



Quantified water intake in laboratory cats from still, free-falling and circulating water bowls, and its effects on selected urinary parameters

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Abstract

Objectives The study objectives were to determine if the method of water presentation (still [S], circulating [C] or free-falling [FF] bowl systems) influences daily water consumption in cats in a controlled environment, and whether differences in water intake affect urine relative super saturation (RSS) for calcium oxalate and struvite, urine specific gravity (USG), urine osmolality (Uosmol) and urine volume.

Methods Sixteen healthy laboratory cats fed a dry diet were individually housed with urine collection systems. Each cat underwent a randomized 2 week crossover period with all bowl systems, allowing a 1 week acclimation period between each crossover. Water intake was measured daily by bowl weight, accounting for spillage and evaporation. USG and urine volume were measured daily, whereas other urinary parameters were measured at various time points throughout each 14 day crossover period.

Results Fourteen cats completed the study. Average daily water intake (ml/kg/day), urine volume, USG and urine RSS for struvite and calcium oxalate were not significantly different between water bowls. Uosmol was significantly higher in C compared with S and FF bowl systems ($P = 0.009$ for both). Three individual cats demonstrated a significant water bowl preference (Cat 4: C > S, $P = 0.039$; Cat 10: FF > C, $P = 0.005$; Cat 11: S > C, $P = 0.037$).

Conclusions and relevance Overall, water bowl type had no appreciable effect on water intake. Uosmol was the only urinary parameter found to be significantly different, and was higher for the C bowl. The implication of this is unknown, considering water intake did not differ significantly between bowls. Alternative methods to increase water intake should be implemented beyond providing unique water bowls in patients where augmented water intake would be beneficial for disease management.

Keywords: Water intake; FLUTD; feline lower urinary tract disease; RSS; relative super saturation; urine specific gravity; urolith

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Introduction

Enhancing voluntary water intake in cats is a chief management strategy for various disease states. This includes patients predisposed to dehydration through polyuria and polydipsia associated with hyperthyroidism, chronic kidney disease and diabetes mellitus, as well as patients with certain forms of feline lower urinary tract disease (FLUTD). FLUTD is an inclusive term to describe conditions of the urinary bladder and/or urethra, such as bacterial infections, masses, urethral plugs, urolithiasis and

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feline idiopathic cystitis (FIC) among other causes.¹ Patients with FIC can benefit from increased water intake to decrease the concentration of noxious stimulants within the bladder lumen via the subsequent increase in urine volume and frequency of urination.² Additionally, those predisposed to urolithiasis benefit from increased water intake as this aids in decreasing urinary precursors to calculi formation.^{3–5}

Various strategies are described to increase water intake in cats. These include increasing the amount of moist food in the diet, increasing dietary salt, increasing protein content (though these data are controversial), ensuring that fresh water is provided at all times, and offering supplemental water through various modalities, such as dynamic water sources.^{3,6–8} Dynamic water sources include those providing different presentations of flowing water, such as circulating (C) and free-falling (FF) bowls.

An appreciation of the curious nature of cats along with online veterinary communications readily available to pet owners suggest that cats would be attracted to moving water sources;^{9–11} however, to our knowledge, there are no other adequately powered, prospective publications investigating voluntary water intake in cats among multiple sources in a highly controlled environment. Thus, the basis for this recommendation seems anecdotal. Two studies have evaluated the influence of supplemental daily water intake of cats by providing it in continuous motion.^{12,13} However, no significant results were found, and there were limitations to the studies, such as sample population and study design.

Considering water intake appears to be an important factor in managing specific disease states in the feline patient, identifying effective approaches to ensure adequate water intake warrants further investigation. For this reason, we designed a study evaluating the more common still (S) water bowl to common styles of flowing water sources (C and FF) (Figures 1–3), and how that

might affect domestic feline drinking habits, as well as subsequent urinary parameters (urine volume, urine specific gravity [USG], urine osmolality [Uosmol] and urine relative supersaturation [RSS] for calcium oxalate and struvite urolithiasis). Each cat was used as its own control to help eliminate inherent variability between individual personalities when comparing water intake between each bowl.

The primary objective of this study was to determine if the method of presenting daily, non-dietary water influenced total daily water consumption among cats in a controlled environment. The secondary objective was



Figure 2 Circulating water bowl



Figure 1 Still water bowl



Figure 3 Free-falling water bowl

to evaluate whether a difference in water intake had any effect on selected urinary parameters that may increase risk of FIC and urolithogenesis,^{14–17} including urine RSS for calcium oxalate and struvite, USG, Uosmol and urine volume. We hypothesized that cats drinking from a moving water source would have a higher daily water intake and thus an increased urine volume, decreased USG and Uosmol, and decreased urine RSS for calcium oxalate and struvite.

