Ileus is a loss of coordinated electromechanical activity of the stomach and small intestine. Gastric distension occurs as a primary event or can be secondary to ileus as a result of a variety of gastrointestinal tract diseases, including proximal enteritis and POI, which can be a major life-threatening complication in horses. Postoperative ileus has a prevalence that ranges from 14% to 47%, with associated mortality rate as high as 83% to 86%. In horses with ileus, the loss of effective transit of gastrointestinal contents can lead to gastric distension and, eventually, gastric rupture and death. The most obvious clinical signs of gastric distension and impending gastric rupture in horses are high heart rate and signs of pain. If gastric distension is suspected, nasogastric intubation is indicated to determine whether distension is present and to relieve the distension by drainage of fluid from the stomach. Failure to obtain fluid from the nasogastric tube is commonly accepted as evidence of gastric decompression. However, in some affected horses, gastric rupture can occur without warning. Furthermore, nasogastric intubation may be an inadequate procedure to identify stomach distension, and determining the efficacy of nasogastric decompression via nasogastric tube is often difficult. Repeated nasogastric intubation or long-term indwelling nasogastric tube placement is often used in horses with ileus to ensure gastric decompression. However, there may be substantial risks associated with repeated or long-term intubation, which include pharyngeal or esophageal mucosal irritation, laceration or perforation, epistaxis, and inadvertent tracheal intubation. Less invasive methods for accurate identification of gastric distension with fluid and determination of the efficacy of nasogastric decompression are warranted. Transcutaneous ultrasonography is a noninvasive procedure that might be useful for identifying gastric distension and determining the efficacy of nasogastric decompression via nasogastric tube.

Transcutaneous ultrasonography of the equine abdomen is commonly used for evaluation of horses with acute signs of abdominal pain, and there are several reports on the use of TUS for evaluation of the stomach in horses. However, to the authors’ knowledge, there is no information on the use of TUS for assessment of gastric distension or the estimation of gastric fluid volume. We hypothesized that TUS could be a useful diagnostic tool to estimate the volume of fluid in the stomach of horses.

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Transcutaneous ultrasonographic evaluation of gastric distension with fluid in horses

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Objective—To develop a transcutaneous ultrasonography (TUS) method for measuring the location of the stomach during various levels of fluid distension and evaluate any correlation between gastric fluid distension and stomach position.

Animals—6 adult horses.

Procedures—Known volumes of water were administered in 2 trials. In trial 1, the stomach was evaluated prior to and after the administration of 2, 4, and 6 L of water. In trial 2, the stomach was evaluated after administration of 6, 8, 10, and 12 L of water. The TUS was performed at the 7th through 16th left intercostal spaces (ICSs). For each volume of water, an image was captured at the most dorsal point in each ICS where the dorsolateral aspect of the stomach wall was viewed. The distance between this point and a horizontal line drawn on the skin at the level of the elbow joint was measured. The measurements at all ICSs were used to estimate the gastric wall height at ICS 12, which was subsequently evaluated for statistical association with volume administered.

Results—Significant correlation between the estimated height of the stomach wall at ICS 12 and the volume of fluid administered was detected. A regression equation to estimate gastric fluid volume when initial values for gastric wall height (cm) at ICS 12 and fluid volume (L) are known was developed.


Abbreviations

POI Postoperative ileus
TUS Transcutaneous ultrasonography
ICS Intercostal space

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The objectives of the study reported here were to develop a TUS methodology for measuring the location of the stomach during various levels of fluid distension and to evaluate any correlation between gastric fluid distension and position of the stomach in horses.

Materials and Methods

This project was approved by the Atlantic Veterinary College Laboratory Animal Care Committee. Six adult horses donated to the Atlantic Veterinary College (2 stallions and 4 mares; 4 Standardbred, 1 Arabian, and 1 Quarter Horse) were used and ranged in weight from 410 to 500 kg (mean, 463 kg). Horses had no history of gastrointestinal disease and no signs of gastrointestinal problems were detected via physical examination. The horses were housed in individual stalls and received grass hay that was fed twice daily until the start of the study.

