

Preoperative parameters (signalment, digital radiography, urinalysis, urine microbiological culture) and novel algorithm improve prediction of canine urocystolith composition

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OBJECTIVE

To determine the accuracy of 4 preoperative parameters (signalment, urinalysis, urine microbiological culture, and digital radiography) in predicting urocystolith composition, compare accuracy between evaluators of varying clinical experience and a mobile application, and propose a novel algorithm to improve accuracy.

ANIMALS

175 client-owned dogs with quantitative analyses of urocystoliths between January 1, 2012, and July 31, 2020.

METHODS

Prospective experimental study. Canine urocystolith cases were randomly presented to 6 blinded “stone evaluators” (rotating interns, radiologists, internists) in 3 rounds, each separated by 2 weeks: case data alone, case data with a urolith teaching lecture, and case data with a novel algorithm. Case data were also entered into the Minnesota Urolith Center mobile application. Prediction accuracy was determined by comparison to quantitative laboratory stone analysis results.

RESULTS

Prediction accuracy of evaluators varied with experience when shown case data alone (accuracy, 57% to 82%) but improved with a teaching lecture (accuracy, 76% to 89%) and further improved with a novel algorithm (accuracy, 93% to 96%). Mixed stone compositions were the most incorrectly predicted type. Mobile application accuracy was 74%.

CLINICAL RELEVANCE

Use of the 4 preoperative parameters resulted in variable accuracy of urocystolith composition predictions among evaluators. The proposed novel algorithm improves accuracy for all clinicians, surpassing accuracy of the mobile application, and may help guide patient management.

Keywords: urolith, quantitative stone analysis, urocystolith, urinalysis, canine

Urocystoliths are commonly identified in canine patients presented to veterinary hospitals.¹ The optimal approach for urocystolith removal would be a technique that achieves the highest success with the least patient morbidity. The 2016 American College of Veterinary Internal Medicine consensus statement advocated for careful evaluation of stone type to ensure proper management prior to considering surgical removal,² and many uroliths can be medically dissolved.

Determination of stone composition is vital for appropriate treatment recommendations, long-term management including medical and dietary therapies for specific stone types,³ and to educate owners about potential recurrence. Minimally invasive interventions are also becoming more widely used,^{2,4,5} and prediction of stone type may identify appropriate candidates for medical dissolution prior to considering removal techniques, which are more invasive and potentially require repetitive general anesthetic events.

Independent factors have been previously evaluated for the ability to predict stone composition, such as patient demographics,⁶ signalment,⁷⁻¹³ patient size,¹⁴ genetic predispositions,¹⁴ concurrent

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diseases,⁹ mean beam attenuation or dual energy on CT,¹⁵⁻¹⁷ urine testing results,^{10,18} and stone characteristics including size, surface, shape, and internal architecture.^{19,20} No single factor appears to be a well-established predictor of stone type, and evaluation of a composite of available information based on a standard minimum database without the need for advanced imaging has not been investigated. Investigational studies have combined multiple factors to improve sensitivity of stone detection, predict risk of urolith development, or detect a specific stone type,²¹⁻²³ but few have documented the ability to predict the most common stone types to guide management. Recently, the Minnesota Urolith Center published a mobile phone application (MN Urolith, iOS version 16; Minnesota Urolith Center)²⁴ to generate predictions of urolith composition using a signalment or photo of a radiograph submitted by the user. Data on the app's accuracy are not yet established in the literature.

The primary objective of this study was to determine the accuracy of stone composition prediction on the basis of 4 preoperative parameters: signalment, urinalysis results, urine microbiologic culture testing, and 1 lateral abdominal radiograph. These parameters are readily available in practice as a minimal database for dogs with documented stone disease. This study had multiple secondary objectives: one was to compare accuracy and reliability in predictions between multiple evaluators of varying experience levels (rotating intern, internist, and radiologist) at 3 training time points: (1) their individual baseline knowledge level, (2) after receiving training in the form of a stone management lecture by a stone disease expert, and (3) using a novel algorithm to guide stone predictions. Another objective was to analyze the prediction results to determine the most commonly misidentified stone types and potential reasons for those incorrect predictions. The last objective was to enter this case series into the MN Urolith application to determine accuracy compared to the algorithm developed by the authors.