Materials and methods

Cats

Seven spayed female and nine castrated male colony cats, aged 2–8 years, were evaluated in a crossover design study. Cats were deemed healthy based on physical examination, complete blood cell counts (CBCs), serum biochemical analysis, complete urinalysis, aerobic bacteriologic culture of urine obtained by cystocentesis and serum total thyroxine (T4) concentration. A body condition score (BCS) of 5–7/9 was considered acceptable for inclusion. Between each crossover period, CBC, serum biochemistry panel and urinalysis (urine dipstick and full microscopic analysis) were repeated to ensure cats maintained their health. Cats were housed in individual cages under conditions of controlled lighting and temperature according to the principles outlined in the National Institutes of Health Guide of the Care and Use of Laboratory Animals.¹⁸ All procedures were reviewed and approved by the University of Tennessee Institutional Animal Care and Use Committee (Protocol Number: 2161_2 12 13).

Diet and feeding protocol

Cats were fed twice daily using the same commercially available dry cat food (Hill's Science Diet Adult Light Feline, dry kibble, Hill's Pet Nutrition Inc, KS, 6% moisture, 9.4 g protein/100 kilocalorie [kcal], 84 mg sodium/100 kcal), approved for adult maintenance by Association of American Feed Control Officials feeding trial protocols, throughout the course of the study.¹⁹ The amount of food fed was based on estimated daily maintenance energy requirements determined by current body weight (kilojoules = $313.6 \times 3.3^{0.67}$ kg body weight, where 1 kilojoule = approximately 0.24 kcal).²⁰ Cats were weighed weekly and the amount of food was adjusted so that cats were maintained to body weight within 5% of their body weight at the initiation of the study.

Experimental design

Cats were randomized in a 3×3 crossover design to three different water bowls – S, C and FF – in which each cat was exposed to each bowl type for one treatment period. Treatment order for each individual cat was determined by random selection from a hat draw. Cats were acclimated to each water bowl for a period of 7

days followed by data collection for a period of 14 consecutive days. Water was changed every 24 h during the study, including the acclimation period. USG and urine volume were measured daily during the 14 day period. Uosmol was measured on days 1, 3, 5, 7, 10, 12 and 14. Twenty-four hour data on urinary excretion of ammonia, calcium, chloride, citric acid, creatinine, magnesium, oxalic acid, phosphorus, potassium, sodium and uric acid were collected and estimation of urinary saturation with calcium oxalate monohydrate and struvite was determined by urine RSS on days 1, 7 and 14 of each crossover period.²¹ The process was immediately repeated twice more to allow each cat an acclimation and collection period for each bowl type; cats remained in the same enclosures with the same collection system throughout the study.

Blood, serum and plasma acquisition and analyses

Blood samples were collected from the jugular vein on the first day of each acclimation period. Blood was divided and analyzed for CBC and serum biochemical analysis by the Clinical Pathology Laboratory, College of Veterinary Medicine, University of Tennessee. Serum total T4 concentration was analyzed by the Endocrinology Laboratory, College of Veterinary Medicine, University of Tennessee.

Water intake analysis

Water intake was measured daily. To accomplish this, each bowl was filled with tap water, weighed on a digital gram scale, placed on a previously weighed absorptive mat, and left for 24 h in each individual enclosure. A specifically designated bowl (sham bowl) of each variety was weighed in the same fashion and placed on a shelf in the room to account for evaporation. Following each 24 h period, each bowl was weighed along with the absorptive mat. Daily water intake was defined as: (the previous day's bowl weight) – (the post-24 h bowl weight) + (the difference between the sham bowl at the start of the 24 h period and its post-24 h weight) + (the difference between the weight of the absorptive mat post-24 h and its weight at the start of the 24 h period) where 1 g water was equivalent to 1 ml of water. Data points were excluded if the subjects flipped their bowls, if the amount of water spilled exceeded the absorptive capacity of the mat, the spilled water extended beyond the mat and/or the subject urinated or defecated in their water bowl. The specific water source was tap water obtained from the research facility the cats were housed in; no mineral analysis was performed on the water for this study.

Urine collection and analysis

Cats were housed individually to facilitate collection of urine samples. Modified litter boxes (quad cages equipped with metabolic pans. BH Inc, Wheatland, Wyo) which

separate urine from feces, were used to eliminate the need for sedation to collect urine.²² These modified litter boxes do not emit or absorb minerals or electrolytes. Thymol-containing receptacles were attached to the bottom of the litter boxes to collect urine over 24 h.²³ Volume was recorded daily during each 14 day testing period. The urinary bladder of each cat was palpated at the beginning and end of each 24 h period and, if required, manual bladder expression to empty the bladder was performed, although this was only performed during the 14 day testing periods.

