Efficacy of a phospholipid-stabilized sulfur hexafluoride microsphere contrast agent and water for hydrosonography of the upper portion of the gastrointestinal tract in dogs

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OBJECTIVE
To investigate the efficacy of a phospholipid-stabilized sulfur hexafluoride microsphere (SHM) contrast agent and water for hydrosonography of the upper portion of the gastrointestinal tract of dogs.

ANIMALS
12 healthy adult Beagles.

PROCEDURES
In a crossover study, each dog was anesthetized and underwent noncontrast ultrasonography then hydrosonography following administration of tap water (30 mL/kg) without (water method) or with SHM (0.1 mL; SHM method) via an orogastric tube. There were at least 3 days between hydrosonographic procedures. Wall thickness, wall layer definition, conspicuity of the mucosal-luminal interface, and image quality were evaluated separately in the near and far fields for the gastric cardia, body, and pylorus and descending duodenum and compared among the 3 scanning methods.

RESULTS
Mean wall thickness measurements did not differ significantly between the water and SHM methods at any location except the far-field gastric cardia where the mean wall thickness for the SHM method was less than that for the water method. In general, the SHM method improved wall layer definition and conspicuity of the mucosal-luminal interface of structures in the near field, compared with noncontrast method. The water and SHM methods both resulted in superior image quality relative to the noncontrast method for the near-field gastric cardia, far-field gastric cardia, and far-field duodenum.

CONCLUSIONS AND CLINICAL RELEVANCE
Results indicated that, for dogs, gastrointestinal hydrosonography by use of the SHM method improved wall layer definition and mucosal conspicuity, particularly in near-field images of the upper portion of the gastrointestinal tract. (Am J Vet Res 2021;82:712–721)
Ultrasonographic evaluation of the gastrointestinal wall is dependent on the extent of gastrointestinal tract distension and amount of air in the lumen. The acoustic window of the gastrointestinal tract can be obscured by air within the lumen, which can interfere with assessment of mild changes in the wall layers or mucosal-luminal interface such as those associated with ulcers and perforations. A collapsed stomach results in substantial variations in wall thickness and limits detection of abnormalities in the wall layers and mass lesions. Conversely, a fluid-dilated stomach facilitates visualization of the wall layers and measurement of wall thickness.

Oral contrast ultrasonography of the gastrointestinal tract, also known as gastrointestinal hydrosonography, is a technique that uses fluid to dilate and reduce air in the lumen of the upper portion of the gastrointestinal tract (upper gastrointestinal tract), thereby improving the acoustic window. Traditionally, tap water has been used for hydrosonography to facilitate detection of foreign bodies in the gastrointestinal lumen and assessment of wall thickness and definition. In human medicine, antifoaming agents, such as simethicone, and microsphere contrast agents are used for hydrosonography of the gastrointestinal tract. One such contrast agent, SHM, consists of sulfur hexafluoride–filled microspheres with phospholipid shells for stabilization. It is primarily administered by the IV route to enhance visualization of the microvasculature of tissues. However, when 1 to 2 drops (approx 0.05 to 0.1 mL) of SHM is added to 200 mL of tap water and orally administered for hydrosonography, the SHMs line the lumen of the gastrointestinal tract, resulting in homogeneous echogenicity of the luminal border with a reduction in air artifacts and excellent delineation and visualization of the mucosal surface.

The purpose of the study reported here was to investigate the efficacy of an SHM contrast agent for gastrointestinal hydrosonography in dogs. Briefly, the quality of ultrasonographic images obtained without contrast (noncontrast method) and following oral administration of tap water (water method) was compared with the quality of images obtained following oral administration of tap water with SHM (SHM method). We hypothesized that the images obtained by use of the SHM method would be superior to those obtained by the water method.

