Water Needs and Hydration for Cats and Dogs

Brian M. Zanghi, PhD
Nestlé Research Center
St. Louis, MO
brian.zanghi@rd.nestle.com

Glossary of Abbreviations
AVP: Arginine Vasopressin
BW: Body Weight
GFR: Glomerular Filtration Rate
LMH: Lean-Mass Hydration
LUTD: Lower Urinary Tract Disease
TBW: Total Body Water

Key Words
eu-hydration
hyperhydration
hypohydration

Abstract
Water is always considered the most essential nutrient. Estimates of daily water requirements have been reported for cats and dogs, yet no consensus exists for how to define adequate hydration in pets. By default, typical recommendations for proper water intake in the healthy pet are to always have fresh water available for the pet's desire to ingest water and establish individual eu-hydration ("true" hydration). This presentation will review what is currently known to establish daily water requirements, followed by a discussion of water ingestion patterns and how that translates into various parameters of assessing hydration status in the healthy cat and dog.

Introduction
Water is always considered the most essential nutrient,[1,2] and estimates of daily water requirements have been reported for cats and dogs.[3] However, there is no consensus on how to define optimal hydration, or optimal water intake volume in pets, or the overall impact of adequate hydration on health. By default, the typical recommendation for the healthy pet is to always have fresh water available for the pet's desire to ingest water and establish individual eu-hydration, but no definition exists on what eu-hydration is in cats and dogs or the target volume of water intake. A basic and limited framework of published research exists on water intake, water balance, and urine parameters with mostly kennel-housed cats or dogs that necessitates citation to work conducted as far back as the 1970s. Much remains to be investigated to expand the current knowledge of water and hydration needs for pet cats and dogs.

Because the hydration state is not static during the day, many situations exist in pets' daily life, or as a result of a health condition, that can cause them to trend into hypohydration status. This challenge is not unique to cats and dogs, as a great deal of research is ongoing in people to understand and establish normative values and acceptable ranges of water intake needs for defining optimal hydration and refining dietary recommendations for water intake.[4-7] Furthermore, the link between inadequate hydration and health-related outcomes has been described for a variety of conditions, including hyperglycemia and accelerated progression of diabetes, higher risk of chronic kidney disease, recurrence of kidney stones, and possibly contribute to hypertension.[7]

The goals of this review are to revisit what is currently known regarding daily water requirements and variations related to dietary moisture in cats and dogs. This will be followed by discussing the existing research that provides some basis for using various physiological measures to begin to assess, and possibly define, hydration status in the healthy cat and dog. This survey of current research also provides an opportunity to identify some significant gaps related to water nutrition as a basis for future studies that can go beyond the current understanding of daily water requirements. Ultimately, future work should consider and explore how "optimal" hydration and daily water intake influence not only metabolic and urological health, but also nonurological physiologies that could include obesity, brain health, cognition, and behavioral patterns that may benefit the pet.

Water as a Medium and a Nutrient
Water is an essential nutrient because it is responsible for supporting a multitude of physiological functions and a medium for metabolic waste removal. In addition, body water also establishes a complex and dynamic body-fluid matrix underlying all metabolic processes. The body water compartment of a cat or dog is in constant flux, thus regulation of water balance and thirst-driven water intake are necessary to replenish the persistent evaporative loss of water through respiration and cutaneous surfaces, as well as periodic loss in urine, saliva, or feces. Tracer studies with heavy water (D_2O) have reported that total body water (TBW) can be wide ranging within a sampling of adult cats (52 to 67% of BW)[8] or dogs (54 to 61% of BW).[9] However, TBW proportion is significantly influenced by proportion of body fat, such that % TBW declines with increasing fatness. This phenomena is also observed in humans, who also can have a range of approximately 50 to 70% TBW, which decreases with increasing % body fat.[7]

TBW is generally considered to be fixed at 73.2% of the fat-free body mass,[10,11] which is also referred to as the lean-mass hydration (LMH) constant. Although 73.2% is the assumed constant used for determining lean-mass and fat-mass proportions of body composition studies, the individual animal's hydration constant will vary. Multiple studies in cats and dogs have reported that the mean hydration constant can range from 71.3 to 75.9% in dogs[9,12,13] and from 71.8 to 75.7% in cats.[8] Although it is not surprising that the TBW proportion decreases with increased body weight, new evidence highlights that LMH also appears to diminish with increasing percent of body fat.[9] Specifically, dogs with >25% body fat had an LMH ranging from 72 to 74%, whereas lean dogs with 7 to 20% body fat had an LMH ranging from 74 to 78%. This may offer insight into an animal's hydration status and body water pool in overweight or obese populations of dogs. The assumption of a standard LMH and reference range of TBW values has also been a topic of discussion related to human nutrition and obesity, particularly because of the increasing prevalence of obesity in humans.[14]

Water Balance Regulation

Ultimately, the degree of water intake results from physiological factors that regulate thirst, which is driven by the body's attempt to maintain cellular homeostasis and stable body water pool during the daily cycling between states of mild hypohydration and mild hyperhydration.[4] The regulation of water balance and thirst are tightly controlled by neuroendocrine mechanisms involving various hormone systems that largely include arginine vasopressin (AVP), or vasopressin, and the renin-angiotensin-aldosterone system. Increases in plasma osmolality above a "natural" set point, or decreases in blood volume, trigger secretion of AVP, which in turn stimulates drinking in dogs[15] and cats.[16,17] While the role of the neuroendocrine systems in regulating water and sodium balance is germane to the overall topic relating to hydration and water intake, more thorough reviews of these systems and the neurobiochemical mechanisms have been described by others.[18-20]