USG was determined daily using a refractometer calibrated for cat urine. On days when Uosmol was determined, 2 ml aliquots from the 24 h urine sample were separated and stored at -80°C until sample analysis. The samples were thawed and thoroughly mixed prior to analysis. Urine osmolality was analyzed in triplicate and averaged. All samples were analyzed for Uosmol within 1 month of collection.

On days when urine RSS was determined, 24 h urine samples were warmed in closed containers kept at 38°C. The pH of the 24 h urine samples was measured with a combination pH electrode (pH Meter 245, Corning Glass Works Science, Corning, NY). Sodium, potassium, chloride, calcium, magnesium, phosphorus and creatinine concentrations were measured within 24 h of collection, using an automated analyzer. Aliquots of 2–3 ml were stored at 4°C until the time of analysis. Aliquots of 4.5 ml of 24 h urine were stored at -20°C for approximately 2 months following the conclusion of collection, at which time ammonia was measured with an ion-selective electrode (Model 95-12 ammonia electrode, Orion Research Inc, Boston, MA).²⁴ One milliliter of urine was acidified with 1.5 ml hydrochloric acid and stored at -20°C for approximately 2 months following conclusion of collection, at which time oxalic acid was measured with ion chromatography.²⁵ Two milliliter aliquots of 24 h urine were stored at -20°C for approximately 2 months following conclusion of collection, at which time citric acid was measured by ion chromatography.²⁶ Two milliliter aliquots of 24 h urine were stored at -20°C for approximately 2 months following the conclusion of collection, at which time anions and cations were determined.²⁷

Urine RSS with calcium oxalate and struvite

Molar concentrations of measured urinary analytes were entered into a microcomputer-based program (EQUIL 89d, University of Florida, Gainesville, FL) and the urine RSS values for calcium oxalate and struvite was estimated.

Statistical analysis

A power calculation using an alpha (α) of 0.05, a beta of 0.9, a difference in means of water intake of 5 ml/kg/day and a difference in SD in water intake of 5 ml/kg/day resulted in a necessary sample size of 13 cats to limit type I and type II errors. Three additional cats were used to

ensure adequate power of the study in case of missed data points and/or cats needing to be removed from the study.

Descriptive statistics were calculated and expressed as mean \pm SD, with minimum and maximum values added in parentheses. Water intake was evaluated as ml/kg/day. Water intake was compared between the three bowls using repeated measures mixed model analysis of variance with treatment (bowl), time (week) and sequence as fixed effects and cats within sequence as a random effect. Mauchly's test of sphericity, normal plots of raw data and residual plots were used to assess model validity. Games-Howell tests were chosen for post-hoc pairwise analyses owing to unequal variances in variables between groups. Similar analyses were run for urine volume, USG and Uosmol, as well as weights. Analyses used $\alpha = 0.05$ as the significance level, and were performed using SPSS statistical software (IBM [SPSS-PASW version 17; SPSS, Somers, NY]).

Results

Sixteen cats were initially enrolled. Two cats, both males, were excluded during the first acclimation period owing to intermittent vomiting. There was no significant difference in the mean weights of cats while they were drinking from any of the bowls ($P = 0.544$). The median BCS of the cats throughout the study was 5 (range 5–7), with only one cat having a BCS of 7/9. Calories offered did not impact mean water intake ($P = 0.815$).

Water intake data were missing from 5.1% ($n = 10/196$) of S, 3.1% ($n = 6/196$) of C and 0.5% ($n = 1/196$) of FF bowl data points, with 2.9% ($n = 17/588$) missing water intake data points among all cats. Average daily water intake (ml/kg/day) was not significantly different between water bowls (S 27.483 ± 5.847 [20.04–42.26], C 26.327 ± 7.342 [18.71–49.16], FF 26.137 ± 6.487 [17.80–40.05]; $P = 0.942$) (Table 1), there was no effect in treatment order ($P = 0.161$) and there was no significant interaction between water bowls and treatment order ($P = 0.176$). There was no significant difference in average water intake (ml/kg/day) between any 1 week time period ($P = 0.139$) (Table 2). There were no interactions between time and bowl type ($P = 0.541$), time and treatment order ($P = 0.165$), or time, bowl and treatment order ($P = 0.174$).