Materials and Methods

Animals

The study had a crossover design. Each dog underwent gastrointestinal hydrosonography twice (once by use of the water method and once by use of the SHM method) with at least 3 days between hydrosonographic examinations. All study procedures were reviewed and approved by the Institutional Animal Care and Use Committee of Chonnam National University, and the dogs were cared for in accordance with the Guidelines for Animal Experiments of Chonnam National University (CNU IACUC-YB-R-2019-108).

Twelve purpose-bred Beagles (6 sexually intact males and 6 sexually intact females) with a mean age of 2.5 years (range, 1 to 4 years) and weight of 10.2 kg (8.8 to 11.4 kg) were enrolled in the study. All dogs were considered healthy on the basis of results of a physical examination, CBC, serum biochemical and electrolyte analysis, and abdominal radiographic and ultrasonographic examinations. The dogs were individually housed in cages (1.9 X 1.5 X 3 m), were fed a commercial dry dog food, and had ad libitum access to tap water throughout the observation period.

Ultrasonographic examination

Food but not water was withheld for 12 hours from each dog prior to each hydrosonographic examination. Then abdominal radiography and ultrasonography were performed to confirm that the upper gastrointestinal tract was adequately empty for the procedure. Anesthesia was induced and maintained with an IM injection of zolazepam hydrochloride–tiletamine hydrochloride (0.75 mg/kg) and medetomidine hydrochloride (0.05 mg/kg), which were combined in the same syringe. Once anesthetized, each dog was positioned in dorsal recumbency.

Ultrasonography was performed by use of an ultrasound machine with a 100-MHz linear transducer. The time gain control was set at its central position, and the power was set at a constant level with a gain of 64 dB.

For each dog, the order in which the water and SHM methods were performed was randomized by means of a random number generator. During each anesthesia session, an ultrasonographic examination of the stomach and duodenum was first performed without contrast by each of 2 independent investigators (SP and JWJ). Then, an 8F feeding tube was inserted through the oral cavity into the stomach to remove as much gas as possible from the stomach. Once the gas was removed, the assigned contrast agent (tap water [30 mL/kg] without [water method] or with 0.1 mL of SHM [SHM method]) was infused through the feeding tube, and the feeding tube was removed. Each of the 2 observers independently rescanned the stomach and duodenum, beginning at 30 seconds and ending within 10 minutes after administration of the assigned contrast agent. The SHM was mixed with the tap water immediately prior to administration for the SHM method.

Each observer acquired ultrasonographic images of the near-field wall and far-field wall of the cardia, body, and pylorus of the stomach and descending duodenum during each examination (noncontrast, water, and SHM methods). The gastric cardia was scanned with the transducer positioned over the ventral midline and observed in the short and narrowing gastric area passing through the diaphragm. The gastric body was examined by positioning the
transducer transverse to the body axis at the level of the left medial liver lobe. The pylorus was scanned at the outlet portion of the stomach where the lumen became markedly narrow and the wall was thickest in the longitudinal axis view. The descending duodenum was examined by positioning the transducer over the most lateral small intestinal loop in the longitudinal plane at the level of the right kidney.

Each dog was monitored for signs of gastrointestinal upset, such as vomiting, diarrhea, and loss of appetite, for 2 days following completion of each hydrosonographic procedure.

Image analysis

All identifying information was removed from the image files, and all images were independently reviewed by the 2 investigators (SP and J-WJ) who had performed the ultrasonographic examinations. The quality of the images and the gastrointestinal wall thickness were determined at each of the 4 areas of interest (gastric cardia, body, and pylorus and descending duodenum). The thickness of the near-field wall and far-field wall was measured separately at each site, with care taken to avoid rugal folds as much as possible. For each wall, a caliper was placed on the outer aspect of the serosa and the inner mucosal border. The mucosal-luminal interface was defined as the thin, smooth, hyperechoic line between the mucosal layer and the gastrointestinal lumen. For the qualitative assessment, the definition of the wall layers, conspicuity of the mucosal-luminal interface, and image quality were each subjectively assigned a score on scale from 1 to 3 (Appendix), where 1 was poor visualization and 3 was optimal visualization of the variable in question.

