine ph. The dogs were cared for in accordance with Institutional Animal Care and Use Committee protocols. The dogs' primary living space was cleaned twice daily. Throughout the duration of the experiment, dogs were given opportunities for exercise and provided human interaction, which included but was not limited to play (toys), grooming, and other human-dog interactions (ie, petting). Water was available ad libitum throughout the entire experiment. The range of nutrients for all dry (66) and wet (33) foods are presented in Tables 1 and 2. Each food was formulated in accordance with the Association of American Feed Control Officials[7] nutrient guide for dogs. Each food was fed to a group of 10 dogs to maintain body weight. Excess food was removed daily and orts were weighed and recorded. Food samples were collected for nutrient content analysis.

### Sampling and Analyses

Freshly voided urine samples were collected twice per day on Days 5, 6, and 7 and were measured via a pH meter (Fisher Scientific Accumet® AR 15, Vernon Hills, Illinois). All feed samples were analyzed for moisture (method 930.15), calcium (method 968.08), sodium (method 968.08), potassium (method 968.08), magnesium (method 968.08), chloride (method 969.10), sulfur (method 923.01), phosphorus (method 965.17), methionine, and cystine (method 994.12) according to the Association of Official Analytical Chemists.[8]

**Statistics**

Data were analyzed using the General Linear Models procedure of SAS[9] in order to determine the means, standard deviation, minimum, and maximum for observed nutrients across foods. Data was then analyzed to predict urine pH by using the Regression procedure of SAS.[9] Regression analysis was done to determine if calcium, sodium, potassium, magnesium, chloride, sulfur, phosphorus, methionine, and/or cystine contributed to the prediction of urine pH.

## RESULTS

Stepwise regression was used to determine which cations and anions were of important for predicting urine pH. The dry and wet model included sodium, potassium, chloride, sulfur, phosphorus and cystine (Table 3). This analysis resulted in the following prediction equation for both wet and dry foods:

$$\text{Urine pH} = 7.30 + (0.54 \times \text{sodium}) + (0.63 \times \text{potassium}) - (0.53 \times \text{chloride}) - (1.67 \times \text{sulfur}) - (0.61 \times \text{phosphorus}) + (2.07 \times \text{cystine})$$

The new model accounted for 14% variation in individual (n = 990) observed urine pH and 28% of the variation observed in average (n = 99) urine pH in the dogs fed 99 foods (Table 3 and Figure 1).

To determine if separating the food types (dry only vs wet only) would result in greater accuracy in urine pH prediction, 2 more models were developed (dry only and wet only). The wet model included sodium, potassium, chloride, sulfur, phosphorus, methionine, and cystine (Table 3). This analysis resulted in the following prediction equation for wet foods:

$$\text{Urine pH} = 6.97 + (1.37 \times \text{sodium}) + (1.24 \times \text{potassium}) - (0.98 \times \text{chloride}) - (3.19 \times \text{sulfur}) - (0.58 \times \text{phosphorus}) + (1.06 \times \text{methionine}) + (1.03 \times \text{cystine})$$

The new model accounted for 24% variation in individual (n = 330) observed urine pH and 51% of the variation observed in average (n = 33) urine pH in the dogs fed 33 foods (Table 4 and Figure 2).

The dry model included sulfur, phosphorus, and methionine (Table 5). This analysis resulted in the following prediction equation for dry foods:

$$\text{Urine pH (dry foods)} = 8.09 - (1.15 \times \text{sulfur}) - (0.50 \times \text{phosphorus}) - (0.16 \times \text{methionine})$$

The new model accounted for 16% variation in individual (n = 660) observed urine pH and 33% of the variation observed in average (n = 66) urine pH in the dogs fed 66 dry foods (Table 5 and Figure 3).

## DISCUSSION

Urolithiasis is a common cause of urinary tract disease in companion animals.[1,2] Management and prevention of urolith formation has been linked with diet and urine pH in both dogs and cats.[10] Similar to cats, dogs are prone to the formation of the same types of uroliths, including both struvite and calcium oxalate.[2,4,5] Unlike the cat, struvite uroliths are not typically produced in a sterile environment in the dog.[2,3] Researchers have linked gender, in particular females, in having an increased risk for this type of urolith formation.[3]

Typically, struvite urolithiasis in dogs results from urinary tract infection by urea-splitting bacteria to form urea and carbon dioxide.[2,11] The resulting ammonia is later converted to ammonium resulting in an increase in urine pH.[11] When urine pH exceeds 6.8, the struvite becomes less soluble and precipitates to form a stone. The degree to which urine pH becomes more alkaline is dependent on the amount of urea present in the urine. The amount of urea present in the urine is directly related to protein intake.[10]