Table 1 Average daily water intake between water bowls

Bowl type	Daily water intake (ml/kg/day)*		
	Mean \pm SD	Minimum	Maximum
S	27.483 ± 5.847	20.04	42.26
C	26.327 ± 7.342	18.71	49.16
FF	26.137 ± 6.487	17.80	40.05

* $n = 14$, $P = 0.942$, values taken per 14 day testing period
S = still; C = circulating; FF = free-falling

Table 2 Average daily water intake by week

Week	Water intake (ml/kg/day)			<i>P</i> value
	Mean ± SD	Minimum	Maximum	
1	27.5528 ± 7.47119	18.94	45.77	0.139
2	27.6959 ± 4.53065	19.72	38.77	
3	26.4487 ± 7.4776	17.78	50.47	
4	25.9820 ± 7.05718	19.73	47.86	
5	26.7742 ± 6.12648	18.05	40.39	
6	26.4274 ± 6.17171	17.67	39.72	

Table 3 Average daily water intake by bowl, from cats with a significant water bowl preference

Cat identification	Bowl type	Water intake (ml/kg/day)*			Bowl preference
		Mean ± SD	Minimum	Maximum	
4	S	20.048 ± 3.798	15.17	30.13	C >S (<i>P</i> = 0.039)
	C	24.680 ± 5.408	11.81	31.10	
10	C	26.946 ± 4.464	19.68	34.90	FF >C (<i>P</i> = 0.005)
	FF	38.218 ± 10.497	16.56	50.28	
11	S	32.540 ± 5.620	23.25	40.02	S >C (<i>P</i> = 0.037)
	C	26.987 ± 5.579	17.98	37.62	

*Values taken per 14 day testing period

S = still; C = circulating; FF = free-falling

Table 4 Average daily water intake by week for cats exhibiting bowl preferences

Cat identification	Bowl type	Week	Water intake (ml/kg/day)			<i>P</i> value
			Mean ± SD	Minimum	Maximum	
4	S	1	20.37 ± 4.99	15.18	30.13	0.989
		2	19.71 ± 2.45	15.14	23.06	
	C	1	27.01 ± 4.34	19.49	31.10	0.350
		2	22.34 ± 5.63	11.81	30.28	
10	C	1	25.05 ± 3.87	19.69	29.53	0.369
		2	28.83 ± 4.45	22.94	34.90	
	FF	1	38.03 ± 11.46	16.57	50.39	0.998
		2	38.39 ± 10.35	19.26	47.28	
11	S	1	37.12 ± 2.40	33.03	40.03	0.997
		2	27.96 ± 3.71	23.25	33.13	
	C	1	28.52 ± 6.90	17.98	37.63	0.734
		2	25.44 ± 3.76	20.35	29.27	

S = still; C = circulating; FF = free-falling

Three individual cats demonstrated a significant water bowl preference (cat 4: C = 24.68 ± 5.40 [11.81–31.10] >S = 20.04 ± 3.79 [15.17–30.13], *P* = 0.039; cat 10: FF = 38.2 ± 10.49 [16.56–50.28] >C = 26.94 ± 4.46 [19.68–34.90], *P* = 0.005; cat 11: S = 32.54 ± 5.62 [23.25–40.02] >C = 26.98 ± 5.579 [17.98–37.62], *P* = 0.037) (Table 3). There was no significant difference in the average water intake (ml/kg/day) between individual weeks in each of the bowls

described above for cat 4 (C bowl, *P* = 0.350; S bowl, *P* = 0.989), cat 10 (FF bowl, *P* = 0.998; C bowl, *P* = 0.369) or cat 11 (S bowl, *P* = 0.997; C bowl, *P* = 0.734) (Table 4).

Urinary data were excluded from several cats owing to failure to urinate in the modified litter pan or aversion to bladder expression for 24 h urinary parameters. Urine volume (ml/kg/day; n = 11) (S: 15.485 ± 4.434 [11.29–24.55], C: 15.001 ± 3.163 [11.39–21.17], FF: 15.913 ± 3.069

Table 5 Average daily urine volume, daily urine specific gravity (USG) and measured urine osmolality (Uosmol) by bowl type

	Bowl type			P value
	S	C	FF	
Average ± SD (minimum–maximum) daily urine volume (ml) (n = 11)	15.485 ± 4.434 (11.29–24.55)	15.001 ± 3.163 (11.39–21.17)	15.913 ± 3.069 (11.97–22.31)	0.513
Average ± SD (minimum–maximum) daily USG (n = 13)	1.050 ± 0.008 (1.040–1.060)	1.051 ± 0.008 (1.030–1.060)	1.051 ± 0.013 (1.030–1.080)	0.595
Average ± SD (minimum–maximum) Uosmol* (mOsm/kg) (n = 11)	2175.7 ± 480.7 (1562.8–3405.6)	2584.7 ± 735.6† (1381.8–3662.0)	2108.6 ± 508.3 (1422.0–3421.0)	0.009