Water Intake and Daily Water Needs of Cats and Dogs

Based on the most recent review on water requirements of cats and dogs,[3] daily water intake volume (mL) has been reported using three different methods: 1) mL/kg BW; 2) mL/kg dry matter ingested; and 3) mL/ME kcal ingested (water:calorie intake ratio). Across all these methods, water intake can be achieved from a combination of the ingestion of water as food moisture, free water from drinking, and metabolic water. Metabolic water is generated from the oxidation of macronutrients (fats, carbohydrates, and protein) and can be calculated as 10 to 16 mL water per 100 kcal ME[21] or through the calculation of water (g) per 100 g macronutrient (107, 60, or 41, respectively).[3]

Although there does not appear to be a consensus or recommendation on which method is the most accurate or appropriate, the third method based on water:calorie intake ratio provides a convenient means of closely estimating a healthy pet's water need while accounting for different compositions of diet and varying levels of activity that result in changing levels of calorie consumption. However, some evidence exists that when exercising dogs in an extremely cold climate, this method overestimates the true need.[22] Another limitation is that changes in the ratio are accurate only if caloric intake is verifiably stable.

In general, the daily water:calorie intake ratio for estimating a cat's water need has been reported to be 0.6 to 0.7 when ingesting dry food[23-25] and 0.9 when ingesting wet food.[26] In sedentary dogs eating dry food, a 1:1 ratio previously was reported,[3] and recent research by Nestlé Purina has generally confirmed this estimate (1.1:1, B. Zanghi, unpublished data). In dogs, total water intake appears to be similar regardless of diet type (dry or wet food).[15]

This difference of the daily water:calorie ratio observed in healthy cats is because they self-regulate total water consumed through drinking to meet their daily needs in response to the moisture content of the food.[3,23,27,28] The higher ratio in cats eating wet food is a result of ingesting a large portion of their daily water as food moisture, thus they drink very little free water. By contrast, cats eating dry food receive considerably less water from food but drink significantly more water. However, this volume of water ingested through drinking when cats are fed a dry food does not typically compensate for the water received in wet food. Unfortunately, pet owners have a misperception that their cat drinks sufficiently when eating dry food because they can readily observe the cat drinking, and thus believe the cat must be adequately hydrated (Nestlé Purina, consumer research). Interestingly, the opposite perception also exists in which pet owners who regularly feed wet food indicate that they rarely observe the cat drinking, therefore they assume the animal must be dehydrated.

The currently accepted understanding for cats is that the higher total water intake and higher water:calorie intake ratio while eating wet food results in greater diuresis and that cats eating dry food, while having a lower daily water:calorie ratio, are equally sufficient in meeting daily water requirement.[3] However, cats with lower urinary tract diseases (LUTDs) appear to benefit from increased total water intake and urine output. Therefore, for health concerns related to LUTDs in cats, nutrition studies have provided some evidence that increased water intake can be achieved through modification of dietary moisture to increase food-water[27-29] or sodium content to stimulate drinking.[30-32]

Human research has demonstrated that increasing water intake to increase urine volume and dilution is typically recommended as one method of addressing the prevention of urolith recurrence.[33,34] To increase fluid intake in people, voluntarily drinking more water is most common but also includes drinking various other common beverages.[33,35] While increased total water intake for cats has been achieved through diet modification or stimulating thirst with sodium, no studies have been reported on making liquid intake more palatable to increase drinking, or through modifying the water composition, which has been widely examined in people. Although additions of flavorings to water or use of fountains have been previously suggested,[36] only a single study has reported water intake from the use of a fountain versus a bowl,[37] which did not result in improved urine dilution as indicated by similar urine specific gravity and osmolality between water sources. With regard to flavor and nutrient-enriched drinking water, initial studies by Nestlé Purina in healthy cats[25] and dogs (B. Zanghi, unpublished data) have revealed that water intake through drinking and dilution of urine can be significantly increased when provided with nutrient-enriched water.

Defining Hydration Status: What Is Optimal Versus Adequate?

Hydration is a dynamic process between water intake and loss, with a constant regulation to maintain a stable total body water pool.[38] Many factors influence daily water loss and thus hydration, including environment, health condition, age, physical activity, water availability, and diet. Factors such as environment, water availability, and physical activity play a significant role in acutely shifting hydration status. However, factors like age, health condition, and diet can have a chronic influence on hydration status.

Although targeting a healthy or optimal hydration status is believed to be important for pets and people, the physiological parameters and daily water requirement to achieve the desired level of "optimal" hydration are still undefined. This is the focus of much ongoing work within human nutrition to better define biomarkers associated with optimal hydration and more refined targets for daily water intake.[7,38-41] Early categorical grouping of hydration was generally based on hypohydration (dehydration), eu-hydration, and hyperhydration (water intoxication). However, questions remained on what biomarkers to use to assign an individual to a hydration status. These are still critical points of discussion and debate.[42-44]

One measure that has been demonstrated in the past to be important in describing some delineation of eu-hydration in healthy people is the very narrow range of average, but not individual, serum osmolality (279 to 281 mOsm/kg). However, serum osmolality has been shown to be maintained across a very wide range of total daily water intake (1.7 to 7.9 L H2O/d).[5] This narrow range of serum osmolality was confirmed in a separate study (289 to 292 mOsm/kg with water intake <1.2 to 4 L/d).[39] Based on this wide range of water intake, urine osmolality for healthy kidney function also can be wide ranging (50 to 1200 mOsm/kg),[46] thus water turnover can be low to high. Consequently, a new perspective has recently emerged to consider hydration more as a "process" instead of a "state."[7] The idea of a hydration process is based on growing evidence that a low-hydration process (low daily TBW turnover) may have detrimental health consequences.[47-49] A low-hydration process would be a result of low daily water intake and low urine volume output with higher urine osmolality.

