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Ultrasound Assessment of Gastric Content and Volume

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Background: **Aspiration of gastric contents can be a serious perioperative complication, attributing up to 9% of all anesthesia-related deaths. However, there is currently no practical, noninvasive bedside test to determine gastric content and volume in the perioperative period.**

Methods: **The current study evaluates the feasibility of using bedside ultrasonography for assessing gastric content and volume. In the pilot phase, 18 healthy volunteers were examined to assess the gastric antrum, body, and fundus in cross-section in five prandial states: fasting and after ingestion of 250 mL of water, 500 mL of water, 500 mL of effervescent water, and a solid meal. In the phase II study, the authors concentrated on ultrasound examination of the gastric antrum in 36 volunteers for whom regression analysis was used to determine the correlation between gastric volume and antral cross-sectional area.**

Results: **The gastric antrum provided the most reliable quantitative information for gastric volume. The antral cross-sectional area correlated with volumes of up to 300 mL in a close-to-linear fashion, particularly when subjects were in the right lateral decubitus position. Sonographic assessment of the gastric antrum and body provides qualitative information about gastric content (empty or not empty) and its nature (gas, fluid, or solid). The fundus was the gastric area least amenable to image and measure.**

Conclusions: **Our preliminary results suggest that bedside two-dimensional ultrasonography can be a useful noninvasive tool to determine gastric content and volume.**

ASPIRATION of gastric contents can be a serious perioperative complication associated with significant morbidity and mortality.[1,2] In particular, aspiration of solid particulate matter, large volumes, or fluid with low PH carries high morbidity. Several anesthetic-related interventions (*e.g.*, timing of anesthesia and surgery, regional *vs.* general anesthetic technique, mode of induction, and airway management modality) are recommended to minimize aspiration risk.[3] However, assessment of perioperative aspiration risk relies almost exclusively on clinical history that may not be reliable. Currently, there is no practical, noninvasive bedside test to determine gastric content volume in the perioperative period.

The aim of the current prospective study is to examine the feasibility of portable ultrasonography for assessing gastric content and volume. The specific aims of this study are: (1) to describe the sonographic appearance of the stomach when empty and after ingestion of standardized volumes of fluid and a solid meal, (2) to determine the cross-sectional area (CSA) of antrum, body, and fundus using ultrasound before and after fluid and solid ingestion, and (3) to determine if there is a numerical correlation between ingested volume and CSA in different parts of the stomach (antrum, body, and fundus).

Materials and Methods

Phase I Pilot Study

After obtaining University Health Network Research Ethics Board (Toronto, Ontario, Canada) approval and written informed consent, 18 healthy volunteers were included in this prospective, observational study. Inclusion criteria were 18 yr of age or older, American Society of Anesthesiologists physical status classification I to II, body mass index less than 35 kg/m^2, and ability to understand the study protocol and provide informed consent. Exclusion criteria were any condition that may predispose subjects to have an increased residual gastric volume at baseline (*e.g.*, pregnancy), diabetes, and a history of upper gastrointestinal disease or surgical procedures of the esophagus or the upper abdomen.

Study subjects were scanned by a certified sonographer experienced in diagnostic abdominal ultrasound in five separate sessions: (1) at baseline (after 8 h of fasting); (2) after intake of 250 mL of water; (3) after intake of 500 mL of water; (4) after intake of 500 mL of water plus effervescent powder (4 g of gas-producing agent sodium bicarbonate, citric acid and simethicone; EZEM, Quebec, Canada); (5) after a standardized solid meal (tuna sandwich). Ultrasonographic views of three gastric locations (antrum, body, and fundus) were obtained using a curvilinear array 2- to 5-MHz transducer and a Philips HD11XE system (Philips Healthcare, Markham, Ontario, Canada) with image compounding technologies. Images were obtained with the stomach at rest, between peristaltic contractions. At each session, the scan was started 3 min after completing the ingestion.

Three gastric locations were examined in cross-section in the supine position first, followed by the right lateral decubitus position for a total of six views (three gastric locations in two subject positions) at each of the five scanning sessions.

