Original Article

Prevalence and risk factors of concurrent osteoarthritis and urolithiasis in dogs in Thailand (2018–2020)

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Abstract

Osteoarthritis is a degenerative joint disease that significantly impacts dog health, often leading to chronic pain, reduced mobility, and behavioral changes that may predispose dogs to secondary conditions such as urolithiasis. This study aimed to investigate the association between osteoarthritis and urolithiasis in dogs using radiographic imaging data collected from the Small Animal Teaching Hospital, Chulalongkorn University, Thailand, over a three-year period (January 2018 to December 2020). A total of 16,377 dogs were included, and cases of osteoarthritis, urolithiasis, or the concurrent occurrence of both conditions were identified through a systematic database review. Binary logistic regression models were used to assess associations between breed group, individual breed type, sex, and neuter status. Our results revealed that dogs diagnosed with osteoarthritis had significantly higher odds of developing urolithiasis compared to those without osteoarthritis ($p < 0.001$; OR = 1.7). Among these cases, 321 dogs were concurrently diagnosed with urolithiasis, with the Toy breed group being excessively affected. Further analysis showed that small breeds, particularly Chihuahuas, Pomeranians, Pugs, Shih Tzus, and Malteses, had a significantly increased risk of developing the concurrent diseases. Males also had higher odds of developing urolithiasis, while neuter status showed no significant association. These findings suggest that mobility and behavioral changes associated with osteoarthritis, such as reduced overall mobility and water intake, and prolonged urine retention, may contribute to the development of secondary diseases such as urolithiasis. The significant predisposition of the Toy breed group to both conditions highlights the need for targeted management strategies, with breed groups, individual breed type, and sex playing key roles in their concurrent development.

Keywords: concurrent disease, dogs, osteoarthritis, toy breeds, urolithiasis

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Introduction

Osteoarthritis (OA) is a common clinical and pathological outcome of various joint disorders, ultimately leading to structural and functional deterioration of the joint, often accompanied by lameness and pain. This condition is frequently referred to as degenerative joint disease (DJD), as it affects the entire joint, including all associated tissues. However, it is most notably characterized by the progressive loss of and the deterioration of articular cartilage and the formation of osteophytes. The etiology of OA is complex, and the mechanisms remain unclear. Primary OA is largely considered idiopathic but is associated with several risk factors, including aging and obesity (Anderson *et al.*, 2020). In contrast, secondary OA, which arises from underlying joint injuries, is believed to be the most prevalent form in dogs (Witsberger *et al.*, 2008; Gilbert *et al.*, 2019). Beyond its direct effects on joint function, OA has been linked to broader consequences, warranting further investigation into its potential associations with other comorbidities.

One of the most significant consequences of OA in dogs is chronic pain, which induces a prolonged state of pain and stress beyond the normal healing time and affects the entire body. This chronic pain often leads to physical instability, disability, and a significant decline in overall welfare (Pelletier *et al.*, 2016; Capon, 2021). Additionally, OA impacts behavior and daily activities, contributing to changes that extend beyond physical impairment. Chronic pain often results in reduced mobility, which adversely influences overall behavior and quality of life, potentially leading to frustration and decreased activity. Research has shown that OA alters gait patterns, causing affected dogs to walk more slowly, pause frequently, or seek assistance when encountering obstacles such as steep inclines, uneven terrain, or long distances. In severe cases, mobility impairments may prevent walking altogether (Hielm-Bjorkman *et al.*, 2009; Walton *et al.*, 2013; Brown, 2014; Cachon *et al.*, 2018; Belshaw *et al.*, 2020).

Beyond mobility issues, OA also influences fundamental behaviors such as food and water intake. While dogs with good mobility typically maintain normal eating and drinking habits, even mild stiffness resulting from OA can lead to slight reductions in consumption. As mobility worsens, these reductions become more pronounced, with moderate stiffness resulting in decreases of over 50% and severe immobility leading to reductions exceeding 80%. In the most severe cases, dogs with very poor mobility, stiffness, and minimal activity will develop anorexia and have moderate loss of skin turgor (Malkani *et al.*, 2024). These reductions in food and water intake not only aggravate the direct effects of OA but also increase the risk of secondary conditions, such as urolithiasis. Decreased activity levels and reduced water intake contribute to an environment conducive to the formation of urinary stones, further complicating the health of affected dogs.