Methods

Study design and population

This was a prospective experimental study. The electronic veterinary medical record database of the Schwarzman Animal Medical Center was searched for canine urocystolith cases between January 1, 2012, and July 31, 2020. Inclusion criteria were the 4 preoperative parameters (signalment, urine culture, urinalysis, and lateral abdominal radiograph) documented in the medical record and quantitative urolith composition analysis from IDEXX Reference Laboratories. Dogs were excluded if any of this information was missing.

In addition, the following information was collected on each dog: species of bacteria identified from urine and/or urolith microbiological culture if infection was present, type of removal procedure performed (cystotomy, percutaneous cystolithotomy,

voiding urohydropropulsion, laser lithotripsy, or cystoscopic basket retrieval), date of procedure, and the prediction obtained from the MN Urolith application when case information was entered using instructions from the Minnesota Urolith Center website.²⁵

A database was created including all 4 criteria for each dog. Radiographs were included for both radiolucent and radiopaque stones.

Six veterinarians employed at the Schwarzman Animal Medical Center in 2021 were recruited for participation in the study ("evaluators"), consisting of 2 rotating interns (graduated from veterinary school < 1 year prior to entering the study), 2 board-certified internists, and 2 board-certified radiologists. The evaluators were informed of the study design but did not receive case data or any additional resources (lecture or algorithm) until the corresponding round of the study was initiated. The evaluators were blinded to the correct answers in each round until all 3 rounds of the study were completed. Each subsequent round was conducted 2 weeks after the prior round, and the order of cases was randomized in each round to reduce pattern recognition.

Data collection

Data were collected from each evaluator in 3 rounds, each separated by 2 weeks. In the first round, all cases were randomized. Each evaluator was given the 4 preoperative parameters for each dog, with no additional resources. Evaluators were instructed to predict stone types on the basis of their preexisting clinical knowledge. In the second round, the same data were randomized in a different order. Each evaluator watched a 1-hour teaching lecture on urolith identification and management by a board-certified internist who has been primarily managing stone disease for over a decade. Evaluators then re-evaluated all data. In the third round, evaluators followed a novel algorithm developed by the authors to make their predictions (**Supplementary Figure S1**). All case data were again randomized. Predictions were determined to be correct or incorrect on the basis of comparison to the laboratory quantitative stone analysis results for each dog.

A break of 2 weeks was given between each round to reduce evaluator fatigue and reduce evaluator recognition of case data despite randomization. The same data were used in each round to ensure the difficulty was consistent, but the order of presentation was reorganized using a random number generator.

Comparison to MN Urolith application

The same case data were also entered into the MN Urolith mobile application (iOS version 16; Minnesota Urolith Center),²⁴ which allows users to enter a photo of a radiograph or signalment (but does not include urinalysis data) to predict stone composition. The application was utilized by following the instructions provided by the Minnesota Urolith Center website.²⁵ Users are instructed to input signalment data into the application, which then provides example radiographs of different stone types. To obtain a predicted stone type, users must use clinical judgment

to select an example radiograph that most closely matches the data being input. Users can further refine the prediction by uploading a photo of a radiograph into an image-recognition function, which does not use or integrate the signalment data input from the previous steps. These steps were followed for each dog included in the study to obtain a prediction from the application, and this was compared to the commercial quantitative analysis results.

Statistical analysis

Descriptive statistics were used to characterize the study sample and individual patient data. Categorical variables such as signalment, urinalysis results, urine and stone culture results, type of procedure performed for stone removal, and stone type identified on IDEXX laboratory quantitative analysis are represented as frequency (percent). Data were analyzed for accuracy (percentage correct), and changes in accuracy between rounds were described for each evaluator. Evaluator inter-rater reliability (agreement and consistency) of stone score was assessed using the intraclass correlation, with an intraclass correlation coefficient (ICC) of > 0.9 being excellent, 0.75 to 0.9 being good, 0.5 to 0.75 being moderate, and < 0.5 being poor. The κ statistic was used to evaluate the level of agreement (correct answer of predicted stone type or not) between evaluators and the mobile application, with a κ statistic of 1 indicating perfect agreement, 0.8 to 1 indicating very good agreement, 0.4 to 0.6 moderate agreement, 0.2 to 0.4 fair agreement, < 0.2 poor agreement, and 0 meaning no better than by chance. Repeated-measures ANOVA was used to assess percent accuracy of the evaluators as a whole across rounds. Post hoc testing with Bonferroni correction was used to compare percent accuracy at each round to the other. All P values were 2-sided with statistical significance evaluated at the 0.05 α level. Ninety-five percent CIs were calculated to assess the precision of the obtained estimates. All analyses were performed in R version 4.3.1 (R Foundation for Statistical Computing).²⁶