Prior to the ultrasonographic examination, feed was withheld for 16 hours and water was withheld for 8 hours to allow maximal emptying of the stomach. Horses were not allowed access to feed or water during the study (from the beginning of the first trial to the end-point of the second trial). The horses were lightly sedated with xylazine (0.5 mg/kg, IV) for gastroscopic examination with a 3-m flexible endoscope. Gastroscopic examination was performed before each trial to confirm that the stomach was free of food and fluid, and if the stomach was not empty at the time of the initial gastroscopic examination, feed restriction was continued and the gastroscopic examination was repeated every 8 hours until the stomach was empty. Gastric emptying occurred by 16 hours in 5 horses; 1 horse required 32 hours of feed restriction to achieve gastric emptying because of mild gastric impaction (treated with 6 L of water administered via nasogastric tube). After resolution of the impaction, no other abnormalities were detected in this horse and the water administered in the first trial (6 L) was evacuated from the stomach in 8 hours, as confirmed via gastroscopic examination just before the second trial. Immediately after completion of the gastroscopic procedure, an indwelling nasogastric tube was placed for administration of water. The nasogastric tube was passed to the level of the cardia, which was endoscopically estimated, and secured to the halter. The lumen of the tube was plugged to prevent ingress of air.

With the stomach free of food and fluid, each horse was examined in 2 trials, with 8 hours between each of the trials to allow maximal emptying of water added (6 L from the first trial). The nasogastric tube was left in place only during each trial and removed between trials. In each trial, water was administered through the nasogastric tube by gravity flow. In the first trial, ultrasonographic imaging was performed prior to the administration of water and following the administration of 2, 4, and 6 L of water. Prior to the second trial, a second gastroscopy was performed to confirm that the water added in the first trial was evacuated from the stomach, and then, ultrasonographic imaging was performed following the administration of 6, 8, 10, and 12 L of water.

To quantify any effect of gastric emptying on the results, 6 L of water was administered in both trials and...
results of TUS were compared. In the first trial, the final volume of 6 L of water administered was achieved at the end of the trial, approximately 20 minutes after sequential administration of 2-L volumes of water began; in the second trial, the 6 L of water was administered as a single volume at the start of the trial.

**Ultrasonographic technique**—Ultrasonographic imaging of the stomach was performed on the left thoracic wall from the 7th to the 16th ICS. This area was clipped of hair, and the 7th through 16th ICSs were numbered and delineated with a permanent marker to facilitate examination. A horizontal line was also drawn on the skin at the level of the point of the elbow. The skin was cleaned with isopropyl alcohol and acoustic coupling gel was applied to allow adequate contact of the transducer. The ultrasonographic examinations were performed with a 3.5-MHz sector transducer with a maximum depth of 20 cm. Scanning was performed from dorsal to ventral. The transducer was oriented transversely so that dorsal was to the right on the video screen. Identification of the stomach was based on identification of regional anatomic features and the stomach’s ultrasonographic appearance. The stomach wall was visible as a large curvilinear fluid-gas interface located in the left cranial abdominal quadrant, caudal to the liver and medial to the spleen (Figure 1). The TUS examination was initiated dorsally (dorsoventral direction) in each intercostal space. The image was captured when the most dorsolateral portion of the stomach wall was visualized, at the most dorsal point of the ICS. The dorsolateral area of the stomach wall was chosen because it is the most superficial portion of the stomach when the stomach is evaluated with a TUS technique performed in the dorsoventral direction. The images were captured in expiration to minimize gas interference from the left lung, which could obscure the stomach wall.

Prior to administration of water and for each of the volumes of water given, a single static image was captured in each ICS at the highest point at which the stomach wall was visible (most dorsolateral portion of the stomach wall observed). Externally, the distance from the highest point of the stomach to the horizontal line drawn on the skin was measured with a ruler and recorded as the stomach wall height in centimeters (Figure 2).

