Recent advances in veterinary endourology have resulted in development of minimally invasive procedures, such as voiding urohydropropulsion, transurethral cystoscopic basket retrieval, cystolith fragmentation via transurethral cystoscopic-guided lithotripsy, and laparoscopic and keyhole transvesicular techniques, for removal of cystoliths from dogs and cats.\(^1\)\(^{-6}\),\(^a\) Such techniques are typically limited to relatively small cystoliths. Thus, accurate estimates of cystolith size are critical in determining whether specific cystoliths are amenable to removal by minimally invasive procedures. Overestimation of cystolith size could result in selection of more invasive forms of treatment (eg, cystotomy) with associated higher hospitalization costs, longer recovery times, and higher risk of complications; underestimation could result in selection of ineffective or inappropriate forms of treatment.

A previous in vitro study\(^7\) suggested that double-contrast cystography and ultrasonography were the most accurate diagnostic imaging methods for detecting and enumerating cystoliths. However, that study did not assess the ability of various imaging modalities to accurately estimate cystolith size, and in a subsequent study,\(^8\) ultrasonography was found to substantially overestimate the size of a plastic-covered metal bolt that was part of the bladder model. To our knowledge, studies comparing the accuracy of estimates of cystolith size obtained with various diagnostic imaging modalities are needed.

In vitro comparison of plain radiography, double-contrast cystography, ultrasonography, and computed tomography for estimation of cystolith size

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Objective —To compare accuracy of estimates of cystolith size obtained by means of plain radiography, double-contrast cystography, ultrasonography, and computed tomography.

Sample Population —30 canine cystoliths ranging from 1 to 11 mm in diameter with various mineral compositions.

Procedures —A bladder phantom model was created by filling a rubber balloon with saline (1% NaCl) solution and positioning it on top of a 2% gelatin cushion at the bottom of a water-filled 4-quart container. Cystoliths were individually placed in the bladder phantom and imaged by each of the 4 techniques. For each image, cystolith size was measured by 2 radiologists with computerized calipers, and size estimates were compared with actual cystolith size.

Results —Mean cystolith size estimates obtained by means of radiography, cystography, and computed tomography did not differ significantly from each other. However, for ultrasonographic images, mean ± SD difference between actual and estimated cystolith size (2.95 ± 0.73 mm) was significantly higher than mean difference for radiographic, cystographic, and computed tomographic images. For ultrasonography, mean ± SD percentage overestimation in cystolith size was 68.4 ± 51.5%.

Conclusions and Clinical Relevance —Results indicated that measurements of cystolith size obtained by means of ultrasonography may overestimate the true size. This suggests that cystolith size estimates obtained by means of ultrasonography should be interpreted with caution whenever cystolith size may influence patient management. (Am J Vet Res 2010;71:374–380)
ties have not been published. The purpose of the study reported here, therefore, was to compare accuracy of estimates of cystolith size obtained by means of plain radiography, double-contrast cystography, ultrasonography, and computed tomography.

**Materials and Methods**

Cystoliths—Thirty cystoliths selected from an archive maintained at the Michigan State University Veterinary Teaching Hospital of naturally occurring canine cystoliths that had been removed by means of cystotomy were used in the study. Mineral composition of the cystoliths was determined by means of quantitative mineral analysis, and cystoliths were selected such that 10 each consisted of > 80% CaOx, > 80% MAP, or > 80% urate. To minimize sizing errors and positioning artifacts associated with irregularly shaped cystoliths, an attempt was made to choose cystoliths that had a more or less regular shape. Each cystolith was measured with a handheld digital caliper, and the largest dimension was recorded as the true size of the cystolith. Cystoliths were selected so that there were 2 cystoliths of each of the 3 mineral compositions in each of the following 5 size categories: 1 to 2.99 mm, 3 to 4.99 mm, 5 to 6.99 mm, 7 to 8.99 mm, and 9 to 11.0 mm. Surface characteristics were recorded, and each cystolith was weighed and photographed. All cystoliths were soaked in saline (1% NaCl) solution for approximately 18 hours before imaging to minimize bubbles at the cystolith–saline solution interface.