Results

Study population

A total of 175 canine urolith cases met the inclusion criteria for the study. All dogs were client-owned patients of the Schwarzman Animal Medical Center Interventional Radiology, Surgery, and/or Internal Medicine services between January 1, 2012, and July 31, 2020. Dogs were reported as Shih Tzu ($n = 18$), Yorkshire Terrier (13), Havanese (13), Miniature Schnauzer (11), Cavalier King Charles Spaniel (7), Bichon Frise (7), Maltese (6), English Bulldog (6), Chihuahua (4), Lhasa Apso (4), mixed breed (4), Pomeranian (4), Pug (4), Jack Russell Terrier (4), Bulldog cross (3), Dachshund (3), Dalmatian (3), Golden Retriever-Poodle cross (3), Miniature Poodle (3), Maltese-Yorkshire Terrier cross (3), Poodle cross (3), Cocker Spaniel-Poodle cross (2), German Shepherd Dog (2), Japanese Chin (2), Maltese cross (2), Miniature Pinscher (2), Papillon (2), pit bull-type dog (2),

Portuguese Podengo (2), Portuguese Water Dog (2), Saint Bernard (2), Standard Schnauzer (2), Shih Tzu cross (2), Terrier cross (2), Yorkshire Terrier-Poodle cross (2), and 1 each of American Staffordshire Terrier, Australian Terrier, Border Collie, Chihuahua cross, Coton de Tulear, Doberman, French Bulldog, German Spitz, Hound cross, Italian Greyhound, Miniature Poodle cross, Norfolk Terrier, Pembroke Welsh Corgi, Standard Poodle, Retriever cross, Rottweiler, Shepherd cross, Shiba Inu, Soft Coated Wheaten Terrier, Toy Fox Terrier, and Toy Poodle. Mean age was 8.3 ± 3.3 years (range, 0.8 to 18.5 years) and mean body weight was 11 ± 9 kg (range, 6 to 60 kg). Forty-eight of 175 (27%) dogs were spayed females, 2 of 175 (1%) were intact females, 109 of 175 (62%) were neutered males, and 16 of 175 (9%) were intact males.

Urinalysis results of the included dogs had a mean urine specific gravity of 1.026 ± 0.011 (range, 1.007 to 1.055), and urine pH levels were pH 5 ($n = 4$), pH 5.5 (4), pH 6 (32), pH 6.5 (25), pH 7 (45), pH 7.5 (23), pH 8 (19), and pH 8.5 (23). Sixty-five of 175 (37%) dogs had crystalluria present on urinalysis. Of these dogs, crystal types included struvite (magnesium ammonium phosphate, $n = 27$), calcium oxalate (23), cystine (7), phosphate (4), urate (1), and multiple crystal types simultaneously (3). Thirty of 175 (17%) dogs had bacteria reported on preoperative urinalysis.

All included dogs had both a urine culture and stone culture performed. There was no growth on the preoperative urine culture in 138 of 175 (79%) dogs, while 37 of 175 (21%) had at least one species of bacterial growth. Of the dogs with bacterial growth, bacterial species included *Escherichia coli* ($n = 17$), *Staphylococcus* spp (11), *Enterococcus* spp (6), *Streptococcus* spp (3), *Klebsiella* spp (3), *Mycoplasma* spp (1), *Corynebacterium* spp (1), and *Citrobacter* spp (1). Stone culture results were obtained from all dogs after stone removal, and 136 of 175 (78%) dogs had no bacterial growth while 39 of 175 (22%) had at least 1 species of bacterial growth. Of the dogs with bacterial growth, bacterial species included *Staphylococcus* spp ($n = 17$), *E coli* (10), *Enterococcus* spp (7), *Pseudomonas* spp (4), *Proteus* spp (1), *Streptococcus* spp (1), *Micrococcus* spp (1), *Acinetobacter* spp (1), *Enterobacter* spp (1), and *Klebsiella* spp (1). Fifty-four (31%) dogs were receiving (or had received) antimicrobial treatment < 2 weeks prior to the documented preoperative urine culture, and 82 (47%) dogs were receiving (or had received) antimicrobial treatment < 2 weeks prior to the documented stone culture. Three dogs had a negative urine culture but positive stone culture; 1 dog had a positive urine culture but negative stone culture. Twenty-two dogs had a different bacterial species on stone culture compared to their preoperative urine culture. Sixteen dogs had the same bacterial species present on their preoperative urine culture and their stone culture.