For people, drinking makes up the majority of total water intake, whereas food water content is highly variable accounting for approximately 20 to 30% of total water intake[50,51] and metabolic water production providing only a small proportion. By contrast, as described above in cats, and possibly dogs, dietary moisture significantly influences total daily water intake and directly impacts the proportion of water intake through drinking. Using diet moisture as the example (wet food versus dry food), the distinct difference in total daily water intake and water:calorie intake ratio in cats poses a fundamental question related to categorically defining hydration status. What is the basis for defining eu-hydration, and should or does the hydration process apply, particularly in cats that naturally produce very concentrated urine?

If the assumption is that cats, and possibly dogs, eating a dry food with free access to fresh water are maintaining eu-hydration, then pets eating a wet food or high-moisture food may be considered trending toward hyperhydration and having greater diuresis. Thus, this would likely result in an increased body water turnover, which would suggest a higher hydration process. Alternatively, if ingesting wet food was the basis of maintaining eu-hydration, then by default the ingestion of dry food would suggest that pets may be maintaining a slightly hypohydration status. A third perspective is that maybe both scenarios are truly eu-hydration, which further suggests consideration of the approach of assessing hydration as a process and the need to account for daily volume in and volume out. In this case, ingestion of dry food or wet food may have each pet fall within some yet-to-be determined place on a low-to-high spectrum of the "hydration process" and related total body water turnover.

The approach to using a hydration process may or may not be appropriate for pet cats and dogs. Or, the biomarkers that are used to define various degrees of hydration for cats and dogs may differ from those used for people. In contrast to humans, serum osmolality in cats has been reported over a very wide range (276 to 361, Table 1), and while it is less broad for dogs (281 to 333, Table 2), it is still considerably greater than in people. In addition, once diet type and moisture content are established for the individual cat and dog, total daily water intake remains relatively stable when the pet has a predictable routine and maintains a mildly active to sedentary lifestyle. Compared to total water intake in the adult human, attempting to determine and recommend the volume of water intake per day for dogs is possible but not ideal, because body weight (BW) can vary dramatically across breeds, thus volume ranges will require caveats to account for pet BW. However, this comparison may work

Table 1. Mean (± SD) serum, urine, and water intake measures in adult cats by separate or combined gender, ingesting dry or wet food with free access to tap water.

Health Status (Age)	Gender and Food Type*	N	Serum Osmolality (mOsmo/kg)	Urine Specific Gravity (g/mL)	Urine Osmolality (mOsmo/kg)	Daily Water Intake (mL/kg BW)	Refs
healthy (3-15 years)	M+F# - dry	23	310 ±11	1.053 ±0.007	2222 ±257	20.9±9.1	53
	Female - dry	11	312 ±11	1.050 ±0.008	2177 ±315	19.6 ±8.9	
	Male - dry	12	309 ±12	1.052 ±0.009	2197 ±312	22.0 ±9.2	
	median (range)		313 (283-332)	1.052 (1.026-1.072)	2200 (1199-2864)	19.8 (6.5-61.5)	
healthy (2-11 years)	Female - dry	5	305 ±12	1.058 ±0.005	2402 ±194		28
	Male - dry	7	300 ±12	1.060 ±0.005	2445 ±234		
	median (range)	12	300 (286-327)	1.059 (1.052-1.068)	2428 (2194-2874)	109.2 (93.0-128.0)††	
	Female - wet	6	319 ±7	1.055 ±0.005	2197 ±187		
	Male - wet	6 (9)†	323 ±13	1.049 ±0.008	2197 ±343		
	median (range)		317 (310-341)	1.054 (1.036-1.064)	2071 (1398-2550)	29.7 (17.7-126.3)††	
healthy (0.5-10 years)	M+F - dry	12	ND	1.055 ±0.005	2469 ±367	22.9 ±10.2	37
	Female - dry	6	ND	1.056 ±0.004	2496 ±334	ND	
	Male - dry	6	ND	1.054 ±0.005	2442 ±428	ND	
	median (range)		ND	1.055 (1.046->1.060)	2372 (1977-3105)	ND	
healthy (0.5-21 years)	Female - dry	NR	ND	~1.050‡	ND	ND	60
	Male - dry	NR	ND	~1.050‡	ND	ND	
	Female - wet	NR	ND	~1.040‡	ND	ND	
	Male - wet	NR	ND	~1.050‡	ND	ND	
	median (range)	949	ND	1.050 (1.005-1.090)	ND	ND	
healthy (2-9 years)	M+F - dry	6	ND	~1.053 ±0.005	ND	103.4 ±13.0**	27
	M+F - wet	6	ND	1.036 ±0.005	ND	144.7 ±12.7**	
healthy (adult)	Male - dry	10	ND	ND	ND	156**	26
	Male - wet	9	ND	ND	ND	156**	
healthy (1-8 years)	Male - dry	10	ND	1.051	ND	211.6 ±67.2**	61
	Male - dry	10	ND	1.040	ND	234.6 ±61.7**	
healthy (NR)	Male - dry	15	ND	1.056 ±0.007	2079 ±541	179 ±42**	24
idiopathic cystitis	M+F - dry	28	ND	1.052 ±0.012	ND	ND	29
(1-7 years)	M+F - wet	18	ND	1.041 ±0.013##	ND	ND	

* food type indicated as dry is representative of food with less than 10% moisture, whereas wet is representative of food having approximately 65-75% moisture
#M+F: combination of males and females
†number in brackets is for the number of pets used for urine data
‡visually estimated mean based figure 4 from reference 60
†† representative of only free water volume ingested (total mL/d)
**data units: total mL /d
##data collected after 6 months of feeding diet
ND: not determined NR: not reported

Table 2. Mean± SD) serum, urine, and water intake measures in healthy, adult dogs, reported by separate or combined gender, ingesting dry with free access to tap water.

