Research in Veterinary Science 115 (2017) 366–370

Contents lists available at ScienceDirect

Research in Veterinary Science

journal homepage: www.elsevier.com/locate/rvsc

Epidemiologic evaluation of canine urolithiasis in Thailand from 2009 to 2015

Vachira Hunprasit[a,b,*], Carl A. Osborne[a], Pamela J. Schreiner[c], Jeff B. Bender[d], Jody P. Lulich[a]

[a] Department of Veterinary Clinical Science, College of Veterinary Medicine, University of Minnesota, MN, USA
[b] Faculty of Veterinary Science, Chulalongkorn University, Bangkok, Thailand
[c] Division of Epidemiology and Community Health, University of Minnesota, Minneapolis, USA
[d] Department of Veterinary Population Medicine, University of Minnesota, MN, USA

ARTICLE INFO

Keywords:
Urolithiasis
Canine
Thailand
Epidemiology

ABSTRACT

The cross-sectional study described the epidemiology of 8560 canine urolith submissions from Thailand to the Minnesota Urolith Center between January 2009 and December 2015. The frequency of urolith types, the relationships between urolith type and breed, sex, and neutered status, and change of annual submission proportion over the study period were analyzed. Struvite was the most common canine urolith (44%), and was commonly found in intact females with a mean age of 6.3 ± 3.1 years. Calcium oxalate was the second most common (27%), more frequently found in intact males with a mean age of 8.8 ± 3.3 years. Compound, purine, cystine, calcium phosphate, and silica urolith were less common. During the study period, the proportion of struvite urolith significantly decreased from 48% in 2009 to 39% in 2015 ($p < 0.001$). The proportion of CaOx increased from 21% in 2009 to 32% in 2015 ($p < 0.001$). The results of this study can help veterinarians predict urolith composition to select diagnostic tests and to initiate therapy prior to urolith removal.

1. Introduction

Urolithiasis is a common and recurrent problem in dogs, estimated to occur in 0.4–2.0% of dogs receiving medical care (Bovee and McGuire, 1984). The type of urolith may vary depending on age, breed, and sex of the dog, the type of food consumed, and geographic location of where the dog resides (Franti et al., 1999; Ling et al., 1998a; Ling et al., 1998b).

Selecting safe and effective urolith-removal procedures depends on reliable identification of urolith composition. Although radiographic appearance aids prediction of composition, some urolith types are radiographically indistinguishable (Weichselbaum et al., 1999; Weichselbaum et al., 2001). Likewise, in some urolith-forming dogs, crystalluria is absent or incongruent with the type of urolith residing in the patient (Fromsa et al., 2011). Knowing the prevalence of the different types of uroliths, and the likelihood at which they occur in particular breeds, sexes and ages of dogs, can help veterinarians more accurately predict their mineral composition.

Unfortunately, epidemiologic information is not available for dogs in Thailand. The results of similar studies conducted in different geographic areas may not be applicable because of differences in geography, diet and breed popularity. The purpose of this study is to evaluate epidemiological data from urolith-forming dogs in Thailand to assist veterinarians in this region to more effectively administer medical care.

2. Materials and methods

2.1. Sample population

Canine urolith submissions from Thailand to the Minnesota Urolith Center between January 2009 and December 2015 were reviewed. The information evaluated from each record included quantitative mineral composition of the urolith, year of submission, breed, sex, neutered status, age, and location of urolith within the urinary tract of the dog.

2.2. Urolith analyses

Mineral composition of uroliths was determined by polarization microscopy and infrared spectroscopy. A urolith without a nidus or shell that contained ≥ 70% of a single mineral was identified by that mineral. A urolith without a nidus or shell that contained < 70% of any single mineral was referred to as a mixed urolith. Compound uroliths were defined as having a central core or outer layer containing ≥ 70%

* Corresponding author at: Department of Veterinary Clinical Science, College of Veterinary Medicine, University of Minnesota, MN, USA.
E-mail address: hunpr001@umn.edu (V. Hunprasit).

http://dx.doi.org/10.1016/j.rvsc.2017.07.008
Received 21 November 2016; Received in revised form 13 June 2017; Accepted 8 July 2017

of a single mineral with an opposing outer layer or central core of a different mineral.