Radiographic data from the case population preoperatively included dogs with radiopaque stones and radiolucent stones (based on no visible stones but a known stone upon removal). Stones were visible (radiopaque) in 153 of 175 (87%) dogs on the

lateral abdominal radiograph based on radiologist report, and 22 of 175 (13%) dogs had radiolucent stones not visible on radiographs, based on lack of stone identification in the radiologist report. Of the dogs with radiopaque stones, all had cystolithiasis present, 8 had concurrent urethroliths present, and 3 had concurrent ureterolithiasis present.

The stone composition in the case population consisted of calcium oxalate stones in the majority of dogs (60%), followed by magnesium ammonium phosphate (struvite, 14%), urate (7.4%), cystine (6.9%), calcium phosphate (5.1%), and silica (0.6%). Mixed stones were identified in 5.7%, defined in previous literature as stones with < 70% composition of 1 mineral type.^{27,28}

Stone removal for analysis was accomplished via cystotomy in 45% of dogs, percutaneous cystolithotomy in 42%, voiding urohydropropulsion in 7.4%, cystoscopy with basket retrieval in 4%, and laser lithotripsy in 2.3%.

Evaluator accuracy

Predictions were determined to be correct or incorrect by using the commercial quantitative stone analysis for each dog as the “gold standard.” In the first round, accuracy (percentage of correct predictions) was 58% and 63% for the 2 interns, 78% and 82% for the 2 internists, and 80% and 83% for the 2 radiologists. In the second round, after a training lecture, accuracy was 76% and 79% for the 2 interns, 86% and 89% for the 2 internists, and 87% and 89% for the 2 radiologists. In the third round, after the algorithm was followed, accuracy was 93% and 94% for the 2 interns, 95% and 96% for the 2 internists, and 96% and 96% for the 2 radiologists.

The accuracy of all evaluators improved as they progressed through the study from round 1 (baseline knowledge only) to round 2 (training lecture provided) to 3 (algorithm used; **Figure 1**). When evaluators were compared as a whole between rounds, percent accuracy was significantly different between the 3 rounds ($P = .002$). In post hoc testing, percent accuracy was significantly different when comparing rounds 1 and 2 ($P = .016$), rounds 1 and 3 ($P = .009$), and rounds 2 and 3 ($P = .007$). In each round, accuracy of the 2 interns was lower than the board-certified specialists, but this discrepancy was greatest in round 1 and smallest in round 3. When comparing between specialists, the accuracy of the radiologists and internists was similar in all rounds.

When stratified by stone type, evaluators in round 1 correctly identified the stone 72% of the time for struvite, 63% for calcium oxalate, 11% for calcium phosphate, and 0% for cystine, silica, urate, and mixed stone types. In round 2, evaluator accuracy was 96% for calcium oxalate, 80% for struvite, 56% for calcium phosphate, 7.7% for urate, and 0% for cystine, silica, and mixed stone types. In round 3, evaluator accuracy was 100% for calcium oxalate, 100% for calcium phosphate, 100% for cystine, 100% for struvite, 85% for urate, and 0% for silica and mixed stone types.

The most frequently incorrectly predicted stone types were stones of mixed composition and silica,