Health Status (Age)	Gender	N	Serum Osmolality (mOsmo/kg)	Urine Specific Gravity (g/mL)	Urine Osmolality (mOsmo/kg)	Daily Water Intake (mL/kg BW)	Refs
Mongrel (3-15 years)	M+F	19	~298	ND	1514 ±436	63-67	62
	female		ND	ND	ND		
	male		ND	ND	ND		
	median (range)		ND	ND	ND		
Kelpie (2 years)	female	4	ND	ND	ND	72.9 ±7.4	63
Beagle or Hound	M+F	12	ND	ND	ND	27.5 ±3.6	64
(0.5-10 years)	female	6	ND	ND	ND	28.8 ±4.1	
	male	6	ND	ND	ND	26.2 ±2.8	
	median (range)		ND	ND	ND	26.6 (22.5-35.7	
Beagles and Labrador	female	6	298 ±6	1.022 ±0.012	879 ±446	66.5 ±31.4	NP
Retriever	male	8	294 ±5	1.034 ±0.010	1356 ±323	56.5 ±16.8	
(2.4-11 years)	median (range)	14	295 (286-305)	1.033 (1.008-1.046)	1278 (268-1801)	57.0 (35.4-122.6)	
Breed not specified	female	4	ND	ND	ND	36.8 ±21.4	65
(adult)	median (range)		ND	ND	ND	32.1 (16.6-66.5)	

NP: Nestlé Purina, unpublished data

for cats, as there is much less variation in BW among breeds. Regardless, if applying the water:-calorie ratio as a surrogate for total water intake when cats are housed indoors in a climate-controlled environment and calorie intake is stable, then the day-to-day range of group mean water:calorie ratio tracked over seven days is relatively narrow (0.55 to 0.69, B. Zanghi, unpublished data). This contrasts the water intake range in people. The day-to-day variation is slightly greater in dogs based on the range of group mean water:calorie ratio tracked over 14 days (1.0 to 1.4, B. Zanghi, unpublished data). Although water:calorie ratio does not discern if water intake is increasing or calorie intake is decreasing, in situations where food intake is known to be stable, this measure is likely valuable to normalize water intake across all breeds of dogs and cats and provide a basis for estimating a low or high hydration process.

Biomarkers of Hydration: Characterizing Normal Ranges Is Needed

Using the same logic that is the focus of ongoing research in human nutrition to assess hydration, it appears that it will be important to further characterize the various physiological measures of urine and water intake across a range of health populations with varying demographics.[4,7,52] While many urine measures are traditionally used as a clinical reference to assess normal or abnormal kidney function, several of these measures could be used to establish confidence intervals, percentile ranges, and thus targeted estimates within the feline or canine population to at least define eu-hydration. This is obviously easier said than done, as much work is necessary to determine how and to what extent eu-hydration may differ between breeds, gender, body composition, age, etc. With the

Figure 1. Dog data (N=345) comparing urine osmolality (mOsmo/kg) generated from samples collected 5 times over 2 weeks in N=35 dogs on same days as water:calorie (mL:ME kcal) data was recorded, followed by replicating the collection a second time several weeks later.

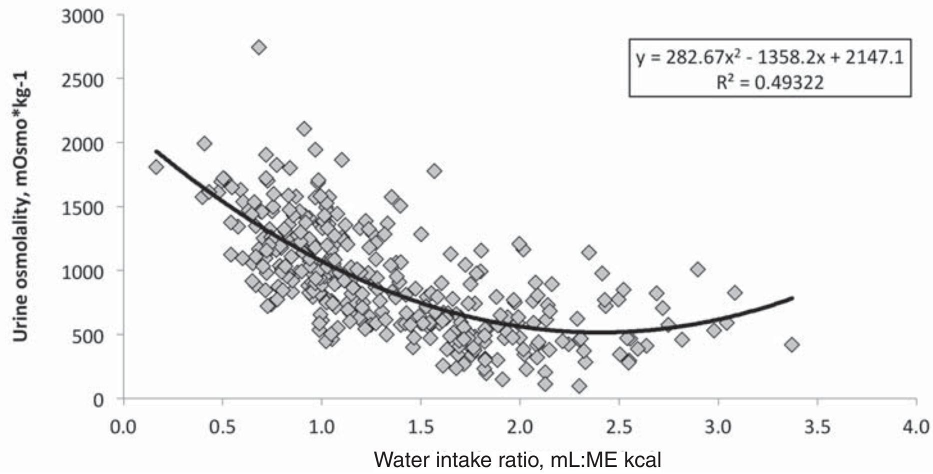


Figure 2. Dog data (N=325) comparing urine osmolality (mOsmo/kg) and serum osmolality (mOsmo/kg) generated from samples collected 5 times over 2 weeks in N=33 dogs, followed by replicating the collection a second time several weeks later.

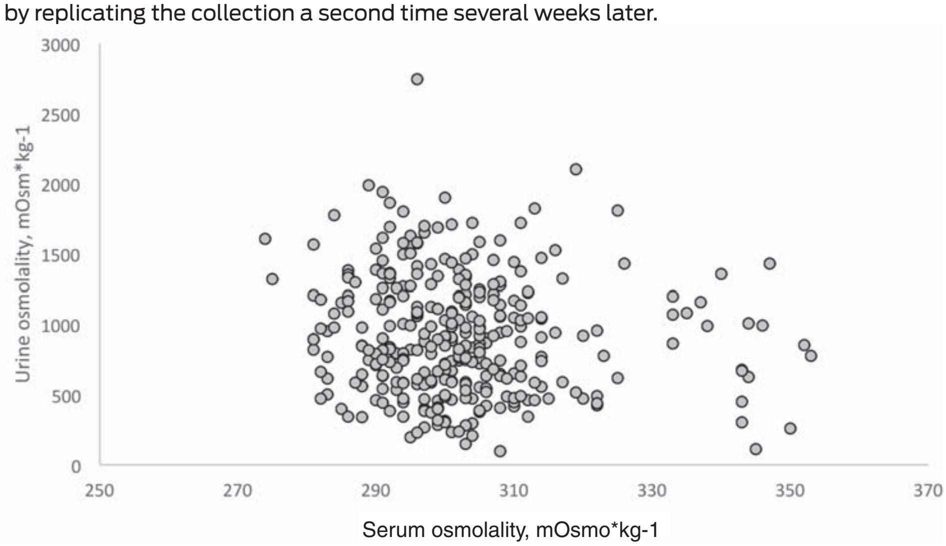


Figure 3. Cat data (N=135) comparing urine osmolality (mOsmo/kg) and serum osmolality (mOsmo/kg) generated from samples collected 3 times over 2 weeks in N=23 cats (tap water), followed by replicating the collection a second time several weeks later(test water). [53]