2.3. Statistical analyses

Descriptive statistics of categorical variables, including mineral composition, breed, sex, neutered status, and anatomic location were presented in percentages, and age as mean ± SD. Age between male and female for each urolith type was compared by Student's *t*-test. The relationship between urolith type and breed, sex, and neutered status were examined by χ^2 test. The change of the annual submission percentage of each urolith type was evaluated by Cochran-Armitage trend test (Armitage, 1955). Statistical analyses were performed using SAS/STAT™ software (SAS Institute Inc., Cary, NC, USA). The level of statistical significance was set at 0.05.

3. Result

From 2009 to2015, 8560 canine urolith submissions were received from 139 veterinary hospitals in Thailand. Of 8560 submissions, 239 (2.8%) were from the upper urinary tract and 8321 (97.2%) were from the lower urinary tract (Table 1). Fifty-one percent (4288) were from male dogs: 3294 were intact and 994 were neutered. Forty-seven percent (4002) were from female dogs: 3008 were intact and 994 were spayed. Sex was not reported in 270 submissions. The average age of dogs at the time of urolith removal was 7.2 ± 3.4 years. Seventy-three breeds were reported: of these breeds, 78.2% of uroliths were from 7 breeds: Shih Tzu (2464; 28.8%), mixed breed (1449; 16.9%), Miniature Poodle (1057; 12.3%), Pomeranian (712; 8.3%), Pug (394; 4.6%), Yorkshire Terrier (319; 3.7%), and Chihuahua (310; 3.6%).

3.1. Struvite urolith

Forty-four percent (3750) was struvite. Struvite uroliths were more common in females (68.9%) than males (31.1%) ($p < 0.001$)and more common in intact than neutered dogs ($p < 0.001$). The average age of dogs with struvite uroliths was 6.3 ± 3.1. Age was not different between males and females (6.3 ± 3.2 years vs. 6.2 ± 3.0 years, $p > 0.05$). Struvite uroliths were identified in 57 pure breeds. Common breeds included Shih Tzu (1284; 34.2%), Miniature Poodle (508; 13.5%), Pomeranian 192; 5.1%), Pug (154; 4.1%), Chihuahua (110; 2.9%), Golden Retriever (81; 2.2%), and Yorkshire Terrier (80; 2.1%). The annual proportion of struvite submissions decreased from 47.8% in 2009 to 39.4% in 2015 ($p < 0.001$).

3.2. Calcium oxalate urolith

Twenty-seven percent (2328) of uroliths were CaOx. Calcium oxalate uroliths were submitted more often from males (83.7%) than females (16.3%) ($p < 0.001$) and more common in intact animals than neutered ($p < 0.001$). The average age of dogs with CaOx urolith was 8.8 ± 3.3 years: average age of males and females did not differ (8.7 ± 3.3 years vs. 9.1 ± 3.1 years, p-value > 0.05). Calcium oxalate uroliths were reported in 48 pure breeds. Common breeds included Shih Tzu (523; 22.5%), Pomeranian (341; 14.6%), Miniature Poodle (257; 11.0%), Yorkshire Terrier (156; 6.7%) and Chihuahua (125; 5.4%). There was a significant increase in the annual proportion of CaOx urolith submissions from 21.2% in 2009 to 32.4% in 2015 ($p < 0.0001$).

3.3. Compound urolith

Fourteen percent (1203) of uroliths were compound. Compound uroliths were more common in females(59.6%) than in males (40.4%) ($p < 0.001$). The average age of dogs with compound uroliths was 7.5 ± 3.4 years which average age of males and females did not differ (7.7 ± 3.6 years vs. 7.4 ± 3.2 years, $p > 0.05$). Compound uroliths were identified in 41 pure breeds. Common breeds included Shih Tzu (366; 30.4%), Miniature Poodle (179; 14.8%), and Pomeranian (105; 8.7%). A uniform central core was present in all compound uroliths. Of these, 401 (33.3%) had a central core of struvite of which 62.3% had an outer layer of Calcium phosphate (CaP). Three hundred and thirty-seven (28%) had a central core of CaOx of which 71% had an outer layer of struvite. Thirty-six uroliths had a nidus which was not composed of elements filtered by the kidneys. Of these 36 foreign items, 26 were filamentous material consistent with suture, two were composed of plant material and one was rubber material. The outer layer of these foreign body-associated compound uroliths was predominantly struvite (Table 2).