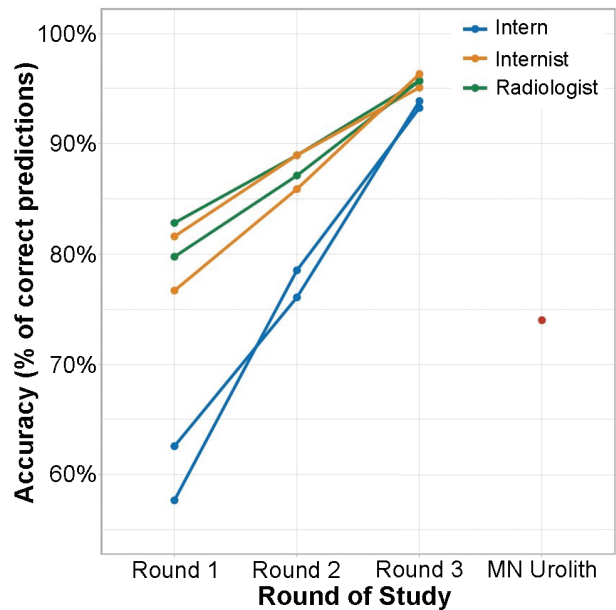


Figure 1—Accuracy (percentage of correct predictions out of 175 total canine urolith cases) of the 6 evaluators and the MN Urolith mobile phone application (red dot). Evaluators consisted of 2 rotating interns, 2 board-certified internists, and 2 board-certified radiologists, who were each tested at 3 time points with 2 weeks between each time point: baseline knowledge (round 1), training lecture provided (round 2), and using our novel algorithm (round 3; Supplementary Figure S1). In each round, they predicted the urolith type in 175 client-owned dogs that presented to the Schwarzman Animal Medical Center between January 1, 2012, and July 31, 2020. Evaluators were given signalment, urinalysis, urine culture data and a lateral abdominal radiograph for each dog. The same case data were input into the MN Urolith mobile application to determine its accuracy (red dot). A prediction was considered correct if it matched the quantitative laboratory stone analysis of the dog.

although there were low numbers of both of these stone types included (10 dogs and 1 dog, respectively). Calcium phosphate, cystine, and urate stones also had poor accuracy when predicted using baseline knowledge in round 1 among all evaluators. Calcium oxalate and struvite stones were the most frequently correctly predicted stone types by all evaluators in round 1. Other than mixed and silica stones, all other stone types had improved accuracy with each sequential round of the study. At the end of the study in round 3, 4 out of 7 stone types were predicted by evaluators with 100% accuracy using this case set (calcium oxalate, calcium phosphate, cystine, struvite), and 1 stone type had an 85% accuracy (urate). In addition to calculating mean accuracy in each round, evaluator fatigue was assessed by calculating the mean accuracy of each evaluator’s first half of responses (based on the order they were entered into the response spreadsheet) compared to the mean accuracy of their second half of responses. For all evaluators in all rounds, the difference in mean accuracy between their first and second half of responses was < 3%, with the second half actually having a higher mean accuracy in some rounds.

Interevaluator reliability and κ statistic

Overall agreement and consistency between all evaluators improved as they progressed from rounds 1 to 3. In round 1, agreement of all evaluators was moderate, with an ICC of 0.587 (95% CI, 0.525 to 0.65) and consistency of all evaluators was moderate at 0.594 (95% CI, 0.532 to 0.656). In round 2, agreement of all evaluators was good at 0.759 (95% CI, 0.713 to 0.802) and consistency was good at 0.760 (95% CI, 0.714 to 0.803). In round 3, both agreement and consistency of all evaluators was close to excellent at 0.884 (95% CI, 0.858 to 0.907). When stratified by round, agreement and consistency showed similar patterns between all evaluators and was moderate for round 1 and improved to be close to excellent (ICC > 0.9) for round 3.

The level of agreement for all evaluators for correct versus incorrect predictions had a κ of 0.498 in round 1, 0.625 in round 2, and 0.795 in round 3. When stratified by stone type, agreement between all evaluators improved as they progressed from round 1 to 3 and was close to perfect agreement (κ > 0.9) for 5 of 7 stone types in round 3. Agreement remained poor (κ < 0.2) for the 2 most rare and most incorrectly predicted stone types, which were silica and mixed.

Comparison to MN Urolith application

Overall accuracy of the MN Urolith application using the same case dataset as the evaluators in this study was 74% (Figure 1) when the instructions provided by the Minnesota Urolith Center were followed. The application predicted calcium oxalate and struvite stone types with overall good accuracy (90% and 96%, respectively), and this was higher than the 6 evaluators for these stone types using their baseline knowledge, though not as high as when the algorithm was used for any evaluator. The application predicted mixed stone types with 10% accuracy, surpassing the evaluators in all 3 rounds (0% in each round), although overall accuracy of mixed stone types remained low. The application predicted calcium phosphate with moderate accuracy (67%). However, using our case set, accuracy of the application was poor for other stone types included in the study (23% for urate, 8% for cystine, and 0% for silica).