The antrum was imaged in a parasagittal plane in the epigastric area (fig. 1a) using the left lobe of the liver, the

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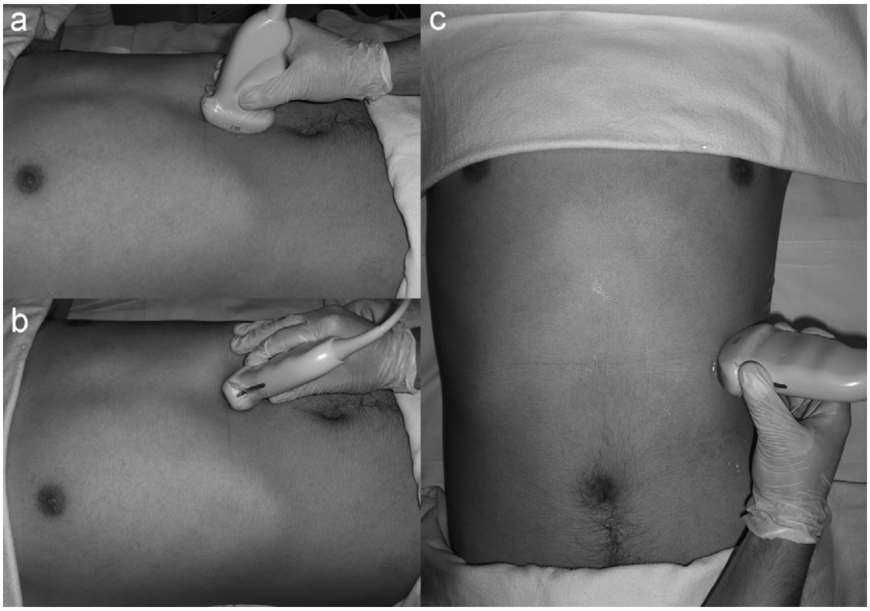

Fig. 1. Transducer position to scan the gastric (*A*) antrum, (*B*) body, and (*C*) fundus.

inferior vena cava, and the superior mesenteric vein as internal landmarks. The two vessels are usually visualized slightly to the right of the abdominal midline. Once these vessels were identified, the transducer was rotated slightly clockwise or counterclockwise to best obtain a true cross-sectional view of the antrum (the smallest possible cross-sectional view). The anteroposterior and craniocaudal diameters were measured in this view.

The gastric body was imaged by angling the transducer towards the left subcostal area (fig. 1 b). Depending on the shape of the stomach, the images were obtained with the transducer in a sagittal-oblique plane in some subjects and a more transverse (axial oblique) plane in other subjects. The craniocaudal and anteroposterior diameters were measured.

For the fundal views, a left lateral intercostal, trans-splenic approach was used (fig. 1c). The transducer was angled to capture the view medial and superior to the splenic hilar vessels. Anteroposterior and lateromedial diameters were measured.

Both qualitative and quantitative information was obtained from each gastric area during each session. All study subjects completed all study assessments.

For the quantitative component of the study, CSA of the antrum, body, and fundus (a two-dimensional section) was calculated according to the formula previously used by Bolondi,[4] using two maximum perpendicular diameters. This formula essentially represents the surface area of an ellipse, as follows: $CSA = (AP \times CC \times \pi)/4$, where AP is the anteroposterior diameter and CC is the craniocaudal diameter.

Phase II Study: Development of a Quantitative Model

On the basis of the pilot study findings, we narrowed our focus on the gastric antrum, which seemed to be the most reliable portion of the stomach to image and measure. We hypothesized that there is a numerical correlation between antral CSA and gastric content volume. In the Phase II study, 36 healthy subjects were recruited after obtaining University Health Network Research Ethics Board (Toronto, Ontario, Canada) approval and informed consent. Similar inclusion and exclusion criteria as in Phase I were applied. The subjects were randomly assigned to ingest one of six different volumes of water (0 mL, 100 mL, 200 mL, 300 mL, 400 mL, and 500 mL) after a period of overnight fast (a minimum of 8 h) for liquids and solids. Randomization was done according to a computer-generated list of random numbers. Each subject was randomized twice on two different days, for a total of 72 separate sessions and data sets.

A certified sonographer who was blinded to the ingested volume scanned the gastric antrum at each session after a standardized protocol as described for phase I. Only the antral views and measurements were obtained. Subjects were scanned 3 min after ingesting the assigned volume, first supine, followed by the right lateral decubitus position immediately thereafter.

Statistical Analysis and Sample Size Calculation

On the basis of the pilot study results, to replicate a correlation of $r = 0.86$ with a significant F test (at $P \leq 0.05$) and a power of 90% and allowing for greater expected variability from performing independent measures of different volumes in different individuals, we estimated that a sample size of 36 subjects would be needed. To increase the predictive accuracy of the model, we randomized each subject to two different volumes for a total of 72 data sets (two data sets per subject).