Bladder phantom—A bladder phantom was constructed to eliminate the need for live animals and to minimize variability in imaging conditions. A 4-quart plastic storage container lined with a gelatin cushion and filled with water was used to simulate soft tissue components surrounding the urinary bladder (Figure 1). A nontransparent rubber balloon attached to a 3.5-cm-long piece of 3/8-inch (internal diameter) polyvinyl tubing was used to simulate the urinary bladder. The polyvinyl tubing was used to instill saline solution, air, or contrast medium into the balloon and allowed for placement and removal of cystoliths.

To construct the bladder phantom, a 2-cm-thick layer of a 2% gelatin solution was molded to the bottom of the storage container, and a second layer of gelatin was molded around a temporary balloon filled with approximately 500 mL of water that had been placed in the center of the gelatin cushion. When the temporary balloon was removed from the second gelatin layer, a concavity remained that allowed the artificial bladder to be consistently positioned within the container. The container was filled with distilled water until the balloon was covered by 2 cm of water, and a second storage container from which the bottom had been removed and covered with plastic wrap was placed on the surface of the water in the first container. Air bubbles beneath the plastic wrap were then removed, and the plastic wrap was used to provide a working surface for the ultrasonographer to obtain images of the bladder at a fixed distance from the cystolith. Because double-contrast radiography required a mixture of air and contrast medium, the artificial bladder was secured in position underwater with a deeper layer of plastic wrap to prevent the balloon from floating.

Diagnostic imaging—Each cystolith was placed inside the artificial bladder, and the balloon was filled with 360 mL of saline solution to a diameter of 6.5 cm. The artificial bladder containing the cystolith was then submerged and secured within the plastic container and imaged by means of computed tomography, ultrasonography, and radiography, in that order. The saline solution was then removed; the balloon was filled with 355 mL of air and 5 mL of a 1:1 dilution of iodinated radiographic contrast medium and distilled water; and cystography was performed.

Radiology technicians performed computed tomography and ultrasonography, whereas the primary author (KMB) performed radiography and cystography. Transverse computed tomographic images of the bladder phantom were acquired with a commercial unit at an axial slice thickness of 0.625 mm (120 to 140 kVp and 135 to 140 mAs) with a 512 × 512 imaging matrix and standard algorithm. Ultrasonograms of the bladder phantom were obtained with a microconvex curvilinear array transducer. The transducer’s focal zone was adjusted to the level of the cystolith, and the frequency (10 MHz) and gain were fixed for all images; each cystolith was imaged in 2 perpendicular planes. Radiographic and cystographic images were obtained with a direct digital radiology system (95 kVp, 500 mA, and 2.5 mAs). All computed tomographic, ultrasonographic, radiographic, and cystographic images were coded and stored electronically on a standard system for subsequent evaluation.

![Figure 1](image-url)
Evaluation of images—Two radiologists (NCN and JK) blinded to cystolith size and mineral composition independently evaluated all computed tomographic, ultrasonographic, radiographic, and cystographic images and estimated cystolith size by measuring the largest diameter with computerized calipers integral to the imaging software. For radiographic and cystographic images, no attempts were made to correct for magnification. For ultrasonographic images, the largest diameter measured on either of the 2 perpendicular images was recorded as the estimated cystolith size. Computed tomographic images were evaluated as transverse slices with a wide window width and high window level (bone window level), and the largest diameter in any slice was recorded as the estimated cystolith size. Transverse images were not reconstructed to estimate longitudinal diameter. Each cystolith was measured on 3 independent occasions by each of the 2 radiologists.

Data analysis—For each cystolith and each imaging modality, the mean value of the 3 measurements obtained by each of the 2 observers was used as the estimated cystolith size. The true size of each cystolith was subtracted from the estimated size to determine the difference between estimated and true size, with a negative difference indicating an underestimation of the true size and a positive difference indicating an overestimation of the true size. Percentage difference was then calculated by dividing the difference in size by the true size. Data for difference between estimated and true size and for percentage difference were analyzed by means of split-plot ANOVA with grouping factors for cystolith type and cystolith size group and a repeated factor for imaging modality. Post hoc comparisons were made by means of the Bonferroni t test. All statistical analyses were performed with commercially available software. For all analyses, a value of \( P < 0.05 \) was considered significant. Data are presented as mean ± SD.