Estimates of daily water intake have been reported for dogs, yet standardized criteria for defining optimal hydration, appropriate water intake volume, and the overall impact of proper hydration on dog health have not been established. Existing research primarily quantifies daily water intake as milliliters per kilogram (mL/kg) of body weight, incorporating water obtained from various sources, including food moisture, voluntary water consumption or drinking, and metabolic water. However, the relationship between an individual dog's water intake and its corresponding urine concentration, as measured by specific gravity, remains unclear (Zanghi and Gardner, 2018). Insufficient water intake has been directly linked to the formation of urinary stones and is considered one of the primary contributing factors. Reduced water intake leads to decreased diuresis, resulting in high urine concentration and supersaturation of minerals, which promotes stone formation within the urinary tract (Gamage *et al.*, 2020). Urinary stones may develop in both the upper urinary tract, including the kidneys and ureters, and the lower urinary tract, including the bladder and urethra, with the majority initially forming in the kidneys (Bao *et al.*, 2020).

The formation of urinary stones or uroliths requires specific conditions, such as sufficiently high urine concentrations of urolith-forming substances and prolonged urine transit time within the urinary tract (Pridsadangbud *et al.*, 2022). In dogs with OA, behavioral changes, including reduced mobility, decreased water intake, and lower frequency of micturition, can create or exacerbate these conditions, particularly in small-breed dogs. Reduced activity associated with OA often leads to insufficient water intake, concentrating urine, and increasing the risk of urolith formation. Additionally, small breed dogs may naturally produce lower urine volumes, which has been linked to their predisposition to urolithiasis (Rotat *et al.*, 2016). These interconnected health challenges underscore the importance of addressing OA-related behavioral changes to mitigate the risk of secondary conditions like urolithiasis. Despite these concerns, limited research has explored the link between OA and urolithiasis in dogs.

In this study, the American Kennel Club (AKC) classification system was used as a reference for breed groups and individual breed types. The AKC serves as a registry for purebred dogs and provides detailed breed standards, including characteristics related to appearance, temperament, and behavior. It also categorizes breeds into seven groups based on their historical roles, such as Sporting, Hound, Working, Terrier, Toy, Non-Sporting, and Herding (Zapata and Zapata, 2024). Therefore, this study aimed to retrospectively assess whether OA is associated with an increased risk of developing urolithiasis in dogs with particular attention to breed-related predispositions.

Materials and Methods

Study design: This retrospective study utilized clinical data from medical records obtained between January 2018 and December 2020 from the radiographic imaging unit at the Small Animal Teaching Hospital, Chulalongkorn University, Thailand. The dataset included clinical records extracted from a properly configured practice management system and consisted primarily of radiographic findings. Demographic

information such as species, breed, sex, and neuter status was collected. Radiographic images were systematically reviewed to confirm the presence of OA, urolithiasis, or the concurrent occurrence of both conditions.

Database search: Candidate cases were identified through searches conducted in a Microsoft Excel database covering the three-year sampling period. A manual review of medical records was conducted to confirm each diagnosis using radiographic findings that met predefined case search criteria. The analysis was limited to dog patients, and records involving other species, unspecified species, or those lacking sufficient demographic and diagnostic data for statistical analysis were excluded.

A systematic search was conducted to identify confirmed cases based on radiographic diagnosis using specific search terms. Search terms were tested and adjusted to account for variations in spelling and terminology in radiographic diagnoses. For the identification of OA cases, the keyword searches included terms such as "osteoa*," "OA," "degen*+joint*," "joint dise*," "DJD," "osteoph*," and "arth*" (Anderson *et al.*, 2018). For the identification of urolithiasis cases, keyword searches included terms such as "cystic," "calculi," "calculus," and "urolith." Cases with concurrent occurrence of both OA and urolithiasis were identified based on the presence of relevant keywords from both diagnostic categories.

Statistical analysis: The relevant records were exported to Microsoft Excel for data cleaning and subsequently analyzed using SPSS software version 16.0 to perform binary logistic regression with univariable and multivariable models. This analysis aimed to evaluate associations between potential risk factors and the presence of OA, urolithiasis, or the concurrent occurrence of both conditions. Negative cases were defined as all dogs in the medical record population that did not meet the diagnostic criteria for any of the three conditions. The study population included 16,377 dogs, representing all visits to the radiographic imaging unit during the three-year study period. Additionally, a focused analysis was conducted on a subset of 16,007 dogs, including only the most common breeds with at least ten individuals in each case.