3.4. Purine urolith

Five percent (415) of uroliths were purine. Purine uroliths were overrepresented in males compared to females (86.8% vs. 13.2%; p-value < 0.001). The average age of dogs with purine urolith was 6.5 ± 3.6 years. Female dogs (5.8 ± 2.8 years) with purine urolith were of similar age as male dogs (6.7 ± 3.7 years) ($p > 0.05$). Purine urolith was identified in 25 pure breeds. Common breeds included Dalmatian (120; 28.9%), Shih Tzu (74; 17.8%), Pug (44; 10.6%), Miniature Poodle (20; 4.8%), Yorkshire Terrier (14; 3.4%), and Pit Bull Terrier (14; 3.4%). There was a significantly decrease annual proportion of purine uroliths over time from 7.7% in 2009 to 3.4% in 2015 (p-value < 0.001).

3.5. Calcium phosphate urolith

Two percent (147) of urolith were CaP. Calcium phosphate were more common in males(62.2%) than females (37.8%) ($p = 0.0112$). The average age was 7.5 ± 3.6 years. Male dogs with CaP uroliths were younger than female dogs (7.0 ± 3.8 years vs. 8.3 ± 3.4 years

Table 1
Epidemiological data: type, sex, age, and anatomic location distribution of the uroliths.

Urolith type	n	Sex			Age (y)	Location of urolith	
		Male[a]	Female[a]	no report		Upper urinary tract	Lower urinary tract
Struvite	3750	1127 (929/198)	2501 (1924/577)	122	6.3 ± 3.1	91 (38.1%)	3659 (44.0%)
CaOx	2328	1899 (1403/496)	371 (241/130)	58	8.8 ± 3.3	63 (26.4%)	2265 (27.2%)
Compound	1203	469 (346/123)	691 (527/164)	43	7.5 ± 3.4	35 (14.6%)	1168 (14.0%)
Purine	415	349 (257/92)	53 (43/10)	13	6.5 ± 3.6	15 (6.3%)	400 (4.8%)
CaP	147	89 (65/24)	54 (35/19)	4	7.5 ± 3.6	10 (4.2%)	137 (1.7%)
Cystine	134	126 (117/9)	2 (2/0)	6	4.8 ± 2.4	3 (1.3%)	131 (1.6%)
Silica	18	15 (15/0)	3 (3/0)	0	7.6 ± 2.4	1 (0.4%)	17 (0.2%)
Other	565	214 (162/52)	327 (233/94)	24	6.9 ± 2.9	21 (8.8%)	544 (6.5%)
Total	8560	4288 (3294/994)	4002 (3008/994)	270	7.2 ± 3.4	239	8321

[a] Reported as number of intact/number of neutered.

Table 2
Distribution of 889 canine compound uroliths submitted from Thailand between 2009 and 2015.

Mineral composition of outer layer[a]									
Core minerals	Struvite	CaOx	Purine	CaP	Brushite	Silica	Cystine	Other	Total
Struvite	NA	39	22	250	3	0	0	87	401
CaOx	239	NA	13	32	14	4	1	34	337
Purine	51	28	NA	3	0	0	3	13	98
CaP	55	42	0	NA	6	1	1	10	115
Brushite	1	5	0	1	NA	0	0	1	8
Silica	13	24	3	0	0	NA	0	2	42
Cystine	3	1	0	0	1	0	NA	0	5
Foreign body	30	0	2	0	0	0	0	2	34
Other	112	11	15	17	6	0	1	1	163

[a] The outer layer means the adjacent layer to the central core.

p-value = 0.064). Calcium phosphate uroliths were reported in 18 pure breeds. Common breeds included Shih Tzu (35; 23.8%), Pomeranian (19; 12.9%), Pug (15; 10.2%), and Miniature Poodle (14; 9.5%).

3.6. Cystine urolith

There were 134 (1.6%) cystine urolith submissions from Thailand. Most cystine uroliths were from males (94.0%) ($p < 0.001$). The average age of dogs was 4.8 ± 2.4 years. Twenty-two pure breeds were reported. Chihuahua (26; 19.4%) was the most prevalent breed followed by French Bulldog (15; 11.2%), Shih Tzu (12; 8.9%), and Miniature Pincher (11; 8.2%).

3.7. Silica urolith

There were 18 silica urolith submissions. Silica uroliths were only found in intact dogs (15 males and 3 females). The average age of dogs was 7.6 ± 2.4 years. Nine pure breeds were reported for silica uroliths. The most common breed with silica uroliths was Golden Retriever (5; 27.8%).