Results

Subjectively, the quality of images obtained by means of computed tomography, radiography, and cystography was excellent (Figure 2). Minor edge blurring was evident on computed tomographic images of all cystoliths. This was most pronounced with small cystoliths, making it difficult to precisely determine the lateral edges of small cystoliths. Several phantom-induced artifacts were evident on ultrasonographic images (Figure 3), including spurious echoes superimposed over the middle of the balloon. However, none of these artifacts precluded cystolith detection. Subjectively, the balloon wall was somewhat more hyperechoic than the normal canine bladder, and most cystoliths appeared flattened. Acoustic shadowing was seldom seen. Instead, a reverberation or streak artifact was often seen deep to the cystoliths.

Cystolith size could be estimated during 164 of the 180 (91%) evaluations of radiographic images, 177 of the 180 (98.3%) evaluations of cystographic images, and all 180 (100%) evaluations of the ultrasonographic and computed tomographic images. The inability of a radiologist to detect a cystolith on radiographic images was primarily related to cystolith size rather than to mineral composition. For radiographic images, cystolith size could be estimated during 57 of the 60 (95%) evaluations of CaOx cystoliths, 54 of the 60 (90%) evaluations of MAP cystoliths, and 53 of the 60 (88%) evaluations of urate cystoliths. These proportions did not differ significantly among mineral composition types. By contrast, cystolith size could be estimated during only 21 of the 36 (58%) evaluations of radiographic images of cystoliths < 3 mm in diameter but could be estimated during 143 of the 144 (99%) evaluations of radiographic images of cystoliths ≥ 3 mm in diameter. The exception was a 7.2-mm urate cystolith that was iso-opaque to the bladder phantom.

Overall mean ± SD true size of the 30 cystoliths, as determined with a digital caliper, was 5.95 ± 2.89 mm. Mean sizes of the CaOx, MAP, and urate cystoliths were 6.12 ± 3.35 mm, 5.93 ± 2.67 mm, and 5.80 ± 2.92 mm, respectively.
When all 30 cystoliths were considered as a single group, mean ± SD difference between true size and size estimated on computed tomographic images was –0.01 ± 0.78 mm (range, –2.07 to 1.15 mm; Figure 4; Table 1), and mean percentage overestimation of cystolith size was 5.65 ± 20.5% (range, –25.1% to 80.8%; Figure 5). Mean percentage overestimation of cystolith size for cystoliths < 3 mm in diameter was 28.2% (range, –15.9% to 80.8%), whereas mean percentage overestimation of cystolith size for cystoliths ≥ 3 mm in diameter was 0.0% (range, –25.1% to 19.5%).

Mean ± SD difference between true cystolith size and size estimated on ultrasonographic images was 2.95 ± 0.73 mm (range, 1.93 to 4.91 mm; Figure 4; Table 1), and mean percentage overestimation of cystolith size was 68.4 ± 51.5% (range, 22.3% to 240.4%; Figure 5). Mean percentage overestimation of cystolith size was significantly (P < 0.001) higher for cystoliths < 3 mm in diameter (mean ± SD, 153.3 ± 56.5%) than for cystoliths ≥ 3 mm in diameter (34.6 ± 17.3%).

Mean ± SD difference between true cystolith size and size estimated on radiographic images was –0.27 ± 0.74 mm (range, –3.37 to 0.69 mm; Figure 4; Table 1), and mean percentage overestimation of cystolith size was –8.14 ± 15.9% (range, –48.5% to 8.01%; Figure 5). Mean ± SD difference between true cystolith size and size estimated on cystographic images was –0.09 ± 0.28 mm (range, –0.73 to 0.52 mm; Figure 4; Table 1), and mean percentage overestimation of cystolith size was –3.94 ± 8.29% (range, –29.0% to 6.44%; Figure 5).

Values for differences between true and estimated cystolith size and percentage overestimation did not differ significantly among computed tomographic, radiographic, and cystographic images. Ultrasonography significantly overestimated the size of cystoliths in this in vitro model when compared with radiography (P < 0.001), cystography (P < 0.001), and computed tomography (P < 0.001).

![Figure 4](image-url) Figure 4—Difference between true and estimated cystolith size as a function of true cystolith size for 30 cystoliths imaged in a bladder phantom by means of plain radiography (PR), double-contrast cystography (DCC), ultrasonography (US), and computed tomography (CT).

![Figure 5](image-url) Figure 5—Percentage difference between true and estimated cystolith size as a function of true cystolith size for 30 cystoliths imaged in a bladder phantom by means of plain radiography (PR), double-contrast cystography (DCC), ultrasonography (US), and computed tomography (CT).