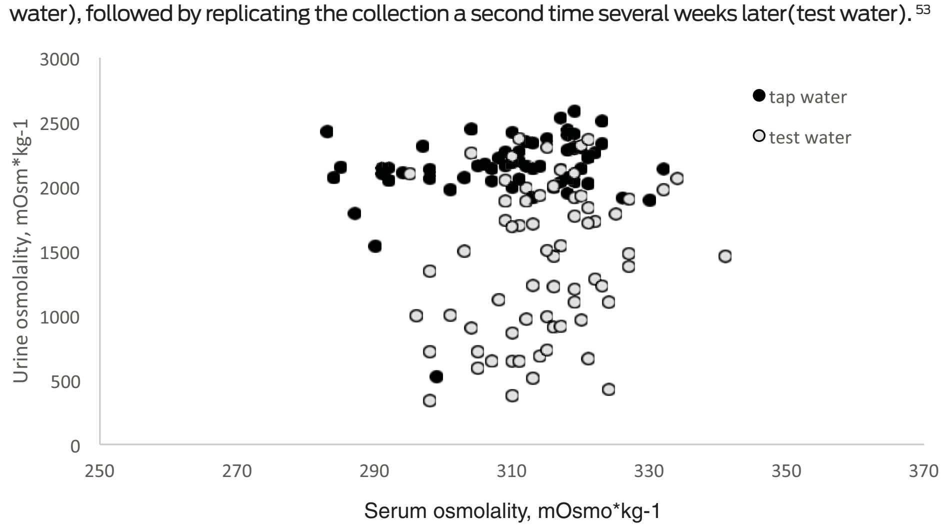


Figure 4. Cat data (N=135) comparing urine osmolality (mOsmo/kg) generated from urine samples collected 3 times over 2 weeks in N=23 cats on same days as water:calorie (mL:ME kcal) data (tap water), followed by replicating the collection a second time several weeks later (test water).[53]

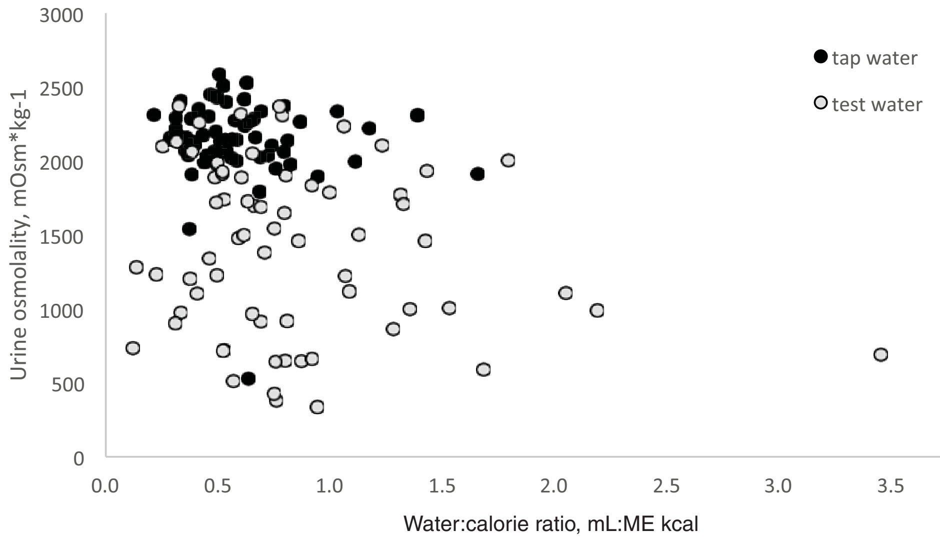
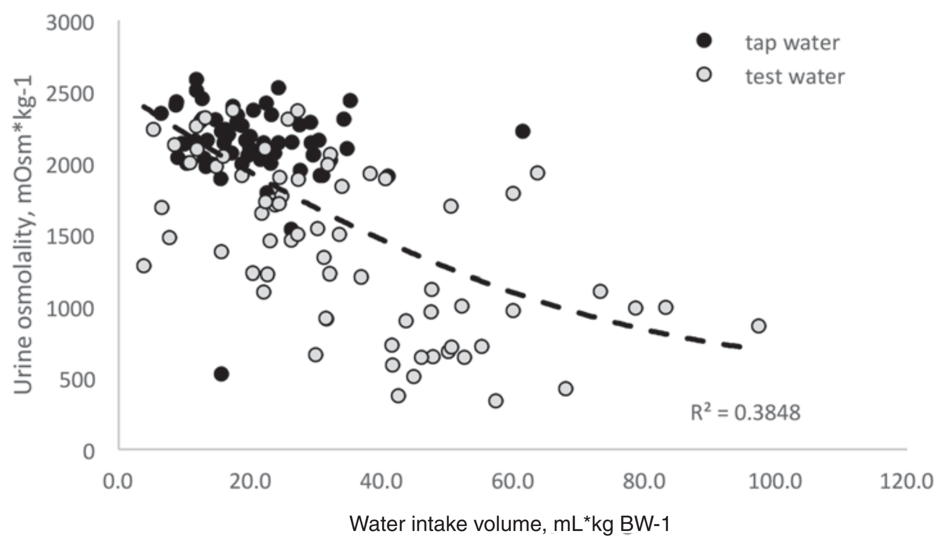


Figure 5. Cat data (N=135) comparing urine osmolality (mOsmo/kg) generated from urine samples collected 3 times over 2 weeks in N=23 cats to the previous day's total water intake volume (mL/kg BW) data (tap water), followed by replicating the collection a second time several weeks later (test water).[53]



existing published literature in cats and dogs, some values have been compiled based mostly on data from healthy pets with segregation of gender and food moisture when possible (Tables 1 and 2).