Discussion

The present study identified 4 preoperative parameters (signalment, urinalysis, urine microbiologic culture testing, and survey lateral abdominal radiographs) that constitute a minimum database for prediction of canine urolith composition and can result in excellent accuracy when a novel algorithm is followed.

Using this minimal database for urolith composition, baseline knowledge of stone prediction alone resulted in variable accuracy on the basis of clinician experience level. All evaluators improved in accuracy from round 1 to 3. The largest disparity in accuracy was found between specialists and interns

in round 1 when only baseline knowledge was used. Although the interns' accuracy remained lower than the specialists in the following 2 rounds, the disparity in accuracy was progressively smaller and the interns' accuracy improved to a greater degree from baseline. In this group of evaluators, this finding was consistent when comparing within experience levels, with the interns performing comparably to each other and the specialists performing comparably to each other. The internists and radiologists also performed comparably to each other despite differences in training, as internists may have less experience assessing radiographs but more experience managing urolith cases, whereas radiologists are more experienced at assessing uroliths on radiography but spend less time assessing urinalysis data or managing these cases. This suggests that a standardized algorithm may be helpful to all evaluators regardless of specialized training.

The finding of highest accuracy in round 3 suggests that the algorithm improves evaluators' prediction success beyond their own knowledge base, even when their own knowledge improves with continuing education. Interestingly, the algorithm did not result in uniform accuracy between evaluator types. A possible reason is that the algorithm still requires a small degree of interpretation by the evaluator, such as the options "opacity more consistent with cortical or medullary bone." It is also possible that more experienced evaluators drew on preexisting knowledge or experiences to some degree when using the algorithm, whether consciously or unconsciously. A small degree of clinical judgment was also required in the MN Urolith application when used according to Minnesota Urolith Center instructions,²⁵ so neither method appears entirely objective.

Using the case data in this study, the MN Urolith application was found to predict with good accuracy the 2 most common stone types, calcium oxalate and struvite, at a level beyond the evaluators' baseline knowledge and even with a teaching lecture. However, the application resulted in a lower accuracy level than the algorithm presented here. The application had the highest accuracy for struvite and calcium oxalate, moderate accuracy for calcium phosphate, and lower accuracy for the 4 less common stone types (urate, cystine, silica, and mixed). Possible reasons for compromised accuracy of the application include the application functionality, which does not include urinalysis data, does not link the separate application functions of signalment and radiograph analysis to allow simultaneous input and prediction formation using these data together, as well as possible compromise of radiograph quality by instructing users to take a photo of the radiograph for submission (although this is a convenient feature). If the radiograph submission function is used alone, the application was not designed to provide a definitive stone type for many dogs but rather classified them as "nonstruvite." If the signalment function is used, the application provides a percentage "match" of multiple predictions, but not a single definitive prediction, requiring users to employ clinical judgment. Conversely, our algorithm

takes longer to use per dog and has more steps and therefore may be less user-friendly and convenient. However, accuracy of most stone types was higher than the application using our case data. These strengths may be combined for future development of a mobile application inspired by the MN Urolith application using this algorithm, and efforts will be made to converge both institutions' contributions to best serve the veterinary community and provide the most accurate application.

The most frequently misidentified stone type was stones of mixed composition. Mixed-composition stones may have features of more than 1 stone type on imaging or urinalysis,²⁹ which may complicate stone prediction using our preoperative parameters and algorithm. Accuracy of silica stones was also poor; however, this may not be representative, as our case set included only 1 dog with silica uroliths due to low prevalence of these stones. As silica is a relatively uncommon stone type in our geographical location and because they can be either lucent or opaque, evaluators may be less familiar with recognizing this stone type.³⁰

A previous study²⁷ of over 77,000 canine uroliths at the Minnesota Urolith Center between 1981 and 1997 reported a frequency of 49.6% struvite and 31.4% calcium oxalate stones, while a more recent study²³ at the University of California-Davis Urinary Stone Analysis Laboratory reported decreasing calcium oxalate frequency (50.1% to 37.7% from 2005 to 2018) and increasing struvite frequency (41.8% to 54.5% from 2005 to 2018). Other geographical areas also reported higher struvite frequencies and lower calcium oxalate frequencies compared to our data. The Canadian Veterinary Urolith Centre reported frequencies of 43.8% struvite and 41.5% calcium oxalate among their submissions between 1998 and 2003.³¹ In the UK, frequencies of 49.5% struvite and 30.7% calcium oxalate were reported from 1997 to 2006,¹⁴ and in Thailand, 44% of submissions were struvite and 27% were calcium oxalate.³²

Our struvite percentage was lower than in most previously reported literature, as we included only dogs that had a stone analysis performed, and if medical dissolution was successful, these patients would not be reflected in our study. In practice at the Schwarzman Animal Medical Center, medical dissolution of predicted struvite stones is highly recommended, so having fewer dogs with struvite stones that had a stone analysis was not surprising.