<table>
<thead>
<tr>
<th>Imaging modality</th>
<th>Cystolith composition</th>
<th>Estimated size (mm)</th>
<th>Difference (mm)</th>
<th>Percentage difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiography</td>
<td>CaOx</td>
<td>5.77 ± 3.28</td>
<td>–0.35 ± 0.47</td>
<td>–8.50 ± 10.7</td>
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<tr>
<td>MAP</td>
<td>5.74 ± 2.90</td>
<td>–0.20 ± 0.39</td>
<td>–6.69 ± 13.9</td>
<td></td>
</tr>
<tr>
<td>Urate</td>
<td>5.53 ± 3.33</td>
<td>–0.27 ± 1.18</td>
<td>–9.23 ± 22.4</td>
<td></td>
</tr>
<tr>
<td>All types</td>
<td>5.66 ± 3.07</td>
<td>–0.27 ± 0.74</td>
<td>–8.14 ± 15.9</td>
<td></td>
</tr>
<tr>
<td>Cystography</td>
<td>CaOx</td>
<td>5.97 ± 3.39</td>
<td>–0.15 ± 0.19</td>
<td>–4.02 ± 4.35</td>
</tr>
<tr>
<td>MAP</td>
<td>5.82 ± 2.68</td>
<td>–0.11 ± 0.37</td>
<td>–5.16 ± 11.2</td>
<td></td>
</tr>
<tr>
<td>Urate</td>
<td>5.78 ± 3.05</td>
<td>–0.02 ± 0.25</td>
<td>–2.65 ± 8.65</td>
<td></td>
</tr>
<tr>
<td>All types</td>
<td>5.86 ± 3.00</td>
<td>–0.09 ± 0.28</td>
<td>–3.94 ± 8.29</td>
<td></td>
</tr>
<tr>
<td>Ultrasonography</td>
<td>CaOx</td>
<td>8.97 ± 3.43</td>
<td>2.84 ± 0.67*</td>
<td>70.6 ± 64.7*</td>
</tr>
<tr>
<td>MAP</td>
<td>9.20 ± 3.31</td>
<td>3.27 ± 0.89*</td>
<td>70.7 ± 49.2*</td>
<td></td>
</tr>
<tr>
<td>Urate</td>
<td>8.55 ± 3.05</td>
<td>2.75 ± 0.58*</td>
<td>63.9 ± 43.6*</td>
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</tr>
<tr>
<td>All types</td>
<td>8.81 ± 3.17</td>
<td>2.95 ± 0.73*</td>
<td>68.4 ± 51.5*</td>
<td></td>
</tr>
<tr>
<td>Computed tomography</td>
<td>CaOx</td>
<td>5.94 ± 2.73</td>
<td>–0.28 ± 0.92</td>
<td>5.08 ± 29.0</td>
</tr>
<tr>
<td>MAP</td>
<td>5.96 ± 2.58</td>
<td>0.03 ± 0.64</td>
<td>3.14 ± 16.4</td>
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</tr>
<tr>
<td>Urate</td>
<td>6.02 ± 2.84</td>
<td>0.22 ± 0.73</td>
<td>8.73 ± 15.1</td>
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</tr>
<tr>
<td>All types</td>
<td>5.94 ± 2.56</td>
<td>–0.01 ± 0.78</td>
<td>5.65 ± 20.5</td>
<td></td>
</tr>
</tbody>
</table>

Data are given as mean ± SD. Overall mean ± SD true size of the 30 cystoliths, as determined with a digital caliper, was 5.95 ± 2.89 mm. Mean sizes of the CaOx, MAP, and urate cystoliths were 6.12 ± 3.35 mm, 5.93 ± 2.67 mm, and 5.80 ± 2.92 mm, respectively.

*Significantly (P < 0.001) different from values obtained for the other imaging modalities.
Discussion

Results of the present study suggested that computed tomography, radiography, and double-contrast cystography provided accurate estimates of the size of solitary cystoliths in a bladder phantom model, regardless of cystolith composition, although the accuracy of computed tomography varied among cystoliths. In contrast, ultrasonographic imaging underestimated the size of solitary cystoliths, suggesting that estimates of cystolith size obtained by means of ultrasonography should be interpreted with caution in situations where accurate sizing is necessary for determining optimal patient care.