Because struvite typically results from bacterial infections, antibiotics are commonly prescribed to dogs having struvite stones. In addition to antibiotics, urine pH and nutrition play a vital role in the treatment and prevention of future struvite urolith formation. Nutrition is typically called into play to manipulate urine pH so stones become more soluble and are less likely to

**Table 3.** Urine pH Prediction Models Determined by Stepwise Regression for Individual Dogs (n = 990) Fed 99 Dry and Wet Foods Using the Nutrient Components of the Food (% dry matter basis).

| Model | Sodium | Potassium | Chloride | Sulfur | Calcium | Magnesium | Phosphorus | Methionine | Cystine | Intercept | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | — | — | -1.18 ± 0.12 | — | — | — | — | — | 7.60 ± 0.05 | 0.09 |
| 2 | — | — | -0.25 ± 0.05 | -1.25 ± 0.12 | — | — | — | — | — | 7.81 ± 0.06 | 0.11 |
| 3 | — | — | -0.26 ± 0.05 | -1.40 ± 0.13 | — | — | — | — | 0.92 ± 0.31 | 7.60 ± 0.09 | 0.12 |
| 4 | — | — | -0.23 ± 0.05 | -1.35 ± 0.13 | -0.28 ± 0.08 | — | — | — | 1.42 ± 0.34 | 7.66 ± 0.09 | 0.12 |
| 5 | — | 0.35 ± 0.13 | -0.25 ± 0.05 | -1.40 ± 0.13 | -0.32 ± 0.08 | — | — | — | 1.46 ± 0.34 | 7.45 ± 0.12 | 0.14 |
| 6 | — | 0.51 ± 0.15 | -0.28 ± 0.05 | -1.51 ± 0.14 | -0.05 ± 0.15 | — | -0.48 ± 0.23 | — | 1.85 ± 0.38 | 7.35 ± 0.13 | 0.14 |
| 7 | — | 0.53 0.14 | -0.28 ± 0.05 | -1.53 ± 0.13 | — | — | -0.54 ± 0.12 | — | 1.88 ± 0.37 | 7.33 ± 0.12 | 0.14 |
| 8 | 0.54 ± 0.21 | 0.63 ± 0.15 | -0.53 ± 0.11 | -1.67 ± 0.14 | — | — | -0.61 ± 0.12 | — | 2.07 ± 0.38 | 7.30 ± 0.12 | 0.14 |

**Table 4.** Urine pH Prediction Models Determined by Stepwise Regression for Individual Dogs (n = 330) Fed 33 Wet Foods Using the Nutrient Components of the Food (% dry matter basis).

| Model | Sodium | Potassium | Chloride | Sulfur | Calcium | Magnesium | Phosphorus | Methionine | Cystine | Intercept | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | — | -0.46 ± 0.07 | — | — | — | — | — | — | 7.43 ± 0.06 | 0.11 |
| 2 | 0.46 ± 0.24 | — | -0.71 ± 0.15 | — | — | — | — | — | — | 7.45 ± 0.06 | 0.12 |
| 3 | 1.00 ± 0.29 | — | -0.93 ± 0.16 | -1.21 ± 0.37 | — | — | — | — | — | 7.80 ± 0.12 | 0.15 |
| 4 | 0.68 ± 0.30 | — | -0.64 ± 0.17 | -2.77 ± 0.53 | — | — | — | 1.25 ± 0.31 | — | 7.57 ± 0.13 | 0.19 |
| 5 | 1.05 ± 0.32 | 0.60 ± 0.21 | -0.80 ± 0.18 | -3.08 ± 0.54 | — | — | — | 1.11 ± 0.31 | — | 7.26 ± 0.17 | 0.21 |
| 6 | 1.25 ± 0.32 | 1.26 ± 0.29 | -0.95 ± 0.18 | -2.80 ± 0.54 | — | — | -0.53 ± 0.16 | 1.11 ± 0.31 | — | 7.04 ± 0.18 | 0.23 |
| 7 | 1.37 ± 0.33 | 1.24 ± 0.29 | -0.98 ± 0.18 | -3.19 ± 0.60 | — | — | -0.58 ± 0.17 | 1.06 ± 0.31 | 1.03 ± 0.71 | 6.97 ± 0.19 | 0.24 |

**Table 5.** Urine pH Prediction Models Determined by Stepwise Regression for Individual Dogs (n = 660) Fed 66 Dry Foods Using the Nutrient Components of the Food (% dry matter basis).