Statistical analysis

Statistical analyses were performed with commercially available statistical software* by an investigator (SP) under the supervision of a statistician (PJJK). Outcomes of interest were wall thickness, wall layer definition, conspicuity of the mucosal-luminal interface, and image quality for each of the 4 areas of interest. Each outcome was compared among the 3 scanning methods (noncontrast, water, and SHM) by use of a Kruskal-Wallis H test followed by a post hoc Scheffe test when necessary. Interobserver reproducibility of the measurements was assessed by calculation of the ICC. An ICC < 0.4 was defined as poor reproducibility, between 0.4 and 0.59 as moderate reproducibility, between 0.60 and 0.74 as good reproducibility, and ≥ 0.75 as excellent reproducibility. All data were summarized as the mean ± SD, and values of P < 0.05 were considered significant.12

Results

Dogs

Gastrointestinal ultrasonographic (noncontrast method) and hydrosonographic (with the water and SHM methods) evaluations were successfully performed in all 12 dogs. None of the dogs developed clinical signs of gastrointestinal upset following the ultrasonographic procedures.

Image analysis

Each of the 2 observers obtained 24 images (near-field and far-field images of the 4 areas of interest with the 3 scanning methods) for each dog. Thus, a total of 576 images were reviewed. Of the 144 images of the gastric cardia obtained, 22 (4 obtained by the noncontrast method, 10 obtained by the water method, and 8 obtained by the SHM method) were excluded from analysis because of a poor window for ultrasonography owing to the deep location of the cardia relative to the transducer. All images obtained from the other 3 sites were acceptable for assessment. Consequently, 554 images were included in the analyses.

The wall thicknesses of the gastric cardia, body, and pylorus and descending duodenum as measured on ultrasonographic images obtained by the 3 scanning methods were summarized (Table 1). The mean near-field and far-field wall thicknesses of the gastric cardia as determined by the SHM method were significantly less than those determined by the noncontrast and water methods. The mean near-field and far-field wall thicknesses of the gastric body determined by the water and SHM methods did not differ significantly but were significantly less than those determined by the noncontrast method. The mean wall thicknesses of the pylorus and descending duodenum did not differ significantly among the 3 scanning methods.

The subjective scores used to describe the extent of definition between the wall layers at each location of interest determined on images acquired by each of the 3 scanning methods were summarized (Table 2). The mean near-field wall layer definition scores for the gastric cardia and pylorus obtained by the SHM method were significantly greater (ie, the wall layers were better defined) than the mean near-field wall layer definition scores for the gastric cardia and pylorus obtained by the noncontrast method. Additionally, the mean near-field wall layer definition score for the pylorus obtained by the water method was significantly greater than the mean near-field wall layer definition score for the pylorus obtained by the noncontrast method (Figure 1). The mean near-field wall layer definition scores for the duodenum obtained by the water and SHM methods did not differ significantly but were significantly greater than the mean near-field wall layer definition score for the duodenum obtained by the noncontrast method. However, most (9/12) near-field images of the duodenum obtained by the noncontrast method were assigned a wall layer definition score of 3, and the remaining 3 images were assigned a wall layer definition score of 2. For all 4 areas of interest, the mean far-field wall layer definition scores did not differ significantly among the 3 scanning methods.

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The subjective scores used to describe the conspicuity of the mucosal-luminal interface at each location of interest as determined on images acquired by each of the 3 scanning methods were summarized (Table 3). The mean near-field conspicuity scores for the mucosal-luminal interface on images obtained by the SHM method were significantly greater than the corresponding mean near-field conspicuity scores for the mucosal-luminal interface on images obtained by the noncontrast method at all 4 locations except the pylorus. The mean near-field conspicuity scores for the mucosal-luminal interface did not differ significantly between the water and SHM methods at any location except the pylorus, where the mean near-field conspicuity score for the SHM method was greater than that for the water method. The mean conspicuity scores for the mucosal-luminal interface did not differ significantly between the noncontrast and water method in either the near field or far field at any of the 4 sites. For the SHM method, the margin of the mucosal surface became thicker and irregular approximately 10 minutes after administration of the contrast agent; therefore, the mucosal-luminal interface was evaluated before that change occurred.