A risk factor analysis was conducted using binary logistic regression in SPSS to evaluate the associations between potential risk factors and the presence of osteoarthritis, urolithiasis, or concurrently diagnosed cases. The primary risk factors were evaluated using both univariable and multivariable binary logistic regression models to assess the associations of breed groups, breed type, sex, and neuter status. The variable 'breed group' was categorized into seven groups based on the AKC breed classifications as Sporting, Hound, Working, Terrier, Toy, Non-Sporting, and Herding. Dogs not recognized by the AKC were classified as mixed breeds. The variable 'breed type' was categorized according to individual AKC-recognized breeds, with mixed breeds used as the reference group. The 'sex' variable represented the biological sex of the dog (male or female), with the female designated as the reference category. The 'neuter status' variable differentiated between intact and neutered dogs, with intact dogs used as the reference category.

Binary logistic regression was initially performed to assess univariable associations between potential explanatory variables and urolithiasis as the dependent variable. The primary analysis examined whether OA was significantly associated with urolithiasis in the total study population. The explanatory variables, including the presence of OA, breed group, breed type, sex, and neuter status, were evaluated for their independent contributions to urolithiasis risk. Univariable logistic regression models were conducted. Odds ratios (OR) with 95% confidence intervals (CI) were reported, and variables with a *p-value* < 0.05 were considered statistically significant. Multicollinearity among independent variables was assessed using variance inflation factors (VIF), and variables with a VIF value > 5 were excluded from the final models, as this indicates high multicollinearity, which can lead to unstable and unreliable coefficient estimates (Gilmour *et al.*, 2022).

All independent variables with a VIF value < 5 were included in the multivariable logistic regression models. Adjusted ORs with 95% CI were calculated to assess the strength of association between the dependent and independent variables. Variables with a *p-value* < 0.05 in the multivariable analysis were considered statistically significant. Due to collinearity with breed type, which was the primary variable of interest, the breed group variable was excluded from the final model. Additionally, neuter status was excluded as it was not significant in the univariable analysis, though its results were reported separately. The final multivariable model included urolithiasis as the dependent variable, with the presence of OA, sex, and breed type as covariates.

Ethics approval: This study was approved under the Institute for Animal Care and Use Committee (IACUC) of Chulalongkorn University, Thailand (approval protocol No. 2431076).

Result

Prevalence analysis: The study initially identified 16,377 dogs by applying predefined case search criteria, including OA, urolithiasis, the concurrent occurrence of both conditions, and negative cases (dogs that did not meet the diagnostic criteria for any of the three conditions) as presented in Table 1. The patient population was nearly evenly distributed between males (51%) and females (49%), with the majority being intact (68.4%) individuals. The estimated three-year period prevalence of each breed is presented in Table 2. Candidate cases were confirmed based on a review of radiographic diagnoses. Using this dataset, the initial analysis evaluated the overall prevalence of osteoarthritis and its association with urolithiasis. For the model analysis, the dataset was refined to include 16,007 dogs, excluding breeds with fewer than ten individuals in each case, to ensure statistical robustness. This analysis aimed to retrospectively assess whether OA is associated with an increased risk of developing

urolithiasis, utilizing both univariable and multivariable binary logistic regression models, as presented in Tables 3 and 4.

Risk analysis: Univariable binary logistic regression revealed a significant association between OA and the diagnosis of urolithiasis, as presented in Table 3. Dogs diagnosed with OA were significantly more likely to be diagnosed with urolithiasis compared to dogs without OA ($p < 0.001$; OR = 1.7, 95% CI: 1.5–2.0). Additionally, the results showed that breed group and sex were significantly associated with the diagnosis of urolithiasis ($p < 0.05$), whereas neuter status was not significantly associated ($p > 0.05$). Significant factors identified in the univariable analysis were included in the final model of the multivariable binary logistic regression, which was built using only dogs from breeds with at least ten individuals in each case.

In the univariable analysis of the breed group model based on AKC classifications, several breed groups demonstrated significant associations with urolithiasis as presented in Table 3. Specifically, dogs in the Toy breed group were significantly associated with an increased likelihood of urolithiasis ($p < 0.001$; OR = 1.7, 95% CI: 1.5–2.0). In contrast, the Non-Sporting breed group was significantly less likely to be diagnosed with urolithiasis compared to mixed breed (p = 0.034, OR = 0.7).