| Model | Sodium | Potassium | Chloride | Sulfur | Calcium | Magnesium | Phosphorus | Methionine | Cystine | Intercept | $R^2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | — | — | — | -1.37 ± 0.13 | — | — | — | — | — | 7.75 ± 0.05 | 0.14 |
| 2 | — | — | — | -1.33 ± 0.13 | — | — | -0.51 ± 0.12 | — | — | 8.08 ± 0.09 | 0.16 |
| 3 | — | — | — | -1.15 ± 0.18 | — | — | -0.50 ± 0.12 | -0.16 ± 0.11 | — | 8.08 ± 0.10 | 0.16 |

**Figure 1.** Average predicted urine pH vs average observed urine pH of 99 canine foods (66 dry and 33 wet foods). Each data point for the average observed urine pH represents the mean urine pH of 10 dogs fed a particular food. Urine pH = 7.30 + (0.54 × sodium) + (0.63 × potassium) - (0.53 × chloride) - (1.67 × sulfur) - (0.61 × phosphorus) + (2.07 × cystine)

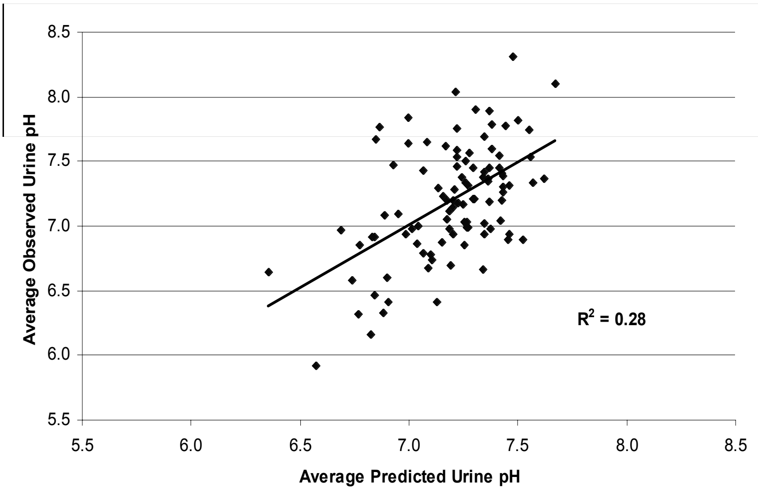
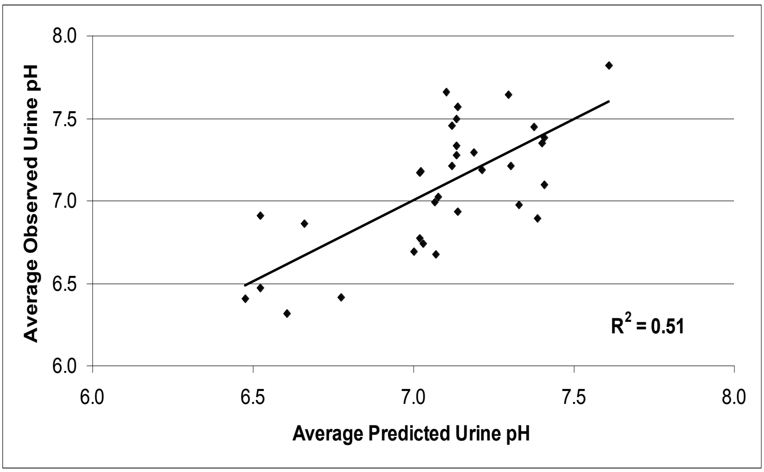



**Figure 2.** Average predicted urine pH vs average observed urine pH of 33 canine wet foods. Each data point for the average observed urine pH represents the mean urine pH of 10 dogs fed a particular food. Urine pH (wet foods) = 6.97 + (1.37 × sodium) + (1.24 × potassium) - (0.98 × chloride) - (3.19 × sulfur) - (0.58 × phosphorus) + (1.06 × methionine) + (1.03 × cystine).