The mean image quality scores for the gastric body in both the near and far fields and the descending duodenum in the far field did not differ significantly between the water and SHM methods and were significantly greater than the corresponding mean image quality scores for the noncontrast method (Table 4). Mean image scores did not differ significantly among the 3 scanning methods for any other location.

The ICC for wall thickness, wall layer definition, conspicuity of the mucosal-luminal interface, and image quality was assessed on the basis of site, scanning method, and location. The ICC for wall thickness, wall layer definition, and image quality was calculated using a 2-way mixed-effects model with repeated measures on the subjects and location of interest as determined on images acquired by each of the 3 scanning methods were excluded from analysis because of a poor window for ultrasonography owing to the deep location of the cardia relative to the transducer.
field, and scanning method used. Thus, 24 ICCs were obtained for each evaluation factor or outcome of interest. For each outcome of interest, most ICCs were > 0.60, which indicated good to excellent reproducibility (Table 5).

Discussion

In the present study, the efficacy of gastrointestinal hydrosonography following administration of SHM (0.1 mL/kg) in tap water (30 mL/kg) via an orogastric tube was assessed by comparison of the quality of ultrasonographic images obtained by that method with the quality of ultrasonographic images obtained without the aid of contrast and following administration of tap water (30 mL/kg) via an orogastric tube. Results indicated that, in general, wall thickness measurements at select areas (near-field and far-field walls of the gastric cardia, body, and pylorus and descending duodenum) of the upper gastrointestinal tract on images obtained by the SHM method did not differ significantly from those on images obtained by the water method, and wall thickness measurements on images obtained by hydrosonographic (water and SHM) methods were generally less than the corresponding measurements on images obtained by the noncontrast method. However, the SHM method was superior to the noncontrast method in terms of image quality and assessment of the conspicuity of the mucosal-luminal interface in the near field for all 4 sites evaluated and for defining wall layers in the near field at all sites except the gastric body. The SHM method was also superior to the water method for assessment of wall layer definition and the mucosal-luminal interface in the near field for the pylorus. Assessment of the mucosal-luminal interface did not differ significantly between the water method and noncontrast method at any location. Both hydrosonographic methods were superior to the noncontrast method in terms of image quality of the near-field gastric body, far-field gastric body, and far-field duodenum.

Twenty-two of the 144 (15.3%) images of the gastric cardia obtained in the present study were excluded from analysis because the deep location of the cardia relative to the ultrasound transducer led to poor visualization of the areas of interest. Administration of the water or water-SHM mixture for the hydrosonographic procedures caused gastric distention, which pushed the gastric cardia further from the ultrasound transducer, so the majority (18/22 [82%]) of excluded images were obtained by the water (n = 10) and SHM (8) methods. The volume of water (30 mL/kg) used to prevent the collapse of the gastric body for the hydrosonographic methods in the present study was selected on the basis of results of a previous study.

However, that volume caused overdistension of the gastrointestinal tract, which impaired evaluation of the far-field wall of the gastric cardia and pylorus. The volume of contrast agent administered for gastrointestinal hydrosonography should be adjusted for each patient on the basis of the site to be evaluated. The amount of SHM (0.1 mL) added to tap water (30 mL/kg) for the SHM method evaluated in the present study was selected on the basis of a protocol used for a human study in which 1 to 2 drops (approx 0.05 to 0.1 mL) of SHM was added to tap water for gastrointestinal hydrosonography.