*Average taken from days 1, 3, 5, 7, 10, 12 and 14

†Greater measurement is statistically significant

S = still; C = circulating; FF = free-falling

Table 6 Average urine relative supersaturation (RSS) per bowl per testing day

Urine analyte	Bowl Type									P value	
	S			C			FF				
	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14	Day 1	Day 7	Day 14		
Struvite RSS (average ± SD)	0.37 ± 0.55	0.80 ± 0.83	0.58 ± 0.68	0.30 ± 0.35	0.31 ± 0.38	0.46 ± 0.44	0.22 ± 0.44	0.48 ± 0.92	0.45 ± 0.52	0.6	
Calcium oxalate RSS (average ± SD)	3.04 ± 1.93	2.02 ± 0.67	3.27 ± 1.82	1.75 ± 0.57	2.10 ± 0.63	2.61 ± 0.85	2.24 ± 0.92	2.41 ± 0.92	2.01 ± 0.88	0.3	

S = still; C = circulating; FF = free-falling

[11.97–22.31]; P = 0.513) and USG (n = 13) (S: 1.050 ± 0.008 [1.040–1.060], C: 1.051 ± 0.008 [1.030–1.060], FF: 1.051 ± 0.013 [1.030–1.080]; P = 0.595) were not significantly different among treatment groups (Table 5). Uosmol (mOsm/kg) (n = 13) was significantly higher for C vs S and FF bowls (C: 2584.7 ± 735.6 [1381.8–3662.0], S: 2175.7 ± 480.7 [1562.8–3405.6], FF: 2108.6 ± 508.3 [1422.0–3421.0]; P = 0.009 for both) (Table 5). Urine RSS for struvite (n = 11 for S, n = 11 for C, n = 12 for FF; P = 0.6) and calcium oxalate (n = 11 for S, n = 11 for C, n = 12 for FF; P = 0.3) were not different between bowls (Table 6).

Discussion

The results from the current study reveal that healthy adult cats do not show a preference towards one specific style of water bowl overall, as determined by water intake, which is similar to previous studies. However, in this study, three (21%) individual cats demonstrated a significant increase in water intake with different bowls, indicating certain cats may demonstrate individual preferences. These preferences were further investigated by evaluating weekly water intake for the specific bowl types; and our goal was to elucidate whether or not there was a significant difference in water intake for each of

the three individual cats within the testing period for the bowls in question. As there was no difference between water intake within the 2 week testing period for any of the pertinent bowl comparisons, we can be more confident this preference truly exists.

Regardless of these preferences, in the present study Uosmol was the only urinary parameter that was significantly different when comparing water intake of the C bowl to the S and FF bowls; however, because the overall water intake did not differ significantly between bowls, the clinical significance is unclear. Few studies have looked into Uosmol changes when stored at -80°C and results are conflicting, though the studies that have shown a statistical difference do corroborate in that samples stored for longer periods of time have lower Uosmol values when compared with baseline.^{28–30} While this was not evaluated in this study, it could be reasoned that the randomization resulted in a larger number of C bowls being tested in the last crossover (ie, longer storage of the Uosmol samples for the S and FF bowls), thus causing a higher Uosmol for the C bowl when comparing with S and FF bowls.

It is interesting that the urine RSS for struvite is undersaturated and urine RSS for calcium oxalate is metastable, which is the desired effect of therapeutic 'urinary stone prevention' diets. As the diet used in this

study is not labeled for struvite dissolution nor calcium oxalate prevention and was likely not tested for these characteristics, it is unclear whether this is a result of the water intake or an inherent aspect of the diet. However, because there was no difference in water intake between bowls nor urine RSS for either urolith type, we suspect this was due to the diet or the natural water intake behavior of the cats used in this study. Based on the study results, it appears that the recommendation to provide flowing water sources may not be as beneficial as previously thought and different management strategies should be more strongly emphasized. It is important, however, not to discount the necessity for fresh, free-choice water, even for the healthy cat. Additionally, it may be ideal to provide multiple types of water bowls, especially for the sick patient, in case preferences towards a water bowl type is present.

Considering the method of water presentation does not appear to increase daily water intake, dietary management may provide a more effective method for increasing total water consumption. Multiple studies have confirmed the correlation between high dietary sodium content (275–400 mg/100 kcal) and an increased urine volume,^{31–33} a strategy that has been used in multiple veterinary therapeutic diets marketed for urinary health and urolithiasis prevention. Increased dietary protein (12.8–16.3 g/100 kcal) has also been suggested; however, studies have revealed contradictory results,^{34,35} and therefore this strategy is controversial.