In most healthy animals, the kidney is normally producing concentrated urine, and fluid intake does not typically occur in excess of need to maintain eu-hydration. In people, urine osmolality has a typical range of 100 to 1200 mOsmo/kg, which decreases with increasing total water intake[40] and is approximately two to three times serum osmolality. Similarly with dogs, urine osmolality can be wide ranging (150 to 1943 mOsm/kg) and also declines with increasing water:calorie intake ratio (Figure 1). Because dogs have a much higher concentrating ability versus humans, this can yield a broad urine:serum osmolality ratio range (0.5 to 6.7, Figure 2). By contrast, cats have a much higher minimum threshold for urine concentration, which typically ranges from approximately 2000 to 3000 mOsm/kg (Table 1). Consequently, this is 5.9 to 8.5 times serum osmolality (Figure 3) when they have free access to tap water regardless of wet or dry food ingestion. One related measurement that needs better characterization is the potential relationship between urine concentration and urine output volume, particularly in cats.

Interestingly, recent research has indicated that urine dilution is possible below 2000 mOsmo/kg in cats when they are provided free access to a nutrient-enriched, flavored water (test water) that increases water intake (Figure 4). However, the dilution in urine is not wholly explained with water:calorie intake ratio, since urine dilution is observed even when the ratio is below 0.6. This is partially influenced by the slight decreased food calorie intake that cats experience while drinking the palatable test water. Examination of this data on the basis of only water intake volume and standardized on a body weight basis (mL/kg BW) provides more clarity to the value of increasing water intake through drinking to support a dilution in urine (Figure 5).

Concentrated urine is also normal with adequate water intake in dogs, and increased water intake will result in diluted urine (Figure 1). Considering this dog data (Figure 1) and cat data (Figure 5) begins to provide some evidence in support of exploring the hypothesis of increased hydration process. However, it is only the first part for dogs and cats since it will be necessary to examine urine output and total water balance to begin characterizing the hydration process more thoroughly.

Based only on the canine data set in Figure 1, and not the body of literature compiled in Table 2, it appears that adequate hydration, or eu-hydration, may be achieved if the water:calorie ratio is at least 0.9 and up to 1.1. Although optimal hydration is yet to be defined, increasing water:calorie intake ratio to at least 1.4, appears to sustain a low to moderately concentrated urine. For cats based solely on the data described in Figure 5, it appears that when cats have approximately 30 mL/kg BW of total water intake per day from all dietary and metabolic sources, urine can be effectively diluted while remaining within normal clinical ranges of healthy kidney function (urine specific gravity >1.025 or osmolality >~1000). This data also corresponds with higher urine output volume and no difference in glomerular filtration rate (GFR),[53] which was confirmed in a separate study.[25] For dogs, characterizing urine output volume, GFR, and other physiological measures will be necessary and beneficial. Finally, because all the data described above is related to healthy pets, it is possible that the optimal water intake requirement or urine-based biomarkers associated with hydration may not likely be similar when comparing healthy individuals to those with LUTDs or renal dysfunction.

Hypohydration and Brain Health

Nutrition research investigating dehydration in people has revealed that humans often experience mild dehydration during daily activities because of inadequate water intake,[4] and studies have generated evidence of this since the 1940s.[54,55] Based on this early work, thirst sensation in people occurs when 1 to 2% of BW is lost because of dehydration. In dogs, evidence has been generated that thirst sensation is triggered with a 0.5 to 1% loss of BW.[56,57]

While seemingly inconsequential in the past, only recently has it become apparent that mild hypohydration (<2%) can have cognitive implications. A study with young adults (men and women) and children indicated that dehydration of <2% loss of BW resulted in impaired cognitive performance and mood.[52,58,59] To date, this type of data does not exist for cats or dogs. The human evidence offers insight on areas to explore to examine the potential impact of mild dehydration on all aspects of pet brain health, behavior, cognitive ability, and even brain development. Because mild dehydration can have an impact on mood and pain sensation in people, this also highlights areas to consider related to pets that are older and/or overweight and suffer from some level of osteoarthritis or joint discomfort, particularly since overweight pets appear to be prone to have proportionally lower total body water relative to lean mass.

Conclusion

This review is an initial attempt to begin compiling available knowledge from healthy pets and identify areas to explore to complete the broader understanding of water and hydration needs. It is clear that a significant amount of research remains before hydration status or hydration process can be defined for pet dogs and cats. The current body of literature appears to establish a basis for aligning targets of daily water intake volumes for wet versus dry foods in cats, but much less so for dogs. How the varying amounts of daily water intake relate to a low, moderate, or high hydration process, along with the prospect of how this impacts long-term health, not only remains to be determined, but could be interesting and possibly very important to consider to improve dietary water recommendations for healthy pets. For pets with some type of urinary tract condition, obesity, and/or geriatric life stage, the need is likely even greater.

References

1. Manz F, Wentz A, Sichert-Hellert W. The Most Essential Nutrient: Defining the Adequate Intake of Water. *J Pediatr*. 2002;141:587-592.

2. Jéquier E, Constant F. Water as an Essential Nutrient: The Physiological Basis of Hydration. *Eur J Clin Nutr*. 2010;64:115-123.