We elected to use a bladder phantom for imaging of cystoliths in the present study to minimize variability of imaging conditions and eliminate the need for live animals. Bladder phantoms have been used in previous in vitro studies\(^7\) of cystolith imaging. However, earlier models were difficult to construct and cumbersome to operate and induced artifacts during imaging. The bladder phantom used in the present study was simple and inexpensive to construct and allowed us to simulate in vivo imaging conditions and standardize variables for all imaging modalities. Depth of the gelatin cushion below the balloon and depth of the water above the balloon were chosen on the basis of the amount of soft tissue typically present between the body wall and bladder wall in medium-sized dogs, as determined by computed tomography.\(^7\) The protocol used for double-contrast cystography resulted in an approximately 5-mm-deep pool of diluted contrast medium with a final concentration of 185 mg of iodine/mL in the bottom of the bladder phantom. This depth and concentration of contrast medium has been shown to be optimal for cystolith imaging.\(^7,12\)

In the present study, only a single cystolith was placed in the bladder phantom for imaging, even though dogs can develop a single or multiple cystoliths.\(^13\) Results of pilot testing with the bladder phantom in our laboratory revealed that multiple cystoliths tended to summate and appear as a few larger cystoliths, rather than as a collection of smaller cystoliths. In particular, with multiple cystoliths, ultrasonography did not consistently provide adequate resolution of individual cystoliths to obtain accurate individual size measurements. For this reason, we chose to use only solitary cystoliths to compare the ability of radiography, cystography, ultrasonography, and computed tomography to accurately estimate cystolith size.

Potential disadvantages of using an in vitro bladder phantom in the present study include imperfect replication of bladder morphology, inability to manipulate the phantom to optimize image quality, and the fact that the model itself may create imaging artifacts not encountered in vivo. Despite these potential disadvantages, in vitro phantoms are well suited for imaging and have been used to evaluate the diagnostic performance of various imaging modalities for detection of cystoliths.\(^7,11\)

Overall, the quality of images obtained by computed tomography, radiography, and cystography was excellent and comparable to the quality of images obtained in vivo. On ultrasonographic images, however, the bladder phantom wall appeared to be more hyperechoic than the normal canine bladder. Cystoliths had a tendency to have a flattened appearance, and reverberation or streak artifacts were noted deep to some cystoliths. A similar flattened appearance was observed in a previous in vitro study\(^7\) in which a lower-frequency transducer (3 to 7.5 MHz) was used. Acoustic shadowing of cystoliths was seldom seen during ultrasonography of cystoliths in the present study. This had been reported in another in vitro study\(^7\) involving bladder phantoms and is consistent with in vivo observations that cystolith shadowing is an inconsistent feature of ultrasonography of the urinary bladder.\(^14\) Spurious echoes in the bladder phantom lumen seen on ultrasonographic images in the present study were similar to those described in previous in vitro and in vivo studies.\(^7,8,13,16\) Artifacts are most commonly produced when a highly reflective object (balloon wall, container, or cystoliths) is imaged adjacent to an anechoic region (urine or saline solution) and may be secondary lobe artifacts,\(^5,10,14\) filling in of anechoic structures,\(^17\) slice-thickness artifacts,\(^18\) or range ambiguity artifacts.\(^19\) Although artifacts were present in most ultrasonographic images in the present study, they appeared to be less extensive than those reported in a previous in vitro study,\(^7,8\) largely because of the absence of metal bolts within the phantom.

In the present study, mean difference between true and estimated cystolith size and mean percentage overestimation of cystolith size for computed tomographic images were not significantly different from values obtained for radiographic and cystographic images. However, a wide variation was noted in percentage overestimation of cystolith size determined from computed tomographic images, indicating that the accuracy of individual cystolith measurements obtained from computed tomographic images varied widely. Subjectively, the quality of the computed tomographic images was considered good, other than blurring of cystolith edges, particularly with small cystoliths. This blurring was most likely a result of partial volume artifact and could have made it more difficult to precisely define the cystolith’s lateral edges, leading to a tendency to overestimate the size of small cystoliths. It is possible that acquiring images with a bone algorithm rather than a standard algorithm would have reduced the edge blurring and improved the accuracy of computed tomography for estimating cystolith size. On the other hand, a recent study evaluating the effect of window and level settings on calculus size determination found that use of a bone window, similar to the settings used in the present study, significantly improved the accuracy of computed tomography for estimating cystolith size. Further studies are needed to determine the optimal computed tomography method for measuring cystoliths in veterinary patients.