Another potential and relatively simple strategy to increase water consumption is to feed high-moisture diets. Commercial kibble diets average <10% moisture, while the majority of canned/moist diets are approximately 80%. One study showed a positive correlation between increased moisture content and improved urinary parameters (USG, urine volume and calcium oxalate RSS) when adding increasing amounts of water to the same base diet. The cats consuming the drier diets drank more water than those eating the wetter diets, but total water daily water intake was still greater in the wet vs dry diets.⁴ This phenomenon has also been described in a study dating back to the 1970s.³⁶

Given the prevalence of FLUTD patients seen (4.6% among private practices in the USA and mildly higher percentages in university settings),⁷ understanding different options for water therapy can play a key role in successful management, such as in FIC. Even with the multiple conditions included under the umbrella of FLUTD, FIC is by far the most encountered (55–69%),^{2,37–40} with recurrence rates reported as high as 50%.⁴¹ While the etiology of FIC is yet to be identified, patients may benefit from increased water intake and subsequent increase in urine volume and frequency of micturition. While conflicting information exists, two studies have shown some improvement in FIC clinical

signs and recurrence rates associated with decreased USG.^{42,43} Increased water intake and urine volume has also been shown to decrease the risk for urolithogenesis (10–20% of FLUTD cases),^{39,44} most specifically calcium oxalate formation.^{4,5} Based on the available studies evaluating water consumption in cats, evidence suggests water bowl selection likely does not play a key role in prevention. Further strategies for increasing intake and improving key urinary parameters should be initiated and likely multimodal. While certain strategies may prove to be more effective than others, each treatment plan should be developed to best match the individual cat.

This study expanded upon the measurements of the two previously mentioned studies evaluating outcomes of different water sources among domesticated feline patients and tried to address their limitations. One study evaluated differences in daily water consumption, Uosmol and USG in a 2 × 2 crossover design in 13 cats that were exposed to an S water bowl and an FF bowl, and no statistical difference in Uosmol or water intake was noted between bowls.¹² No mention of statistical significance was made regarding USG. Limitations of this study included lack of environmental and dietary controls (individually client-owned and housed subjects), the reliance of owners to obtain water bowl measurements, limited data points (two measurement points per cat per bowl) and bowls to account for water evaporation not being evaluated at the same time as the subjects' bowl measurements. The second study evaluated water consumption in nine shelter cats housed in individual kennels within the same room.¹³ It was a 2 × 2 crossover design using S and FF water bowls. This study also found no statistical significance in water consumption between bowl types. Limitations of this study included omission of 11.1% (n = 4/36) of data points owing to water spillage, no measured laboratory values for patient metabolic or endocrine health concerns, a limited acclimation period of 24 h at the beginning of the study (none between bowl types) and only 4 days of measurements.

Despite controlling for a variety of factors in the present study, some study limitations remained. This project included healthy cats rather than cats with a propensity towards the development of FIC, urethral plugs and/or urolithiasis; perhaps flowing water affects water intake differently in cats with systemic illness. In addition, this project used individually housed colony cats as opposed to client-owned cats. A home setting where cats can freely move might change preferences for bowl type. Furthermore, while a home setting may provide less control for study design, it may limit overall stress of the subjects vs confinement in the multi-level, individual enclosures used in this investigation, which could have affected measured results. Unfortunately, to our knowledge, there are no well-correlated studies examining

adequate acclimation periods in colony cats. While two studies evaluating stress levels in non-colony cats in a shelter/cattery setting using behavioral cues and urine cortisol suggest 2–5 weeks, the magnitude of investigated environmental change assessed in these studies does not seem comparable to the present investigation as the colony cats used were frequently utilized in research projects using similar housing situations.^{45,46}

Moreover, loss-of-water intake was, overall, 2.9% ($n = 17/588$), with the majority of missing data points from the still water bowl (5.1%; $n = 10/196$). This is likely owing to the increased ability of cats to flip over these bowls vs the larger C or FF water bowls. Additional data points were missing from urinary parameters; however, owing to the lack of significant difference with water intake data, this was not expected to differ significantly between bowls. While the number of calories offered did not influence water intake, evaluation of caloric consumption with calculation of moisture intake would have been ideal. Regrettably, these data were not collected during the study period although the majority of the cats were observed to consume all food offered to them. Despite these limitations, this project provides the most controlled data to date on water intake and urinary measures with different water bowl types.

Moving forward, it would be pertinent to focus on cats with specific disease states. Additionally, studies investigating the behavior in wild feline species, as well as environmental enrichment in domesticated cats, may be beneficial in understanding the propensity for the domestic species to drink from moving and still water sources.

Conclusions

Though this study neither showed a clinically significant difference in water intake for one specific bowl type, nor an interpretable positive effect on the measured urinary parameters, it provides objective data for practitioners when making recommendations for treatment therapies and can help ensure an optimal plan is designed.

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Conflict of interest Radio Systems Corporation had no influence on study design, results, outcome or reporting of information. Radio Systems Corporation was only made aware of the study results and they had no access to the study data beyond this. Radio Systems Corporation did donate the water bowls at the end of this study, though their intent to do this was not known to the authors/participants until after data collection.