Clinically, the value of predicting stone type is to avoid performing invasive and expensive procedures on patients when they could be avoided, ensuring that stone dissolution is employed where applicable. Struvite is the main stone type that should be dissolved rather than removed, unless obstructive. The prediction accuracy of calcium oxalate stones was 63%, 96%, and 100% (rounds 1 to 3, respectively, among all evaluators) and struvite was 72%, 80%, and 100% (rounds 1 to 3, respectively, among all evaluators), supporting that the success of these predictions would be considered very high.

A significant proportion of dogs (22/175 [13%]) had a different microbial organism identified on

stone culture compared to their preoperative urine culture. This suggests that reinfection (colonization with a different organism) may be an important contributor in dogs with multiple positive cultures, as opposed to relapse (recolonization with the same organism) or persistent ongoing infection with the same organism. This also highlights the importance of submitting a stone culture when stone removal is achieved, even if a preoperative urine culture was performed, especially because many dogs are exposed to antimicrobial therapy during their work-up. Failure to identify that the bacterial species in the lower urinary tract has changed may increase the risk of unsatisfactory patient outcomes despite stone removal.

This study had several limitations. The number of evaluators who participated in and completed the study was small. To further evaluate the accuracy and utility of the proposed algorithm and minimum database of preoperative parameters, this study would ideally be repeated with a greater number of evaluators at each experience level to determine whether these results are repeatable and provide more statistical power to detect differences between groups. Evaluator types could be expanded to include other training and experience levels, such as general practitioners, board-certified surgeons, and veterinary students. The potential for evaluator fatigue to affect accuracy was considered, given the study conditions were not fully reflective of algorithm use in practice, where evaluators would be assessing 1 dog at a time rather than 175 dogs during each evaluation episode. Three out of 6 evaluators voluntarily provided feedback that they felt some degree of fatigue from using the algorithm for 175 dogs. However, the data did not show a major effect attributable to evaluator fatigue, as the mean accuracy of the first half of each evaluator's responses compared to the second half (when they may be more fatigued) changed by < 3% in any round, with the second half having a higher mean accuracy in some rounds. Evaluator bias was also considered given potential for case recognition between rounds, but this was minimized by randomizing the order in which dogs were presented and allowing a period of 2 weeks between distribution of case data to evaluators in each round. In addition, no evaluator knew the correct answers until the study was completed. Despite the potential for evaluator recognition of case data, the same case data were used in each round to ensure the difficulty of data to be evaluated was identical.

The population of urolith cases evaluated in this study was collected retrospectively and may vary from the case population in other hospitals and geographic locations. For example, this study population involved more small- and medium-breed dogs than large dogs, which may have affected the most frequently reported urolith types. All dogs had both urine culture and stone culture data included, which may have represented a selection bias for the study population, as there are dogs in clinical practice that may not have both cultures performed and thus be evaluated differently. Although 7 stone types were

represented, the frequency of the stone types was unequally distributed, with calcium oxalate and struvite being most common. This is likely reflective of actual urolith frequency in clinical practice.

Future studies could investigate the combination of these preoperative parameters and the proposed algorithm in a larger population of evaluators with no training lecture to observe how the algorithm performs independently of any training. If accuracy remains poor with mixed and silica stone types, improvements to current methods for prediction of these stone types is warranted. Our preoperative parameters and algorithm should also be further investigated to determine whether they are able to correctly predict less commonly known breed and genetic predispositions.

Ideally, given the increasing role of technology in clinical practice, the proposed algorithm could be combined with strengths of the more user-friendly MN Urolith application to produce a program that optimizes accuracy while remaining quick and easy to use for clinicians managing urolith cases.

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Disclosures

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Supplementary Materials

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