4. Discussion

Unlike some other geographic regions in the world, the most common urolith identified in dogs in Thailand was struvite (Bende et al., 2015; Houston and Moore, 2009; Low et al., 2010; Vrabelova et al., 2011). Similar to previous studies, females were more often affected than male dogs (Low et al., 2010; Okafor et al., 2013). Struvite uroliths in dogs are mainly caused by urease-producing bacterial infections. The short and wide urethra, in addition to other anatomical differences, is thought to predispose female dogs to increased risk of urinary tract infection compared to males (Seguin et al., 2003). Struvite uroliths in our study were not cultured and urine culture results of study dogs were not available. Nonetheless, we recommend urine culture and antimicrobial sensitivity tests to diagnose underlying infection as a cause and to select effective antimicrobials for its treatment and prevention.

Unlike struvite, CaOx uroliths were more common in male dogs, which is similar to other studies (Houston and Moore, 2009; Osborne et al., 2009; Picavet et al., 2007; Sosnar et al., 2005). The reason for this sex difference is unknown. Similar to other studies, our study also determined that CaOx uroliths are common in small breed dogs (Okafor et al., 2014; Wisener et al., 2010) This may be partly explained by the possibility that small breed dogs tend to be hypercalciuric, compared to large breed dogs (Stevenson and Markwell, 2001).

During the study period, an inverse relationship between the changing proportion of struvite and calcium oxalate was observed. Over time the prevalence of CaOx increased while the prevalence of struvite decreased. Similar changes in urolith prevalence were observed in other studies in different geographic areas (Bende et al., 2015; Ling et al., 2003; Low et al., 2010; Picavet et al., 2007; Sosnar et al., 2005). It has been hypothesized that fewer struvite submissions result from medical dissolution of uroliths and better control of urinary tract infections (Low et al., 2010). It also has been hypothesized that CaOx increased because dogs are living longer (Stevenson et al., 2003). Feeding diets designed to prevent struvite uroliths promote acidic urine and hypercalciuria which are risk factors for CaOx formation (Lekcharoensuk et al., 2001). In many geographical locations, the prevalence of CaOx has already surpassed struvite. Based on the rate of change in the prevalence of struvite and CaOx in our study, we expect that in 2018, CaOx submissions will surpass struvite in dogs residing in Thailand.

The proportion of compound uroliths in the study was higher than in other studies (Ulrich et al., 2009; Vrabelova et al., 2011). In those studies, most compound uroliths had a central core of struvite and outer layer of CaP, as was found in our results. Struvite and CaP carbonate share a common risk factor of reduced solubility in alkaline urine associated with urinary tract infection (Kruger et al., 1999). For compound uroliths with a central core of CaOx surrounded by an outer layer of struvite, it is plausible that the CaOx nidus predisposed to urinary tract infections.

Compound uroliths with a central core composed of a foreign body were uncommon. Several types of foreign body-induced urolithiasis have been reported (Del Angel-Caraza et al., 2011; Houston and Eaglesome, 1999). Suture material is a common (Ulrich et al., 2009) accounting for 76% of urolith submissions with a foreign body nidus. The most common mineral surrounding the foreign body was struvite, which was similar to another report (Ulrich et al., 2009). The presence of foreign body in the urinary tract can initiate urolith formation and significantly reduce the time to urolith recurrence in dogs (Appel et al., 2008). To minimize foreign body-associated urolith recurrence, non-surgical methods (e.g. dissolution, voiding urohydropropulsion) for urolith removal should be considered.

Dalmatian dogs had the highest prevalence for developing purine uroliths, which is similar to other observational studies (Bende et al., 2015; Low et al., 2010; Lulich et al., 2013). In Dalmatians hyperuricosuria and hyperuricosemia are controlled by a simple autosomal recessive trait for which all Dalmatians are homozygous (Bannasch and Henthorn, 2009). A defective SLC2A9 transporter has been identified as the cause (Bannasch et al., 2008).

Another pathogenesis for purine uroliths is hepatic portosystemic shunts, which divert blood purines away from hepatic uricase, an enzyme that degrades urate into allantoin. Portosystemic shunts are common in Yorkshire Terriers (Tobias and Rohrbach, 2003); however, Yorkshire Terriers were uncommon in our study. The Shih Tzu was the second most common breed in Thailand with purine uroliths. Although urolith submission records are not sufficient to accurately identify the underlying cause, Shih Tzu has been identified as a common breed with extrahepatic portosystemic shunts (Caporali et al., 2015).