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References

- 1 AVMA. Pet care: feline lower urinary tract disease. <https://www.avma.org/public/PetCare/Pages/FLUTD.aspx> (accessed November 17, 2017).
- 2 Forrester SD and Towell TL. Feline idiopathic cystitis. *Vet Clin North Am Small Anim Pract* 2015; 45: 783–806.
- 3 Palm C and Westropp J. Cats and calcium oxalate: strategies for managing lower and upper tract stone disease. *J Feline Med Surg* 2011; 13: 651–660.
- 4 Buckley CMF, Hawthorne A, Colyer A, et al. Effect of dietary water intake on urinary output, specific gravity and relative supersaturation for calcium oxalate and struvite in the cat. *Br J Nutr* 2011; 106 Suppl 1: S128–S130.
- 5 Stevenson A, Hynds W and Markwell P. Effect of dietary moisture and sodium content on urine composition and calcium oxalate relative supersaturation in healthy miniature schnauzers and labrador retrievers. *Res Vet Sci* 2003; 74: 145–151.
- 6 Westropp JL and Tony Buffington C. Feline idiopathic cystitis: current understanding of pathophysiology and management. *Vet Clin North Am Small Anim Pract* 2004; 34: 1043–1055.
- 7 Dru Forrester S and Roudebush P. Evidence-based management of feline lower urinary tract disease. *Vet Clin North Am Small Anim Pract* 2007; 37: 533–558.
- 8 Tony Buffington C, Westropp JL, Chew DJ, et al. Clinical evaluation of multimodal environmental modification (MEMO) in the management of cats with idiopathic cystitis. *J Feline Med Surg* 2006; 8: 261–268.
- 9 Charter Vets. Ways to increase your cat's water intake. <http://www.chartervets.com/ways-to-increase-your-cats-water-intake/> (accessed February 20, 2018).
- 10 Huston L. How to get a cat to drink water. <https://www.petmd.com/cat/centers/nutrition/slideshows/does-your-cat-drink-enough-water> (accessed February 22, 2018).
- 11 VetWest Animal Hospitals. Thirsty cat – is it just hot or is something up? <https://www.vetwest.com.au/pet-library/thirsty-cat-is-it-just-hot-or-is-something-up> (accessed February 22, 2018).
- 12 Grant DC. Effect of water source on intake and urine concentration in healthy cats. *J Feline Med Surg* 2010; 12: 431–434.
- 13 Pachel C and Neilson J. Comparison of feline water consumption between still and flowing water sources: a pilot study. *J Vet Behav Clin Appl Res* 2010; 5: 130–133.
- 14 Defauw PA, Van de Maele I, Duchateau L, et al. Risk factors and clinical presentation of cats with feline idiopathic cystitis. *J Feline Med Surg* 2011; 13: 967–975.
- 15 Jones BR, Sanson RL and Morris RS. Elucidating the risk factors of feline lower urinary tract disease. *N Z Vet J* 1997; 45: 100–108.
- 16 Houston DM, Moore AEP, Favrin MG, et al. Feline urethral plugs and bladder uroliths: a review of 5484 submissions 1998–2003. *Can Vet J* 2003; 44: 974–977.