3. Nutrient Requirements of Dogs and Cats. National Research Council. Washington, D.C.: The National Academies Press. 2006:246-250.

4. Armstrong LE. Hydration Biomarkers During Daily Life. *Nutr Today*. 2012;47:S3-S6.

5. Rush EC. Water: Neglected, Unappreciated and Under Researched. *Eur J Clin Nutr*. 2013;67:492-495.

6. Maughan R. Introduction to the European Hydration Institutes' Expert Conference on Human Hydration, Health, and Performance. *Nutr Rev*. 2014;72(S2):55-56.

7. Perrier ET, Armstrong LE, Daudon M, et al. From State to Process: Defining Hydration. *Obesity Facts*. 2014;7(S2):6-12.

8. Zanghi BM, Cupp C, Pan Y, et al. Noninvasive Measurements of Body Composition and Body Water Via Quantitative Magnetic Resonance, Deuterium Water, and Dual-Energy X-Ray Absorptiometry in Cats. *Am J Vet Res*. 2013a;74:721-732.

9. Zanghi BM, Cupp C, Pan Y, et al. Noninvasive Measurements of Body Composition and Body Water Via Quantitative Magnetic Resonance, Deuterium Water, and Dual-Energy X-Ray Absorptiometry in Awake and Sedated Dogs. *Am J Vet Res*. 2013;74:733-743.

10. Wang Z, Deurenberg P, Wang W, et al. Hydration of Fat-Free Body Mass: Review and Critique of a Classic Body-Composition Constant. *Am J Clin Nutr*. 1999;69:833-841.

11. Wang Z, Deurenberg P, Wang W, et al. Hydration of Fat-Free Body Mass: New Physiological Modeling Approach. *Am J Physiol*. 1999;276:E995-E1003.

12. Burkholder WJ, Thatcher CD. Validation of Predictive Equations for Use of Deuterium Oxide Dilution to Determine Body Composition of Dogs. *Am J Vet Res*. 1998 59:927-937.

13. Speakman JR, Booles D, Butterwick R. Validation of Dual Energy X-Ray Absorptiometry (DXA) by Comparison with Chemical Analysis of Dogs and Cats. *Int J Obes Relat Metab Disord*. 2001;25:439-447.

14. Chumlea WC, Schubert CM, Sun SS, et al. A Review of Body Water Status and the Effects of Age and Body Fatness in Children and Adults. *J Nutr Health Aging*. 2007;11:111-118.

15. Ramsay D, Thrasher T. Regulation of Fluid Intake in Dogs Following Water Deprivation. *Brain Res Bull*. 1991;27:495-499.

16. Reaves Jr. TA, Liu HM, Qasim MM, et al. Osmotic Regulation of Vasopressin in the Cat. *Am J Physiol*. 1981;240:E108-E111.

17. Doris PA. Osmotic Regulation of Evaporative Water Loss and Body Temperature by Intracranial Receptors in the Heat-Stressed Cat. *Pflug Arch*. 1983;398:337-340.

18. Bisset GW, Chowdrey HS. Control of Release of Vasopressin by Neuroendocrine Reflexes. *Q J Exp Physiol*. 1988;73:811-872.

19. Fitzsimons J. Angiotensin, Thirst, and Sodium Appetite. *Physiological Rev*. 1998;78: 585-686.

20. Steele JL, Henik RA, Stepien RL. Effects of Angiotensin-Converting Enzyme Inhibition on Plasma Aldosterone Concentration, Plasma Renin Activity, and Blood Pressure in Spontaneously Hypertensive Cats with Chronic Renal Disease. *Vet Ther*. 2002;3:157-166.

21. Nutrient Requirements of Dogs and Cats. National Research Council. Washington, D.C.:The National Academies Press. 2006:39.

22. Hinchcliff K, Reinhart G. Energy Metabolism and Water Turnover in Alaskan Sled Dogs During Running. In: *Recent Advances in Canine and Feline Nutritional Research. Proc Iams Intl Nutr Symp*. Carey D, Norton S, Bolser S (eds). Wilmington, OH:Orange Frazer Press. 1996:199-206.

23. Seefeldt S, Chapman T. Body Water Content and Turnover in Cats Fed Dry and Canned Rations. *Am J Vet Res*. 1979;40: 183-185.

24. Finco DR, Adams DD, Crowell WA, et al. Food and Water Intake and Urine Composition in Cats: Influence of Continuous Versus Periodic Feeding. *Am J Vet Res*. 1986;47:1638-1642.

25. Zanghi B, Gardner C, Reynolds A. Increased Water Intake and Hydration in the Domestic Cat Ingesting a Nutrient-Enriched Water. *Proc Am Coll Vet Int Med*. 2017. (Abstract in press)

26. Jackson O, Tovey J. Water Balance Studies in Domestic Cats. *Feline Pract*. 1977;7:30-33.

27. Buckley CM, 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. *Brit J Nutr*. 2011;106:S128-S130.

28. Xu H, Greco DS, Zanghi B, et al. The Effect of Feeding Inversely Proportional Amounts of Dry Versus Canned Food on Water Consumption, Hydration, Body Composition, and Urinary Parameters in Cats. *Proc Wrld Small Anim Vet Assoc Conf*. Cape Town, South Africa. 2014:852.

29. 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.

30. Hawthorne AJ, Markwell PJ. Dietary Sodium Promotes Increased Water Intake and Urine Volume in Cats. *J Nutr*. 2004;134:2128S-2129S.

31. Xu H, Laflamme D, Bartges J, et al. Effect of Dietary Sodium on Urine Characteristics in Healthy Adult Cats. *J Vet Intern Med*. 2006;20:738.

32. Xu H, Laflamme D, Long G. Effects of Dietary Sodium Chloride on Health Parameters in Mature Cats. *J Feline Med Surg*. 2009;11:435-441.