In the present study, care was taken to avoid rugal folds during measurement of the gastric wall...
thickness. That was particularly challenging on images obtained by the noncontrast method. Rugal folds were more easily identified and avoided on images obtained by the hydrosonographic methods. The mean wall thicknesses of the pylorus and duodenum did not differ significantly among the 3 scanning methods evaluated in the present study. The mean wall thickness of the gastric body did not differ significantly between the water and SHM methods. Moreover, the wall thickness measurements of the gastric cardia and pylorus on images obtained by the noncontrast and water methods were less reproducible because it was difficult to accurately observe the wall boundary, likely owing to poorly defined wall layers at those sites and the typically low quality of those images.

In healthy dogs, the gastric wall is 2 to 5 mm thick, depending on the extent of gastric distention. Results of another study indicate that the mean wall thickness of the gastric cardia is 7.6 mm in dogs that weigh <10 kg and 9.7 mm in dogs that weigh 10 to 19.9 kg. The mean thickness of the pyloric wall is 1.75 mm in dogs that weigh 1.8 to 9 kg and 3.31 mm in dogs that weigh 9 to 36.5 kg. For the dogs of the present study, the mean wall thicknesses for the gastric body, pylorus, and duodenum were similar to those reported for dogs of other studies.

Conversely, the mean wall thickness of the gastric cardia for the dogs of the present study was substantially less than that reported in another study. This discrepancy was attributed to the differences in the location at which the wall of the gastric cardia was measured. In the present study, the wall of the cardia was measured at the markedly narrow portion from the peritoneal side of the

### Table 3—Mean ± SD conspicuity scores for the mucosal-luminal interface of the gastric cardia, body, and pylorus and descending duodenum of the 12 healthy adult Beagles described in Table 1.

<table>
<thead>
<tr>
<th>Gastrointestinal site</th>
<th>Scanning field</th>
<th>Ultrasonographic method</th>
<th>Noncontrast</th>
<th>Water</th>
<th>SHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric cardia*</td>
<td>Near</td>
<td>1 ± 0</td>
<td>1.25 ± 0.46</td>
<td>2.11 ± 0.93</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>1.17 ± 0.58</td>
<td>1.13 ± 0.35</td>
<td>1.11 ± 0.33</td>
<td></td>
</tr>
<tr>
<td>Gastric body</td>
<td>Near</td>
<td>2.42 ± 0.51</td>
<td>2.75 ± 0.62</td>
<td>3 ± 0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>2.17 ± 0.72</td>
<td>2 ± 0.95</td>
<td>2.58 ± 0.79</td>
<td></td>
</tr>
<tr>
<td>Pylorus</td>
<td>Near</td>
<td>1.5 ± 0.52</td>
<td>2 ± 0</td>
<td>2.17 ± 0.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>1.67 ± 0.89</td>
<td>1.92 ± 0.29</td>
<td>2.17 ± 0.39</td>
<td></td>
</tr>
<tr>
<td>Descending duodenum</td>
<td>Near</td>
<td>1.75 ± 0.45</td>
<td>2.33 ± 0.49</td>
<td>2.75 ± 0.45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>2.08 ± 0.29</td>
<td>2.25 ± 0.62</td>
<td>2.92 ± 0.29</td>
<td></td>
</tr>
</tbody>
</table>

*See Tables 1 and 2 for remainder of key.

**Figure 2**—Ultrasonographic images of the gastric body (A and B) and descending duodenum (C and D) of a healthy adult Beagle. A—Image of the gastric body obtained by the noncontrast method. The conspicuity of the mucosal-luminal interface was assigned a score of 1 (poorly visualized) in the near field owing to the presence of reverberation artifacts and a blurred hyperechoic line beneath the mucosal layer such that the luminal space could not be visualized. B—Image of the gastric body obtained by the SHM method. The conspicuity of the mucosal-luminal interface was assigned a score of 3 (remarkably visualized hyperechoic mucosal-luminal interface with continuous, sharp, and thin contours without blurred edges) in the near field. C—Image of the descending duodenum obtained by the water method. The conspicuity of the mucosal-luminal interface was assigned a score of 2 (moderate visualization of the hyperechoic mucosal-luminal interface with discontinuous or thick contours and blurred edges) in the near field and a score of 1 in the far field. D—Image of the descending duodenum obtained by the SHM method. The conspicuity of the mucosal-luminal interface was assigned a score of 3 in the near field and a score of 2 in the far field. See Figure 1 for remainder of key.
diaphragm when traced from the gastric body to the esophagus. In the other study,15 the wall of the gastric cardia was measured at the cardioesophageal junction where it was thickest.