In the multivariable analysis, OA remained significantly associated with an increased risk of urolithiasis, even after adjusting for confounding factors such as sex and breed type ($p < 0.001$; OR = 1.7, 95% CI: 1.5–2.0), as presented in Table 4. Sex was also a significant factor, with males showing higher odds of urolithiasis compared to females ($p < 0.001$, OR = 1.2, 95% CI: 1.1–1.4). Five specific Toy breeds were also identified as having higher odds of developing urolithiasis such as Chihuahua, Pomeranian, Pug, Shih Tzu, and Maltese were significantly associated with higher odds compared to the reference mixed breed (Chihuahua: $p < 0.05$, OR = 1.2, 95% CI: 1.0–1.5; Pomeranian: $p < 0.001$, OR = 1.6, 95% CI: 1.3–1.9; Pug: $p < 0.001$, OR = 2.2, 95% CI: 1.6–3.2; Shih Tzu: $p < 0.001$, OR = 2.2, 95% CI: 1.9–2.7; Maltese: $p < 0.001$, OR = 3.4, 95% CI: 2.0–6.0).

Table 1 Distribution of confirmed cases of osteoarthritis, urolithiasis, and concurrent conditions.

Population Characteristic		Total Population	Osteoarthritis Cases	Urolithiasis Cases	Combined Cases
Number of Individuals		16,377	2,301 (14.1%)	971 (5.9%)	321 (2%)
Sex	Female	8,022 (49%)	1,171	427	138
	Male	8,355 (51%)	1,130	544	183
Neuter Status	Intact	11,200 (68.4%)	1,378	662	199
	Neutered	5,177 (31.6%)	923	309	122
Breed Group	Mixed	5,019 (30.6%)	613	254	73
	Toy	6,827 (41.7%)	986	538	211
	Non-Sporting	2,297 (14%)	246	119	18
	Working	499 (3%)	71	25	2
	Sporting	805 (4.9%)	251	11	9
	Hound	480 (2.9%)	71	11	6
	Terrier	272 (1.7%)	21	9	1
	Herding	178 (1.1%)	42	4	1

Table 2 Estimated prevalence of concurrent osteoarthritis and urolithiasis by individual breed.

Breed	Number of Concurrent Cases Sampled	Estimated Concurrent Cases in Population	Number of Breeds Overall in Total Population	Estimated Breed Prevalence Overall (%)
Number of Individuals	321		16377	
Pomeranian	78	42.5	1,572 (9.6%)	4.96
Shih Tzu	75	35.3	1,802 (11%)	4.16
Mixed	73	98.5	5,024 (30.7%)	1.45
Chihuahua	19	35.7	1,554 (9.5%)	1.22
Pug	18	5.7	289 (1.8%)	6.23
Poodle	14	30.2	1,547 (9.4%)	0.90
Yorkshire Terrier	7	7.1	362 (2.2%)	1.93
Pekingese	7	0.9	27 (0.2%)	25.93
Beagle	6	7.3	302 (1.8%)	1.99
Golden Retriever	5	7.4	257 (1.6%)	1.95
Miniature Pinscher	5	4.2	169 (1%)	2.96
Labrador Retriever	2	6.5	214 (1.3%)	0.93
Maltese	2	2.0	75 (0.5%)	2.67
Cocker Spaniel	2	1.8	93 (0.6%)	2.15
Schnauzer	2	1.5	55 (0.3%)	3.64
French Bulldog	1	7.2	367 (2.2%)	0.27
Corgi	1	1.1	55 (0.3%)	1.82
Terrier	1	0.6	26 (0.2%)	3.85
Chow Chow	1	0.5	23 (0.1%)	4.35
Shiba Inu	1	0.3	16 (0.1%)	6.25
Shar Pei	1	0.1	3 (0.1%)	33.33

Table 3 Univariable binary logistic regression analysis of factors associated with the diagnosis of urolithiasis in dogs.

Independent Variable	Odds Ratio	95% CI		Significance
		Lower	Upper	
Osteoarthritis	1.7	1.5	2.0	<0.001*
Sex				0.002*
Female	Base			
Male	1.2	1.0	1.3	0.002*
Neuter Status				0.099
Intact	Base			
Neutered	1.1	0.9	1.2	0.099
AKC Breed Group				<0.001*
Mixed	Base			
Toy	1.7	1.5	2.0	<0.001*
Non-Sporting	0.7	0.6	0.9	0.034*
Working	0.6	0.4	1.0	0.99
Sporting	0.0	0.0	N/A	0.99
Hound	0.0	0.0	N/A	0.99
Terrier	0.0	0.0	N/A	0.99
Herding	0.0	0.0	N/A	0.99

*Significant P-values are denoted in bold type.
Base indicates the reference category for comparisons.
N/A: not applicable due to insufficient sample.