We elected to not use multiplanar reconstruction of the axial computed tomographic images to estimate the longitudinal diameter of cystoliths within the bladder phantom because it would have been impossible to reconstruct the images while keeping the radiologists blinded to the identity of the cystolith. The lack of multiplanar reconstruction could have led to a measuring error if the greatest diameter lay in a longitudinal or oblique plane. However, it seems unlikely that a
longitudinal reconstruction of the images would have improved the accuracy of computed tomography because our results indicated that evaluation of transverse computed tomographic images was accurate for estimating cystolith size. Also, results of in vivo studies by Elkin and coworkers 

of nephroliths and ureteroliths in people have found that measurement of cystolith size in the longitudinal plane by computed tomography often overestimates the actual diameter. Although computed tomography appears to be a relatively accurate method of estimating cystolith size, it is unlikely that computed tomography will become the method of choice for detection or measurement of cystoliths in veterinary medicine because the method is no more accurate than other modalities that are less expensive and more readily available and that do not require general anesthesia.

Interestingly, ultrasonography significantly overestimated cystolith size for all 3 mineral compositions in the present study. Percentage differences between ultrasonographic estimates of cystolith size and true cystolith size ranged from 22% to 240% for individual cystoliths. Although other studies evaluating the accuracy of ultrasonography to estimate cystolith size have not been reported, a similar propensity of ultrasonography to overestimate the size of objects in a bladder phantom was observed in a previous study. In that study, ultrasonography overestimated the size of plastic-covered bolts in the bladder phantom by 56%. Reasons for the disparity between actual cystolith size and ultrasonography estimates are unclear but are likely related to a combination of limited lateral resolution and imaging artifacts. Lateral resolution is defined as the ability of a transducer to resolve objects that are side-by-side in a plane perpendicular to the ultrasound beam. The inability to adequately separate individual cystoliths in the pilot study may have been attributable to limitations of lateral resolution, making side-by-side cystoliths appear as a single large cystolith. The greatest measured diameter for all cystoliths in the present study lay in a plane perpendicular to the ultrasound beam. Lateral resolution is determined by the focusing properties in a plane perpendicular to the ultrasound beam. Lateral resolution is defined as the ability of a transducer to resolve objects that are side-by-side in a plane perpendicular to the ultrasound beam. Lateral resolution is defined as the ability of a transducer to resolve objects that are side-by-side in a plane perpendicular to the ultrasound beam.

The phenomenon known as the proximal curved-edge artifact likely contributed to the flattened ultrasonographic appearance of the cystoliths in the present study and may have substantially contributed to the overestimation of cystolith size. This artifact was first described when a 25-mm catheter balloon was imaged in a water bath with a linear array transducer. The proximal curved-edge artifact appears as a highly echogenic, curved artifact that extends from the proximal edges of the curved structure. This artifactual extension of the object’s curve makes the object appear flattened and elongated. A second study described the appearance of this artifact in vivo and concluded that the proximal curved-edge artifact is a type of side lobe artifact unique to highly reflective round objects. Side lobe artifacts are spurious echoes that are caused by the reflection of weak ultrasound beams produced by the transducer that are not part of the main ultrasound beam.

We were concerned that the contrast pool used for double-contrast cystography might have obscured some of the smaller cystoliths because the depth of the pool was greater than the maximal diameter of several cystoliths, but this did not happen. All of the cystoliths except a 1.53-mm struvite cystolith were readily apparent on cystographic images. However, it is possible that highly opaque contrast medium obscured the relatively thin margins of some of the less opaque cystoliths, resulting in a smaller apparent diameter.

The present study was designed only to evaluate the accuracy of radiography, cystography, ultrasonography, and computed tomography for estimating the size of a single cystolith in vitro. Importantly, the ability of various imaging modalities to accurately estimate the size of cystoliths in vivo may be complicated by the presence of multiple cystoliths, irregularities in cystolith shape and surface characteristics, and patient variables such as patient movement, body wall thickness, the presence of urinary sediment, degree of bladder distension, and superimposition of other organs. Further investigation is necessary to determine the optimal diagnostic imaging modalities for the comprehensive evaluation of urolithiasis in companion animals.

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