- 17 Hostutler RA, Chew DJ and Dibartola SP. **Recent concepts in feline lower urinary tract disease.** *Vet Clin Small Anim* 2005; 35: 147–170.
- 18 National Research Council. Animals NRC (US) C for the U of the G for the C and U of L. Guide for the care and use of laboratory animals. Washington DC: National Academies Press, 2011.
- 19 Association of American Feed Control Officials. **Model bill and regulations: AAFCO dog and cat food feed protocols.** Champaign, IL: Association of American Feed Control, 2013, pp 151–163.
- 20 Mitsuhashi Y, Chamberlin AJ, Bigley KE, et al. **Maintenance energy requirement determination of cats after spaying.** *Br J Nutr* 2011; 106 Suppl 1: S135–S138.
- 21 Lulich JP, Osborne CA, Lekcharoensuk C, et al. **Effects of diet on urine composition of cats with calcium oxalate urolithiasis.** *J Am Anim Hosp Assoc* 2004; 40: 185–191.
- 22 Pastoor FJ, Van 'T Klooster AT, et al. **An alternative method for the collection of urine and feces and its application in measuring urinary mineral excretion in cats fed diets containing various amounts of phosphorus.** *J Nutr* 1991; 121 Suppl 11: S85–S86.
- 23 Adams LG, Polzin DJ, Osborne CA, et al. **Comparison of fractional excretion and 24-hour urinary excretion of sodium and potassium in clinically normal cats and cats with induced chronic renal failure.** *Am J Vet Res* 1991; 52: 718–722.
- 24 Cooke RJ and Jensen RL. **Micromethod for determining plasma ammonia nitrogen with use of an ion-selective electrode.** *Clin Chem* 1983; 29: 867–869.
- 25 Petrarulo M, Marangella M, Bianco O, et al. **Preventing ascorbate interference in ion-chromatographic determinations of urinary oxalate: four methods compared.** *Clin Chem* 1990; 36: 1642–1645.
- 26 Singh RP and Nancollas GH. **Determination of urinary citrate by high performance ion chromatography.** *Kidney Int* 1985; 28: 985–987.
- 27 Dawborn JK, Patalinghug C and Black SE. **Estimation of sodium, potassium, and chloride in urine using a Technicon AutoAnalyzer.** *J Clin Pathol* 1965; 18: 684–686.
- 28 Adams JD, Kavouras SA, Johnson EC, et al. **The effect of storing temperature and duration on urinary hydration markers.** *Int J Sport Nutr Exerc Metab* 2017; 27: 18–24.
- 29 Reinhart JM, White BJ, Pohlman LM, et al. **Stability of osmolality in previously frozen canine serum and urine samples.** *Vet Clin Pathol* 2016; 45: 665–668.
- 30 Sureda-Vives M, Morell-Garcia D, Rubio-Alaejos A, et al. **Stability of serum, plasma and urine osmolality in different storage conditions: relevance of temperature and centrifugation.** *Clin Biochem* 2017; 50: 772–776.
- 31 Hawthorne AJ and Markwell PJ. **Dietary sodium promotes increased water intake and urine volume in cats.** *J Nutr* 2004; 134 Suppl 8: 2128S–2129S.
- 32 Kirk CA, Jewell DE and Lowry SR. **Effects of sodium chloride on selected parameters in cats.** *Vet Ther* 2006; 7: 333–346.
- 33 Paßlack N, Burmeier H, Brenten T, et al. **Short term effects of increasing dietary salt concentrations on urine composition in healthy cats.** *Vet J* 2014; 201: 401–405.
- 34 Funaba M, Hashimoto M, Yamanaka C, et al. **Effects of a high-protein diet on mineral metabolism and struvite activity product in clinically normal cats.** *Am J Vet Res* 1996; 57: 1726–1732.
- 35 Funaba M, Yamate T, Hashida Y, et al. **Effects of a high-protein diet versus dietary supplementation with ammonium chloride on struvite crystal formation in urine of clinically normal cats.** *Am J Vet Res* 2003; 64: 1059–1064.
- 36 Seefeldt SL and Chapman TE. **Body water content and turnover in cats fed dry and canned rations.** *Am J Vet Res* 1979; 40: 183–185.
- 37 Buffington CA, Chew DJ, Kendall MS, et al. **Clinical evaluation of cats with nonobstructive urinary tract diseases.** *J Am Vet Med Assoc* 1997; 210: 46–50.
- 38 Lekcharoensuk C, Osborne CA and Lulich JP. **Epidemiologic study of risk factors for lower urinary tract diseases in cats.** *J Am Vet Med Assoc* 2001; 218: 1429–1435.
- 39 Kruger JM, Osborne CA, Goyal SM, et al. **Clinical evaluation of cats with lower urinary tract disease.** *J Am Vet Med Assoc* 1991; 199: 211–216.
- 40 Buffington CAT, Westropp JL, Chew DJ, et al. **Risk factors associated with clinical signs of lower urinary tract disease in indoor-housed cats.** *J Am Vet Med Assoc* 2006; 228: 722–725.
- 41 Westropp JL. **Feline idiopathic cystitis.** In: Bartges J and Polzin DJ (eds). Nephrology and urology of small animals. Chichester: Wiley-Blackwell, 2011, pp 745–754.
- 42 Markwell PJ, Buffington CA, Chew DJ, et al. **Clinical evaluation of commercially available urinary acidification diets in the management of idiopathic cystitis in cats.** *J Am Vet Med Assoc* 1999; 214: 361–365.
- 43 Gunn-Moore DA and Shenoy CM. **Oral glucosamine and the management of feline idiopathic cystitis.** *J Feline Med Surg* 2004; 6: 219–225.
- 44 Sævik BK, Trangerud C, Ottesen N, et al. **Causes of lower urinary tract disease in Norwegian cats.** *J Feline Med Surg* 2011; 13: 410–417.
- 45 Kessler MR and Turner DC. **Stress and adaptation of cats (*Felis silvestris catus*) housed singly, in pairs and in groups in boarding catteries.** *Anim Welf* 1997; 6: 243–254.
- 46 McCobb EC, Patronek GJ, Marder A, et al. **Assessment of stress levels among cats in four animal shelters.** *J Am Vet Med Assoc* 2005; 226: 548–555.