Table 4 Multivariable binary logistic regression analysis of factors associated with the diagnosis of urolithiasis in dogs.

Independent Variable	Odds Ratio	95% CI		Significance
		Lower	Upper	
Osteoarthritis	1.7	1.5	2.0	<0.001*
Sex				<0.001*
Female	Base			
Male	1.2	1.1	1.4	<0.001*
Individual Breed Types				<0.001*
Mixed	Base			
Chihuahua	1.2	1.0	1.5	<0.05*
Pomeranian	1.6	1.3	1.9	<0.001*
Pug	2.2	1.6	3.2	<0.001*
Shih Tzu	2.2	1.9	2.7	<0.001*
Maltese	3.4	2.0	6.0	<0.001*

*Significant P-values are denoted in bold type.
Base indicates the reference category for categorical comparisons.

Discussion

In this study, the prevalence of OA was calculated at 14% (2,301 dogs) over a three-year period, from the total population of 16,377 dogs that visited the radiographic imaging unit. This prevalence estimate was significantly higher than a previous study, which reported a prevalence of only 2.5% (Anderson *et al.*, 2018). The earlier study was conducted on a much larger dataset, with a sample population of 455,557 dogs over a one-year study period. The difference between methodological approaches may have contributed to the higher prevalence observed in our study, compared to previous reports that included all dogs presented at the hospital, regardless of whether they underwent radiographic evaluation, which may have led to an underestimation of cases. Additionally, previous estimates suggest that OA prevalence may be as high as 20% in dogs older than one year. However, this figure is based on data from a North American referral dog population (Johnston, 1997).

The three-year prevalence of urolithiasis in this study was calculated at 5.9% (971 out of 16,377 dogs). This estimate was lower than that reported in a previous study, which found a prevalence ranging from 14% to 25% (Parmar *et al.*, 2020). However, the earlier study was based on a much smaller sample size of 106 dogs, all of which were surgical cases involving urinary disorders collected over a five-year period. In contrast, our study included a larger and more diverse population of dogs that underwent radiographic examination, reflecting a broader clinical population. It is important to note that because our analysis relied solely on radiographic imaging, radiolucent uroliths such as those composed of urate or cystine may not have been detected. These differences in study design and case selection likely contributed to the variation in reported prevalence.

This study primarily focused on the prevalence of concurrent OA and urolithiasis over a three-year period, which was estimated at 2% (321 dogs) within a total population of 16,377 dogs. Based on the available literature, this may be one of the first reports to describe the prevalence of these concurrent conditions in small breed dogs, as previous studies have primarily investigated the prevalence of each condition separately (Anderson *et al.*, 2018; Mendoza-López *et al.*, 2019). These results suggest that OA may be one of the risk factors contributing to an increased likelihood of urolithiasis in dogs.

The North American study employed radiographic evidence to identify cases, as OA-related structural changes are detectable through imaging (Johnston, 1997). In contrast, another study has suggested that

data derived from primary-care settings may offer a more accurate reflection of the general population (Anderson *et al.*, 2018). In our study, the reported prevalence may be lower than the actual number of cases due to the method of data collection. We used strict criteria to define cases, which helped improve diagnostic accuracy, but this may have excluded some true cases due to missing additional information, limiting further analysis. Furthermore, the data relied on input from multiple veterinarians in the radiographic unit, leading to variations in how cases were examined, diagnosed, and recorded.