Over the study period, the annual proportion of purine submission decreased. A similar finding has been reported in other studies (Bende

et al., 2015; Low et al., 2010). This may reflect a reduction in the popularity of Dalmatians. (Bende et al., 2015; Herzog, 2006). And backcrossing Dalmatians with English Pointers to reduce the prevalence of the genetic defect (Bannasch and Henthorn, 2009; Safra et al., 2005).

Cystine urolith is uncommon in dogs in Thailand. The most common breed affected with cystine urolith in our study was the Chihuahua which was similar to other study(Case et al., 1992). For cystinuric patients, a new classification system of cystinuria categorizes dogs into autosomal dominant, autosomal recessive, and androgen-dependent cystinuria (Brons et al., 2013). However, the prevalence of mutations affecting dogs in Thailand is unknown.

Silica uroliths were rarely identified in dogs from Thailand. Our results were similar to the results of other studies except those from Mexico where the proportion of silica uroliths were as high as 13.3% (Del Angel-Caraza et al., 2010).

Our study had several limitations. The data were submitted without the record of the province in Thailand that the dog resided. We assumed that dogs came from major metropolitan areas, particularly Bangkok. Therefore, the data may not be representative of dogs residing in less urbanized areas of Thailand. For convenience of the submission, some owners and veterinarians may have misclassified known breeds as mixed breed. This might explain why the number of mixed breed dogs was high. This study did not take into account the recurrent urolith formers where uroliths may be submitted from the same dogs more than once.

Prevalence data in this study can help veterinarians predict urolith composition to select appropriate therapy. For example, in Thailand a radiopaque stone in a female has a high probability of being composed of struvite. This information is especially helpful when managing radiopaque nephroliths because surgical nephrolith removal can cause kidney damage. Kidney damage can be minimized by considering medical dissolution first. Radiopaque uroliths in middle-age, male dogs are likely to be calcium oxalate, especially in small breeds. For these cases, medical therapy is not effective, permitting a decision of urolith removal early after the diagnostic process. Because a large percent of urinary stones in Thai dogs are compound, once removed, uroliths should be submitted for quantitative analysis to detect all minerals in stones to more thoroughly propose effective prevention strategies. The results of this study can help veterinarians predict urolith composition in different breeds, ages and sexes to initiate early and appropriate therapy.

Funding

This work supported, in part, by an educational grant from Hills' Pet Nutrition and the many donations from veterinarians around the world. Study sponsors had no involvement in the design, collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the paper for publication. The authors also thank the Anadamahidol Foundation for funding PhD training for VH.

Conflict of interest

The authors declare they have no conflict of interest.

Acknowledgement

The authors thank Lisa Ulrich, Lori Koehler, Michelle Buettner, Amy Cokley, Sarah Davidson, Kristin Petersen, Sandy Leach and Laurie Swanson of the Minnesota Urolith Center for their technical assistance and Dr. Thomas Fletcher for comments in the manuscript preparation.

References

Appel, S.L., Lefebvre, S.L., Houston, D.M., Holmberg, D.L., Stone, J.E.A., Moore, A.E., Weese, J.S., 2008. Evaluation of risk factors associated with suture-nidus cystoliths in dogs and cats: 176 cases (1999–2006). J. Am. Vet. Med. Assoc. 233, 1889–1895.

Armitage, P., 1955. Tests for linear trends in proportions and frequencies. Biometrics 11, 375–386.

Bannasch, D., Henthorn, P.S., 2009. Changing paradigms in diagnosis of inherited defects associated with urolithiasis. Vet. Clin. North Am. Small Anim. Pract. 39, 111–125.

Bannasch, D., Safra, N., Young, A., Karmi, N., Schaible, R., Ling, G., 2008. Mutations in the SLC2A9 gene cause hyperuricosuria and hyperuricemia in the dog. PLoS Genet. 4, e1000246.

Bende, B., Kovács, K.B., Solymosi, N., Németh, T., 2015. Characteristics of urolithiasis in the dog population of Hungary from 2001 to 2012. Acta Vet. Hung. 63, 323–336.