33. Borghi L, Meschi T, Schianchi T, et al. Urine Volume: Stone Risk Factor and Preventive Measure. *Nephron*. 1999;81:31-37.

34. Guerra A, Allegri F, Meschi T, et al. Effects of Urine Dilution on Quantity, Size and Aggregation of Calcium Oxalate Crystals Induced *in Vitro* by an Oxalate Load. *Clin Chem Lab Med*. 2005;43:585-589.

35. Armstrong LE, Ganio MS, Casa DJ, et al. Mild Dehydration Affects Mood in Healthy Young Women. *J Nutr*. 2012;142: 382-388.

36. Forrester D, Roudebush P. Evidence-Based Management of Feline Lower Urinary Tract Disease. *Vet Clin N Am Small*. 2007;37:533-558.

37. Grant D. Effect of Water Source on Intake and Urine Concentration in Healthy Cats. *J Feline Med Surg*. 2010;12: 431-434.

38. Perrier E, Johnson EC, McKenzie AL, et al. Urine Colour Change as an Indicator of Change in Daily Water Intake: A Quantitative Analysis. *Eur J Nutr*. 2016;55:1943-1949.

39. Perrier E, Rondeau P, Poupin M, et al. Relation Between Urinary Hydration Biomarkers and Total Fluid Intake in Healthy Adults. *Eur J Clin Nutr*. 2013;67:939-943.

40. Perrier E, Buendia-Jimenez I, Vecchio M, et al. Twenty-Four-Hour Urine Osmolality as a Physiological Index of Adequate Water Intake. *Dis Markers*. 2015; 2015:231063. doi:10.1155/2015/231063

41. Perrier E, Bottin JH, Vecchio M, et al. Criterion Values for Urine-Specific Gravity and Urine Color Representing Adequate Water Intake in Healthy Adults. *Eur J Clin Nutr*. 2017. doi:10.1038/ejcn.2016.269 (Epub ahead of print)

42. Shirreffs S. Markers of Hydration Status. *Eur J Clin Nutr*. 2003;57:S6-S9.

43. Armstrong LE. Assessing Hydration Status: The Elusive Gold Standard. *J Am Coll Nutr*. 2007;26:575S-584S.

44. Reimers K. Hydration: Assessment and Recommendations. *Nutr Today*. 2009;44:8-10.

45. NCHS: Third National Health and Nutrition Examination Survey (NHANES III). 1988-1994. U.S. Department of Health and Human Services.

46. Guyton A, Hall J. Regulation of Extracellular Fluid Osmolarity and Sodium Concentration. In: Textbook of Medical Physiology. Guyton AC, Gall JE (eds). Philadelphia: Elsevier. 2006:348-364.

47. Stookey JD, Pieper CF, Cohen HJ. Hypertonic Hyperglycemia Progresses to Diabetes Faster than Normotonic Hyperglycemia. *Eur J Epidemiol*. 2004;19:935-944.

48. Manz F, Wentz A. The Importance of Good Hydration for the Prevention of Chronic Diseases. *Nutr Rev*. 2005;63:S2-S5.

49. Strippoli GF, Craig JC, Rochtchina E, et al. Fluid and Nutrient Intake and Risk of Chronic Kidney Disease. *Nephrology* (Carlton). 2011;16:326-334.

50. Institute of Medicine: Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate. Washington, D.C.: The National Academies Press. 2004.

51. Scientific Opinion on Dietary Reference Values for Water. *EFSA J*. 2010;8:1459-1506.

52. Armstrong LE, Ganio MS, Casa DJ, et al. Mild Dehydration Affects Mood in Healthy Young Women. *J Nutr*. 2012;142: 382-388.

53. Zanghi B, Gardner C, Gerheart L, et al. Increased Water Drinking and Enhanced Hydration in the Domestic Cat When Offered a Nutrient-Enriched Water Instead of Tap Water Paired with Dry Kibble. *J Anim Physiol An N*. (Under review)

54. Voluntary Dehydration. In: *Physiology of Man in the Desert*. New York: Interscience Publishers. Adolph E (ed). 1947:254-270.

55. Greenleaf J. Problem: Thirst, Drinking Behavior, and Involuntary Dehydration. *Med Sci Sport Exer*. 1992;24:645-656.

56. Robinson E, Adolph E. Pattern of Normal Water Drinking in Dogs. *Am J Physiol*. 1943;139:39-44.

57. O'Connor W. Drinking by Dogs During and After Running. *J Physiol*. 1975;250:247-259.

58. Ganio MS, Armstrong LE, Casa DJ, et al. Mild Dehydration Impairs Cognitive Performance and Mood of Men. *Brit J Nutr*. 2011;106:1535-1543.

59. Benton D, Young H. Do Small Differences in Hydration Status Affect Mood and Mental Performance? *Nutr Rev*. 2015;73:83-96.

60. Rishniw M, Bicalho R. Factors Affecting Urine Specific Gravity in Apparently Healthy Cats Presenting to First Opinion Practice for Routine Evaluation. *J Feline Med Surg*. 2015;17: 329-337.

61. Thrall B, Miller L. Water Turnover in Cats Fed Dry Rations. *Feline Pract*. 1976;6:10-17.

62. Thrasher T, Wade C, Keil L, et al. Sodium Balance and Aldosterone During Dehydration and Rehydration in the Dog. *Am J Physiol*. 1984;247:R76-R83.

63. English P, Filippich L. Measurement of Daily Water Intake in the Dog. *J Small Anim Pract*. 1980;21:189-193.

64. Cizek L. Long-Term Observations on Relationship Between Food and Water Ingestion in the Dog. *Am J Physiol*. 1959; 197:342-346.

65. Golob P, O'Connor WJ, Potts DJ. Increase in Weight and Water Retention on Overfeeding Dogs. *Q J Exp Physiol*. 1984; 69:245-256.