In this study, purebred dogs were categorized into seven groups according to the AKC classification, while dogs not recognized by the AKC were classified as mixed breeds. The findings revealed that purebred dogs had 1.2 times higher odds of developing urolithiasis compared to mixed breeds (data not shown). The analysis of breed groups revealed a significant association between the Toy breed group and a higher likelihood of developing urolithiasis in dogs with confirmed OA diagnoses. Within the Toy breed group, five specific breeds, such as Chihuahuas, Pomeranians, Pugs, Shih Tzus, and Malteses, were identified as having significantly higher odds of developing urolithiasis. In contrast, the Non-Sporting breed group was significantly less likely to be diagnosed with urolithiasis. However, none of the individual breed types within this group showed a significant association in this study. Breed predisposition has long been recognized as a common risk factor for specific diseases. This study identified certain breeds with a heightened predisposition to either OA or urolithiasis, potentially due to breed standards, as well as sex or other individual factors. Previous studies have highlighted genetics, conformation, breed, body weight, age, sex, and neuter status as elements that increase, though do not guarantee, the likelihood of these diseases' development in affected breeds compared to others (Anderson *et al.*, 2020; Kopecny *et al.*, 2021). As a non-modifiable factor, breed-related predisposition can serve as a valuable tool for identifying individuals at higher risk, enabling earlier diagnosis and intervention. Nevertheless, it is essential to consider that in some studies, the increased prevalence of disease may also reflect the overall popularity and larger population sizes of specific breeds within the general dog population (Anderson *et al.*, 2020). For instance, a previous study in Thailand estimated the total national dog population at 12.8 million, with small breed dogs accounting for approximately 49.8% of the total population (Thanapongtharm *et al.*, 2021).

The severity of OA varies among dog breeds, with greater severity observed in heavier dogs when all joints are considered. This observation aligns with previous studies indicating that OA tends to be more severe in larger dogs compared to those weighing less than thirty-five kilograms (Gilbert *et al.*, 2019; Villatoro *et al.*, 2023). However, other research suggests that small breeds may have a higher prevalence of OA than medium and large breeds. This variation is likely influenced by multiple factors, including behavioral adaptations, age, body weight, sex, neuter status, genetics, and individual conformation. Additionally, OA may progress more rapidly or remain underdiagnosed in small and medium sized breeds compared to larger breeds (Gilbert *et al.*, 2019; Anderson *et al.*, 2020; Villatoro *et al.*, 2023). Furthermore, smaller breeds like Chihuahuas, Shih Tzus, Malteses and Pomeranians have been identified as having increased odds of developing patellar luxation and/or cruciate ligament ruptures, conditions that can exacerbate OA severity, as secondary causes compared to mixed breed dogs (Anderson *et al.*, 2020; Villatoro *et al.*, 2023). These findings underscore the multifactorial nature of OA, which not only impacts joint health but also triggers other complications that impair quality of life, especially in Toy breed group categories.

Similar to OA, the development and severity of urolithiasis in dogs are influenced by multiple factors, including breed, sex, individual characteristics, and behavioral changes. Previous studies have reported that certain types of uroliths occur almost exclusively in small breeds, with both struvite and calcium oxalate stones being particularly common (Stevenson and Markwell, 2001; Houston *et al.*, 2017). Breed-specific risks have been well documented, with some toy or small breeds consistently demonstrating a higher predisposition to urolith formation. For instance, prior research showed that Chihuahuas, Pomeranians, Pugs, Shih Tzus, and Maltese frequently develop specific types of uroliths, such as calcium oxalate, struvite, urate, and calcium phosphate (Low *et al.*, 2010; Lulich *et al.*, 2013; Houston *et al.*, 2017). Moreover, several breeds have been identified as having substantially higher odds for certain urolith types, including the Maltese, Pomeranian, and Yorkshire Terrier for calcium oxalate and the Bichon Frise, Miniature Schnauzer, and Shih Tzu for struvite (Stevenson and Markwell, 2001). These findings highlight the significant role of breed-related factors in the pathogenesis of urolithiasis, particularly among Toy breed group categories.

Sex was also identified as a significant factor, with male dogs exhibiting higher odds of concurrent urolithiasis. This finding differs from earlier studies on cranial cruciate ligament disease in young dogs and OA in large breeds, which reported no significant differences between sexes (Duval *et al.*, 1999). Similarly, another study found no significant differences in OA severity with respect to sex among large-breed dogs (Gilbert *et al.*, 2019). While sex has been extensively studied as a risk factor for OA and related conditions, findings often vary, and such discrepancies may stem from the influence of confounding factors like body size, weight, neuter status, and hormonal differences, which often interact with sex to influence disease susceptibility (Anderson *et al.*, 2020). In the context of urolithiasis, sex plays a particularly relevant role in determining the type of stone formed. Male dogs are more prone to calcium oxalate uroliths, whereas female dogs are more frequently affected by struvite uroliths. This pattern is attributed to the infection-associated nature of struvite stones and the higher incidence of urinary tract infections in females (Low *et al.*, 2010; Lulich *et al.*, 2013; Houston *et al.*, 2017; Kopecny *et al.*, 2021). Thus, the greater likelihood of males developing calcium oxalate

stones may reflect their lower risk for infection-related uroliths, while the higher prevalence of struvite stones in females corresponds with their increased infection risk across all breeds (Houston *et al.*, 2017; Kopecny *et al.*, 2021).