Bovee, K., McGuire, T., 1984. Qualitative and quantitative analysis of uroliths in dogs: definitive determination of chemical type. J. Am. Vet. Med. Assoc. 185, 983–987.

Brons, A.K., Henthorn, P., Raj, K., Fitzgerald, C., Liu, J., Sewell, A., Giger, U., 2013. SLC3A1 and SLC7A9 mutations in autosomal recessive or dominant canine cystinuria: a new classification system. J. Vet. Intern. Med. 27, 1400–1408.

Caporali, E.H., Phillips, H., Underwood, L., Selmic, L.E., 2015. Risk factors for urolithiasis in dogs with congenital extrahepatic portosystemic shunts: 95 cases (1999–2013). J. Am. Vet. Med. Assoc. 246, 530–536.

Case, L., Ling, G., Franti, C., Ruby, A., Stevens, F., Johnson, D., 1992. Cystine-containing urinary calculi in dogs: 102 cases (1981–1989). J. Am. Vet. Med. Assoc. 201, 129–133.

Del Angel-Caraza, J., Diez-Prieto, I., Pérez-García, C.C., García-Rodríguez, M.B., 2010. Composition of lower urinary tract stones in canines in Mexico City. Urol. Res. 38, 201–204.

Del Angel-Caraza, J., Pérez-García, C.C., Bende, B., Diez-Prieto, I., García-Rodríguez, B., 2011. Mouse barley awn (*Hordeum murinum*) migration induced cystolithiasis in 2 male dogs. Can. Vet. J. 52, 67–69.

Franti, C., Ling, G., Ruby, A., Johnson, D., 1999. Urolithiasis in dogs V: regional comparisons of breed, age, sex, anatomic location, and mineral type of calculus. Am. J. Vet. Res. 60, 29–42.

Fromsa, A., Saini, N., Rai, T., 2011. Diagnosis, Prediction and Mineral Analysis of Uroliths in Canines. Global Veterinaria. 7. pp. 610–617.

Herzog, H., 2006. Forty-two thousand and one Dalmatians: fads, social contagion, and dog breed popularity. Soc. Anim. 14, 383–397.

Houston, D.M., Eaglesome, H., 1999. Unusual case of foreign body-induced struvite urolithiasis in a dog. Can. Vet. J. 40, 125–126.

Houston, D.M., Moore, A.E., 2009. Canine and feline urolithiasis: examination of over 50 000 urolith submissions to the Canadian veterinary urolith centre from 1998 to 2008. Can. Vet. J. 50, 1263–1268.

Kruger, J.M., Osborne, C.A., Lulich, J.P., 1999. Canine calcium phosphate uroliths: etiopathogenesis, diagnosis, and management. Vet. Clin. North Am. Small Anim. Pract. 29, 141–159.

Lekcharoensuk, C., Osborne, C.A., Lulich, J.P., Pusoonthornthum, R., Kirk, C.A., Ulrich, L.K., Koehler, L.A., Carpenter, K.A., Swanson, L.L., 2001. Association between dietary factors and calcium oxalate and magnesium ammonium phosphate urolithiasis in cats. J. Am. Vet. Med. Assoc. 219, 1228–1237.

Ling, G., Franti, C., Ruby, A., Johnson, D., 1998a. Urolithiasis in dogs. II: breed prevalence, and interrelations of breed, sex, age, and mineral composition. Am. J. Vet. Res. 59, 630–642.

Ling, G., Franti, C., Ruby, A., Johnson, D., Thurmond, M., 1998b. Urolithiasis in dogs. I: mineral prevalence and interrelations of mineral composition, age, and sex. Am. J. Vet. Res. 59, 624–629.

Ling, G.V., Thurmond, M.C., Choi, Y.K., Franti, C.E., Ruby, A.L., Johnson, D.L., 2003. Changes in proportion of canine urinary calculi composed of calcium oxalate or struvite in specimens analyzed from 1981 through 2001. J. Vet. Intern. Med. 17, 817–823.

Low, W.W., Uhl, J.M., Kass, P.H., Ruby, A.L., Westropp, J.L., 2010. Evaluation of trends in urolith composition and characteristics of dogs with urolithiasis: 25,499 cases (1985–2006). J. Am. Vet. Med. Assoc. 236, 193–200.

Lulich, J., Osborne, C., Albasan, H., Koehler, L., Ulrich, L., Lekcharoensuk, C., 2013. Recent shifts in the global proportions of canine uroliths. Vet. Rec. 172, 363.