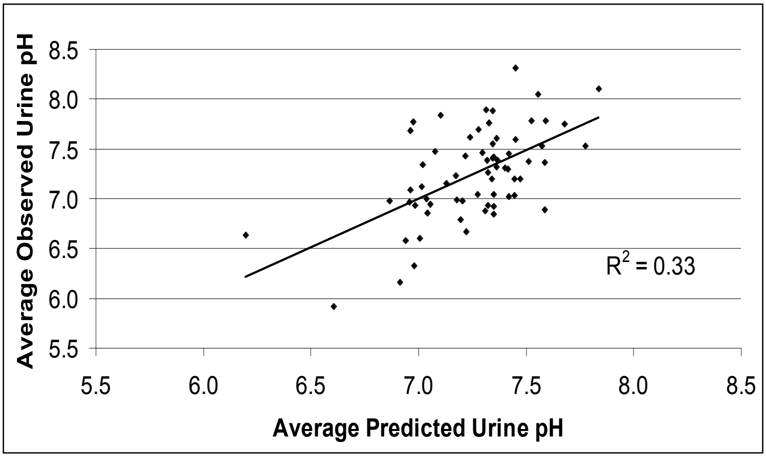



form. Stevenson et al[12] found that urine pH peaked approximately 1 to 4 hours after consumption of the dog's first meal. The response was similar in all feeding groups investigated, thus concluding that urine pH was directly affected by diet.

Typical dietary recommendations for struvite treatment and prevention include consumption of calculolytic foods, which typically have reduced quantity of protein, reduced phosphorus, and reduced magnesium.[10,13] Although reducing the urine pH for struvite management is the goal for managing canine struvite, this approach may not be ideal for all stones because animals consuming these foods may have a greater potential to form calcium oxalate stones.

Calcium oxalate stones have been reported to be the second most common urolith in dogs. Contrary to struvite, calcium oxalate stones are more common in males. In addition, dogs having calcium oxalate stones tended to be older than dogs having struvite stones.[3] This tendency is similar to what has been reported in cats.[6] Most dogs with calcium oxalate stones have a urine pH below 6.5.[3] Similar to struvite stones, urine pH and nutrition play a crucial role in the treatment and prevention of future stone formation. Typical recommendations for calcium oxalate treatment and prevention include reduced protein, reduced calcium, reduced sodium, reduced oxalate, and reduced vitamin D.[3,13]

**Figure 3.** Average predicted urine pH vs average observed urine pH of 66 canine dry foods. Each data point for the average observed urine pH represents the mean urine pH of 10 dogs fed a particular food. Urine pH (dry foods) = 8.09 - (1.15 × sulfur) - (0.50 × phosphorus) - (0.16 × methionine).




methionine accounted for 33% of the variation observed by the model. In dogs fed dry foods, no cations were utilized in the dry model to predict urine pH.

The low $R^2$ for all the models can be explained partially by the narrow range of urine pH observed across all dry and wet products fed. Of the products fed, approximately 80% of the observed urine pH was between the ranges of 6.9 to 7.5. This was expected as there are very few canine products on the market today which attempt to manipulate urine pH to manage and treat stone formation. The higher $R^2$ observed in the wet model was likely the result of the broader range of observed urine pH of the dogs fed the wet products. An interesting finding of this study was the fact that calcium and magnesium did not appear to have any influence on urine pH. Typical recommendations for calcium oxalate and struvite management include reduced consumption of calcium and magnesium; however, neither nutrient played a role in altering urine pH in any of the models.

Because typical recommendations for managing urolith formation involve nutrition and urine pH it becomes important for veterinarians and nutritionists to have a better understanding of how nutrition may impact urine pH. Being able to predict urine pH would enable a nutritionist or veterinarian to formulate foods that are beneficial in achieving a desired urine pH to aid in the prevention or treatment of certain urolith types. To date, no studies have attempted to predict urine pH in dogs using the nutrient content of the food.

In the current study, the total potassium, sodium, phosphorus, chloride, sulfur, and cystine content of the food accounted for 28% of the variation of the dry and wet model. The signs of the coefficients (+ or -) for the dry and wet food model are in agreement with what was expected and has been observed in cats.[6] When separating the dry from the wet model, it appears that different nutrients affect urine pH. The total sodium, potassium, chloride, sulfur, phosphorous, and cystine content of the food accounted for 51% of the variation in dogs fed wet foods. With the exception of methionine, the signs of the coefficients for the wet food model are in agreement with what was expected.[6] The total sulfur, phosphorus, and

## CONCLUSION

In conclusion, urine pH of adult dogs can be predicted from the nutrient components of the food. This enables the formulator to reduce the number of animal studies in order to optimize urine pH (for struvite and/or oxalate prevention) for specific products. In addition, understanding what nutrients effect urine pH can be advantageous to veterinarians who may want to prescribe supplements (eg, methionine, potassium citrate) for managing urine pH. In general, increases in pH were directly related to increases in potassium and sodium and inversely related to sulfur, phosphorous, and chloride. Separate formulas should be used for dry and wet foods in order to maintain accuracy.

## ACKNOWLEDGEMENTS

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