For the dogs of the present study, the wall layers of the gastric body and duodenum were well defined and visualized regardless of the scanning method used. We attributed this to the facts that both structures were located close to the skin surface (and the ultrasound transducer) and that only a small amount of gas was present in the lumen owing to the withholding of food from the dogs for several hours prior to the ultrasonographic evaluations. The wall layers of the gastric cardia and pylorus were not well defined, particularly in the far field, when evaluated with the noncontrast method, and the definition of those wall layers was not significantly enhanced by use of hydrosonography, likely because administration of the contrast agent resulted in gastric distention that caused the gastric cardia and pylorus to move deeper into the abdominal cavity and farther away from the ultrasound transducer.

Ultrasonographically, the mucosal-luminal interface of the gastrointestinal tract typically appears as a thin hyperechoic line between the mucosa and lumen and varies in thickness depending on the smoothness of the mucosal contour.16 Thus, visualization of an intact mucosal-luminal interface can be useful to rule out mucosal lesions, such as ulcers and erosions.1 However, visualization of the mucosal-luminal interface can be challenging during noncontrast ultrasonography if the gastrointestinal lumen is collapsed. During water-contrast hydrosonography, ulcerative lesions appear as mucosal defects outlined by hyperechogenicity,10 but those lesions can be missed if the mucosal surface is not clearly observed.1 When SHM-contrast hydrosonography is performed, erosive lesions of the stomach and duodenum are identified by accumulation of echo signals in the eroded surface.7 Because the echo signal is generated from microspheres during SHM-contrast hydrosonography, it is much stronger and more easily visualized than the signal generated by gas during noncontrast or water-contrast ultrasonography.7

In the present study, a hyperechoic gas signal was observed during noncontrast ultrasonography, and the intensity of that signal varied depending on the amount of gas present in the lumen of the gastrointestinal tract. When that signal was thick and irregular, it impeded observation of the boundary between the mucosa and lumen and generally re-

### Table 4—Mean ± SD image quality scores for the gastric cardia, body, and pylorus and descending duodenum of the 12 healthy adult Beagles described in Table 1.

<table>
<thead>
<tr>
<th>Gastrointestinal site</th>
<th>Scanning field</th>
<th>Noncontrast</th>
<th>Water</th>
<th>SHM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastric cardia*</td>
<td>Near</td>
<td>1.33 ± 0.49*</td>
<td>1.25 ± 0.45</td>
<td>1.33 ± 0.49*</td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>1.25 ± 0.45*</td>
<td>1.17 ± 0.39</td>
<td>1.25 ± 0.62*</td>
</tr>
<tr>
<td>Gastric body</td>
<td>Near</td>
<td>2.25 ± 0.45*</td>
<td>2.83 ± 0.89</td>
<td>2.83 ± 0.39h</td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>1.67 ± 0.49*</td>
<td>2.42 ± 0.51b</td>
<td>2.5 ± 0.52b</td>
</tr>
<tr>
<td>Pylorus</td>
<td>Near</td>
<td>1.75 ± 0.75*</td>
<td>1.92 ± 0.79</td>
<td>2.17 ± 0.39a</td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>1.67 ± 0.65*</td>
<td>1.5 ± 0.52</td>
<td>1.67 ± 0.49a</td>
</tr>
<tr>
<td>Descending duodenum</td>
<td>Near</td>
<td>2.42 ± 0.51h</td>
<td>2.75 ± 0.45</td>
<td>2.83 ± 0.39a</td>
</tr>
<tr>
<td></td>
<td>Far</td>
<td>2.08 ± 0.29*</td>
<td>2.67 ± 0.49b</td>
<td>2.58 ± 0.51b</td>
</tr>
</tbody>
</table>

See Table 1 for remainder of key.