When the stomach was not clearly identified, the image was taken at the same point as that at the previously measured gastric wall height or at the height of the elbow joint if at ICS 7 (because there was no previously measured gastric wall height for ICS 7). The static images were printed on thermal paper. All TUS examinations were performed by the same investigator (ML) with at least one of the other authors present as observer, but the TUS examinations were not repeated by another investigator. A random number was assigned to each printed ultrasonogram, and the images were examined to identify the stomach wall by 2 investigators, 1 of which performed the TUS examinations. The other evaluator was the other author who was present as an observer in all the examinations.

**Statistical analysis**—After completion of all trials, the printed images were examined by 2 investigators who were unaware of the identity of the horse, the volume of water administered, and the number of the ICS. Only measurements from printed images in which the stomach wall was clearly identified by both evaluators were included in the final analysis. The measured gastric wall heights were analyzed in a 2-step procedure to account for repeated measures and different water volumes within each horse. First, from each series of values across ICS 7 to 16, a quadratic regression of the measured heights on the different ICS numbers, allowing for a difference between the first and second trial measurements at 6-L volumes, was used to estimate the height at ICS 12. Second, the estimated heights at ICS 12 for different horses and different water volumes were analyzed by use of a linear mixed model with random horse effects, serial first-order autocorrelation, and a quadratic equation for volume of water. This choice of model was based on examination of the correlation structures and validation of the model assumptions.

**Figure 3**—Graphic representation of gastric wall heights measured via TUS (from 7th through 14th ICSs) obtained from a horse after oral administration of various volumes of water via nasogastric intubation.

**Figure 4**—Graphic representation of gastric wall heights measured via TUS at ICS 12 obtained from 6 horses (solid lines) after oral administration of various volumes of water via nasogastric intubation. Dashed line represents a typical estimated curve for a horse.
The height at ICS 12 was chosen to represent the entire curve of values across different ICSs to obtain a single equation for the effect of the amount of water on height. The equation was in terms of the estimated height at ICS 12 instead of the observed height because the estimated height at ICS 12 also used the values at neighboring points of ICS 12 and was therefore more precise. The estimated and measured heights at ICS 12 were compared to ensure that all estimated values were intuitively accurate. All statistical analyses were performed with software. Values of \( P < 0.05 \) were considered significant.

**Results**

None of the horses had clinical signs of colic or other complications during the study. Both investigators who evaluated the printed ultrasonographic images agreed 100% of the time on the identification of the stomach wall on the printed images. When investigators agreed that the stomach wall was not identified on the images, the images were not included in the final analysis.

Three hundred twenty-one measurements in 42 series of readings across ICSs from the 6 horses were used in the statistical analysis (Figure 3). Across all horses, there were no significant differences between the measurements at 6-L volumes of water in the first and second trials, although in 1 horse (No. 5), a consistently higher volume was measured in the second trial. Subsequent analysis used the mean value obtained when 6 L was administered.

Analysis of the estimated gastric wall heights revealed a significant \((P < 0.001)\) effect of water volume and an estimated SD about the regression curve of 3.1 cm. Furthermore, there was high within-horse correlation \((r = 0.54)\) and serial correlation between increasing water volumes. The estimated heights at ICS 12 ranged from 20.6 to 38.3 cm with a mean of 28.1 cm (Figure 4). The regression analysis (determined on the basis of the linear mixed model for estimated gastric wall height at the 12th ICS and computed by use of restricted maximum likelihood estimation) was as follows:

\[
\text{Height (cm) at ICS 12} = A + \text{horse level} + (B \times \text{fluid volume}) - C \times (\text{fluid volume})
\]

where \( A = 23.03, B = 1.552, \) and \( C = 0.0594. \)

**Discussion**

In an attempt to evaluate the entire stomach, imaging was performed from the 7th through 16th ICSs. It has been reported that the equine stomach is commonly visible via ultrasonography at the 11th, 12th, and 13th ICSs. The 12th ICS was in the middle of the range of ICSs at which the stomach was seen, and its use would therefore avoid extrapolation beyond that range (for horses with measurements missing at some ICSs) and offer optimal precision for determination of the estimated height.