Okafor, C.C., Pearl, D.L., Lefebvre, S.L., Wang, M., Yang, M., Blois, S.L., Lund, E.M., Dewey, C.E., 2013. Risk factors associated with struvite urolithiasis in dogs evaluated at general care veterinary hospitals in the United States. J. Am. Vet. Med. Assoc. 243, 1737–1745.

Okafor, C.C., Lefebvre, S.L., Pearl, D.L., Yang, M., Wang, M., Blois, S.L., Lund, E.M., Dewey, C.E., 2014. Risk factors associated with calcium oxalate urolithiasis in dogs evaluated at general care veterinary hospitals in the United States. Prev. Vet. Med. 115, 217–228.

Osborne, C.A., Lulich, J.P., Kruger, J.M., Ulrich, L.K., Koehler, L.A., 2009. Analysis of 451,891 Canine Uroliths, Feline Uroliths, and Feline Urethral plugs from 1981 to 2007: perspectives from the Minnesota Urolith Center. Vet. Clin. North Am. Small Anim. Pract. 39, 183–197.

Picavet, P., Detilleux, J., Verschuren, S., Sparkes, A., Lulich, J., Osborne, C., Istasse, L., Diez, M., 2007. Analysis of 4495 canine and feline uroliths in the Benelux. A retrospective study: 1994–2004. J. Anim. Physiol. Anim. Nutr. 91, 247–251.

Safra, P., Ling, G., Schaible, R., Bannasch, D., 2005. Exclusion of urate oxidase as a candidate gene for hyperuricosuria in the Dalmatian dog using an interbreed backcross. J. Hered. 96, 750–754.

Seguin, M.A., Vaden, S.L., Altier, C., Stone, E., Levine, J.F., 2003. Persistent urinary tract infections and reinfections in 100 dogs (1989–1999). J. Vet. Intern. Med. 17, 622–631.

Sosnar, M., Bulkova, T., Ruzicka, M., 2005. Epidemiology of canine urolithiasis in the Czech Republic from 1997 to 2002. J. Small Anim. Pract. 46, 177–184.

Stevenson, A.E., Markwell, P.J., 2001. Comparison of urine composition of healthy Labrador retrievers and miniature schnauzers. Am. J. Vet. Res. 62, 1782–1786.

Stevenson, A., Blackburn, J., Markwell, P., Robertson, W., 2003. Nutrient intake and urine composition in calcium oxalate stone-forming dogs: comparison with healthy dogs and impact of dietary modification. Vet. Ther. 5, 218–231.

Tobias, K.M., Rohrbach, B.W., 2003. Association of breed with the diagnosis of congenital portosystemic shunts in dogs: 2,400 cases (1980–2002). J. Am. Vet. Med. Assoc. 223, 1636–1639.

Ulrich, L.K., Osborne, C.A., Cokley, A., Lulich, J.P., 2009. Changing paradigms in the frequency and management of canine compound uroliths. Vet. Clin. North Am. Small Anim. Pract. 39, 41–53.

Vrabelova, D., Silvestrini, P., Ciudad, J., Gimenez, J.C., Ballesteros, M., Puig, P., Ruiz de Gopegui, R., 2011. Analysis of 2735 canine uroliths in Spain and Portugal. A retrospective study: 2004–2006. Res. Vet. Sci. 91, 208–211.

Weichselbaum, R.C., Feeney, D.A., Jessen, C.R., Osborne, C.A., Dreytser, V., Holte, J., 1999. Urocystolith detection: comparison of survey, contrast radiographic and ultrasonographic techniques in an in vitro bladder phantom. Vet. Radiol. Ultrasound 40, 386–400.

Weichselbaum, R.C., Feeney, D.A., Jessen, C.R., Osborne, C.A., Holte, J., 2001. An integrated epidemiologic and radiographic algorithm for canine urocystolith mineral type prediction. Vet. Radiol. Ultrasound 42, 311–319.

Wisener, L.V., Pearl, D.L., Houston, D.M., Reid-Smith, R.J., Moore, A.E., 2010. Risk factors for the incidence of calcium oxalate uroliths or magnesium ammonium phosphate uroliths for dogs in Ontario, Canada, from 1998 to 2006. Am. J. Vet. Res. 71, 1045–1054.