### Table 5—Summary of the reproducibility of ultrasonographic assessments for the outcomes of interest for the dogs described in Table 1.

<table>
<thead>
<tr>
<th>Outcome of interest</th>
<th>No. of ICCs &lt; 0.59 (ICC range)</th>
<th>Noncontrast method (ICC range)</th>
<th>Water method (ICC range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall thickness</td>
<td>19 (0.655–0.97)</td>
<td>5 (0.424–0.574)</td>
<td>3 (near-field cardia, far-field cardia, and near-field pylorus)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 (far-field cardia)</td>
<td>0</td>
</tr>
<tr>
<td>Wall layer definition</td>
<td>17 (0.465–1.000)</td>
<td>7 (0.407–0.536)</td>
<td>1 (far-field cardia)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4 (near-field cardia, far-field pylorus, and far-field pylorus)</td>
</tr>
<tr>
<td>Conspicuity of the mucosal-luminal interface</td>
<td>23 (0.621–1.000)</td>
<td>1 (0.500)</td>
<td>0</td>
</tr>
<tr>
<td>Image quality</td>
<td>21 (0.660–0.867)</td>
<td>3 (0.421–0.593)</td>
<td>1 (far-field cardia)</td>
</tr>
</tbody>
</table>

The ICCs for wall thickness, wall layer definition, conspicuity of the mucosal-luminal interface, and image quality were assessed on the basis of site, scanning field, and scanning method used. Thus, 24 ICCs were calculated for each outcome of interest. An ICC < 0.4 was defined as poor reproducibility, between 0.4 and 0.59 as moderate reproducibility, between 0.60 and 0.74 as good reproducibility, and ≥ 0.75 as excellent reproducibility.

See Table 1 for remainder of key.
sulted in a score of 1 being assigned for conspicuity of the mucosal-luminal interface. The water method distended the gastric lumen and minimized the gas effect, thereby allowing clearer visualization of the hyperechoic mucosal-luminal interface, compared with the noncontrast method. However, although the subjective scores for conspicuity of the mucosal-luminal interface for the water method were numerically greater than those for the noncontrast method, the mean score for conspicuity of the mucosal-luminal interface did not differ significantly between the water and noncontrast methods. The water method clearly differentiated the gastric wall from the lumen, but the hyperechoic mucosal-luminal interface was indistinct. That observation suggested the water method may be more useful than the noncontrast method for detection of ulcerative lesions.

During hydrosonography by use of the SHM method, the mucosal-luminal interface was more echogenic and clearer than that during hydrosonography by use of the water method. Compared with the noncontrast method, the SHM method significantly improved the conspicuity of the mucosal-luminal interface at all locations except the far-field gastric cardia, far-field gastric body, and far-field pylorus. Those findings were comparable to observations in human patients in which SHM-contrast hydrosonography results in visualization of erosive lesions in the stomach and duodenum as accumulations of echo signals in the eroded mucosal surface. Endoscopy is the best method for evaluation of gastrointestinal mucosal surfaces; however, it requires specialized equipment and requires the patient to be anesthetized.

Use of the SHM method for gastrointestinal hydrosonography can complement gastroscopy in veterinary patients.

For the dogs of the present study, all ultrasonographic examinations were performed in basic B mode rather than in harmonic detection mode, which is generally used for vascular contrast examinations. The harmonic detection mode detects only harmonic signals, whereas the basic B mode detects both basic and harmonic signals. Thus, basic B mode is considered more appropriate than harmonic detection mode for ultrasonographic examination of the anatomic structures of the upper gastrointestinal tract. Basic B mode ultrasonography has a high mechanical index, which destroys the phospholipid shells surrounding the SHMs and leads to the accumulation of large amounts of gas within the gastrointestinal lumen over time. In the present study, the mucosal-luminal interface became thicker and irregular approximately 10 minutes after administration of the water-SHM mixture. Therefore, the mucosal-luminal interface should be evaluated as soon as possible after oral administration of SHM.