The most dorsolateral area of the stomach wall was chosen as the point of image capture via TUS because it is the most superficial portion of the stomach wall when the stomach is ultrasonographically evaluated in a dorsoventral direction throughout the ICSs. In addition, the dorsolateral area of the stomach wall was always identified when the stomach was ultrasonographically identified. Fluid-gas interface was not chosen as the point of image capture; it was not always evident because we tried to minimize the amount of gas in the stomach.

It was assumed that gastric emptying would affect the fluid volume in the stomach, so the study was designed as 2 trials/horse. The time needed to complete each trial was approximately 30 minutes. Performing the procedure as a single trial would have increased the time needed and thus increased the potential for gastric emptying, which might have altered the results obtained at the larger fluid volumes. Xylazine administration (0.5 mg/kg, IV) was used in an attempt to minimize the effects of gastric emptying within this time frame. This dose of xylazine inhibits duodenal motility for 30 minutes after administration and thus slows the rate of gastric emptying. Because the presence of an indwelling nasogastric tube has a negligible effect on the gastric emptying rate of liquids in horses, the nasogastric tube was left in place for the duration of each trial.

To quantify any effect of gastric emptying on the results, the administered volume of 6 L of water was used in both trials, and no consistent or significant effect was detected. Alternatively, removal of the added volume of water (endoscopically) at the end-point of each trial (6 L and 12 L) could have been attempted.

Gas distension of the stomach from gastroscopic examination could change the position of the stomach and therefore affect the measurements obtained in this study. In an attempt to minimize the amount of gas, the stomach was allowed to deflate through the endoscopic biopsy instrument channel at the end of each gastroscopic examination. In addition, the nasogastric tube lumen was plugged when not in use to avoid introduction of air. Although efforts were made to minimize the amount of gas in the stomach, the gas was not totally eliminated and it is possible that it affected the measurements obtained. Because nasogastric intubation of the stomach may alter gastric observation via ultrasonography, the nasogastric tube used in this study was secured in place in the distal portion of the esophagus, just orad to the cardia.

Because lung-gas interference can obscure the dorsal portion of the stomach wall, the images were captured in expiration, which minimized errors in the measurements of the stomach wall heights. However, it was not always possible to avoid the lung-gas interference, and its effect was not standardized in the study.

Ultrasonography has gained popularity as a diagnostic imaging method because it is noninvasive, rapid to perform, and relatively inexpensive, compared with other methods. In the present study, TUS seemed to be an accurate method for identification of the gastric wall, as indicated by total agreement between both investigators who evaluated the images. Dorsocaudal displacement of the stomach wall was considered ultrasonographic evidence of gastric distension.

There was substantial variation among horses for the estimated gastric wall height at ICS 12, which
could represent individual horse characteristics (eg, size, breed, and sex). Even if such characteristics could be included in the modeling, the authors consider the use of a single estimation equation for all horses unrealistic and suggest instead a 2-step procedure in which an estimated gastric wall height at ICS 12 is calibrated against a known gastric fluid volume to determine the horse level in the equation. The estimated gastric wall height at ICS 12 would be determined in the same way as in the present study from ultrasonographic measurements at the ICSs where the stomach wall was visible. After calibration, the equation could be used (in reverse) to estimate gastric fluid volume from ultrasonographic measurements, preferably again across all intercostal spaces. The calculations involved could easily be used in a spreadsheet. Results of the present study suggested that TUS for gastric fluid estimation could be a useful diagnostic tool in horses with an acute abdominal crisis or those affected by POI. For instance, after the initial examination for colic, estimation of gastric fluid volume may have usefulness to determine whether nasogastric intubation is needed for gastric decompression and to monitor the efficacy of decompression. Further development of this technique is necessary before it can be used clinically. First, the repeatability and reproducibility of multiple TUS measurements on the same horse by the same and different operators should be determined. The agreement found in the interpretation of images obtained by a single operator was promising but may not reflect the real repeatability and reproducibility of the method. Second, the study should be repeated with a random and larger sample of horses from a well-defined study population. The definition of the population should reflect the potential clinical use of the method and also impose restrictions on individual horse characteristics to make the use of a common estimating equation (after calibration) realistic. The resulting estimating equation derived from the study should include confidence intervals that take into account the differences among horses in the population.

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