Neuter status was not identified as a significant factor in the development of concurrent urolithiasis in this study. This finding contrasts with prior research on osteoarthritis, which has consistently reported that neutered dogs are at greater risk of joint diseases than their intact counterparts. For instance, neutered males and females have been shown to have an elevated risk of cranial cruciate ligament disease, which leads to the secondary development of OA (Duval *et al.*, 1999; Taylor-Brown *et al.*, 2015). These inconsistencies highlight the need for further investigation into the underlying biological mechanisms. One proposed explanation involves the link between neutering and weight gain, which has been associated with increased joint stress and subsequent disease development (McGreevy *et al.*, 2005; Witsberger *et al.*, 2008; Adams *et al.*, 2011). Age may also serve as a confounding factor, as neutered dogs are often older, which itself contributes to the risk of both OA and urolithiasis (Anderson *et al.*, 2020). In the context of urolithiasis, our findings diverge from earlier reports indicating a higher likelihood of calcium oxalate and struvite urolith formation in neutered dogs (Lulich *et al.*, 2013; Kopecny *et al.*, 2021). The lower proportion of neutered dogs in our sample population (31.6%) may partially account for this discrepancy, suggesting that population differences may influence the observed outcomes.

This study primarily focused on the prevalence of concurrent OA and urolithiasis in dogs, revealing that 2% (321 dogs) of the total population exhibited both conditions simultaneously. As previously discussed, Toy breeds, particularly Chihuahua, Pomeranian, Pug, Shih Tzu, and Maltese, were found to have a significantly higher predisposition to these diseases individually (Lulich *et al.*, 2013; Houston *et al.*, 2017; Anderson *et al.*, 2020; Villatoro *et al.*, 2023). Notably, the present study further demonstrated that these same breeds are also prone to developing both conditions concurrently, with overlapping diagnoses recorded within the same data collection period. Among the 16,007 cases analyzed, 276 (1.7%) cases were diagnosed with both OA and urolithiasis. The distribution of concurrent cases was particularly elevated in the five Toy breeds mentioned above, with observed case numbers exceeding the estimated overall prevalence. This indicates a disproportionately higher burden of concurrent disease in these breeds, suggesting a breed-specific vulnerability. These findings support the hypothesis that OA may act as a potential risk factor contributing to an increased likelihood of urolithiasis in dogs, particularly among predisposed breeds within the Toy breed group.

OA, through its impact on mobility and behavior, may predispose affected dogs to secondary conditions like urolithiasis. This altered behavior, including reduced water intake, decreased activity, and prolonged urine retention, is likely to contribute to the development of uroliths by promoting urine concentration and mineral supersaturation. In small breed dogs, the predisposition to urolithiasis may indeed be related to their lower urine volume (Rotat *et al.*, 2016). When water consumption is reduced, urinary concentration increases, enhancing the risk of crystal and stone formation in the urinary tract (Jummai *et al.*, 2018; Ahmed, 2024). As previously reported in multiple studies (Anderson *et al.*, 2020; Kopecny *et al.*, 2021; Malkani *et al.*, 2024), the Toy breed group's predisposition to both OA and urolithiasis may arise from a combination of breed-specific traits, sex-related differences, and behaviorally mediated physiological changes.

In conclusion, this study highlighted a significant association between OA and an increased risk of urolithiasis in dogs, particularly within the Toy breed group categories. Dogs diagnosed with OA-positive had higher odds of urolithiasis ($p < 0.001$; OR = 1.7). Among OA-positive dogs, significant factors associated with urolithiasis included breed groups, individual breed type, and sex, whereas neuter status was not a significant predictor. Toy breeds, including Chihuahua, Pomeranian, Pug, Shih Tzu, and Maltese, had significantly higher odds of developing urolithiasis compared to mixed breed dogs. Additionally, male dogs were at a greater risk than females. These findings suggest that OA may contribute to an increased likelihood of urolithiasis and highlight the critical role of breed group, individual breed type, and sex in the concurrent development of these conditions.

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