During ultrasonographic examination of the gastrointestinal tract, gas within the gastrointestinal lumen often causes reverberation artifacts and degrades image quality, impairing observation of the wall layers, mucosal surface, and luminal contents or foreign bodies. The use of water for hydrosonography reduces those artifacts. When SHM is added to water for hydrosonography, the intense signal produced by the microspheres could cause other severe and obscuring artifacts. However, in the present study, both the water and SHM methods resulted in high-quality images, and the mean image quality score did not differ significantly between those 2 methods at any location. This was likely because only a small amount of SHM (0.1 mL) was used for the SHM method, which minimized the generation of artifacts.

Collectively, the results of the present study indicated that hydrosonography may be useful for evaluation of the mucosal surface and wall layers of the upper gastrointestinal tract of dogs. Given the high cost and short shelf life of SHM, the water method may be preferred over the SHM method. However, the SHM method did result in superior images and will result in a better diagnostic study if cost is not a consideration. In the present study, the water and SHM methods appeared to provide little advantage over the noncontrast method for evaluation of gastrointestinal wall layer definition and conspicuity of the mucosal-luminal interface. Adjustment of the volume of contrast agent administered for hydrosonography might reduce gastrointestinal distention, reduce abdominal pressure, and improve visualization of areas of interest.

The present study was not without limitations. Histologic examination of the upper gastrointestinal tract was not performed for the dogs of the present study; therefore, although the dogs appeared clinically normal, it is possible some dogs had minor gastrointestinal lesions, such as mild gastritis. Also, the SHM method was evaluated for only 1 dose (0.1 mL) of SHM, and the dose of SHM might affect the image factors assessed. Finally, all dogs of the present study were apparently healthy, and the scanning methods were not assessed in dogs with confirmed lesions in the upper gastrointestinal tract.

Compared with noncontrast ultrasonography, gastrointestinal hydrosonography by use of the water or SHM method improved wall layer definition and conspicuity of the mucosal-luminal interface, particularly in near-field images. Subjectively, images obtained by use of the SHM method were generally of higher quality than images obtained by use of the water method, despite the fact that the mean image quality scores did not differ significantly between those 2 methods. Use of the SHM method did not result in any significant artifacts. Therefore, we recommend that SHM be considered for hydrosonography to improve wall layer definition and mucosal conspicuity of the upper gastrointestinal tract.

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The authors declare that there were no conflicts of interest.

Footnotes
a. Zoletil, Virbac, Carros, France.
b. Domitor, Orion Corp, Espoo, Finland.
c. Prosound Alpha 7, Hitachi-Aloka, Tokyo, Japan.
d. SonoVue, Bracco Imaging, Milan, Italy.
e. SPSS Statistics, version 25, IBM Corp, Armonk, NY.

References

Appendix appears on the next page
**Appendix**

Description of the subjective scoring system used to assess ultrasonographic images in a study conducted to investigate the efficacy of SHM and water for hydrosonography of the upper portion of the gastrointestinal tract of dogs.

<table>
<thead>
<tr>
<th>Evaluation factor</th>
<th>Score</th>
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<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Wall layer definition</td>
<td>Poorly visualized wall layers without distinction between layers; only 1–2 layers clearly observed</td>
</tr>
<tr>
<td>Conspicuity of the mucosal-luminal interface</td>
<td>Mucosal-luminal interface poorly visualized</td>
</tr>
<tr>
<td>Image quality and artifacts</td>
<td>Image hard to interpret because of the presence of severe artifacts</td>
</tr>
</tbody>
</table>