Demographics (age, gender, weight, height, and body mass index) were investigated with descriptive analysis. They were summarized by using median and interquartile range values for continuous and frequency and percentage

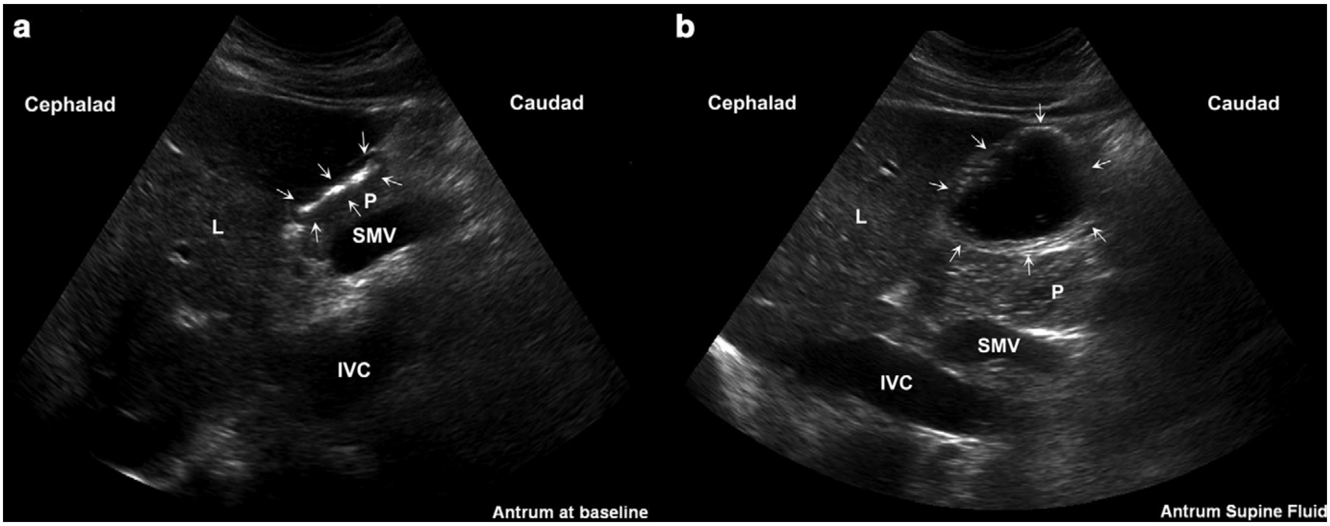

Fig. 2. Antral images at baseline (*A*) after 8 h of fasting and (*B*) after ingestion of 500 mL of water. IVC = inferior vena cava; L = liver; P = páncreas; SMV = superior mesenteric vein. *Arrows* = gastric antrum.

values for categorical variables. The distribution of CSA measurements (for both lateral and supine positions) was investigated graphically by using histogram. Normalization was applied when needed, with the use of logarithmic transformation. Pearson correlations were calculated among CSA-lateral, CSA-supine, and volume. The relationship between volume and CSA-lateral or CSA-supine was also investigated graphically with the use of boxplots. Inverse regression analysis was performed using CSA measurement as outcome and volume as predictor, potentially adjusting for significant demographic covariates (age, gender, weight, height, body mass index). A manual model selection procedure was followed where the selected model was the one with highest adjusted R^2 statistic among all the models with only significant covariates (based on the partial F test, $P < 0.1$).

This type of analysis was used for the generation of mathematical formulae and confidence bands that can be used for the prediction of volume values that correspond to a given area measurement value.[5]

Finally, a confirmatory analysis was performed by fitting random intercept models for CSA measurements by using the same covariates as those for the selected inverse linear regression models. These models were used to investigate potential within-subject correlation of CSA measurements. Proximity of the coefficient and SE estimates with those from the linear regression models would validate the results.

Results

Phase I Pilot Study

Eighteen subjects (12 men, 6 women) were studied in Phase I (18–55 yr, 152–180 cm, 49–92 kg, BMI 19–28 kg/cm^2).

Qualitative Data. At baseline (fasting state), the gastric antrum appears flat (anterior and posterior walls usually juxtaposed), with a round to ovoid shape in either the supine or right lateral decubitus positions (fig. 2a). Several tissue layers of the gastric wall are best seen in the fasting state, as follows: the innermost mucosal-air or mucosal-fluid interface (echogenic), muscularis mucosa (hypoechoic), submucosa (echogenic), muscularis propia (hypoechoic), and the serosa interface (echogenic).

After water ingestion (250 mL and 500 mL), the antrum becomes round and distended, with clearly visible hypoechoic fluid content producing effacement of the posterior wall (fig. 2b). Typically, the antrum appears larger when subjects move from the supine to the right lateral decubitus position as the fluid moves towards the more dependant areas.

After ingestion of effervescent water and with the subjects in the supine position, the gas rises towards the anterior wall of the stomach, and the fluid moves towards the more dependent areas of the stomach (*i.e.*, the posterior wall in the supine position). Consequently, a hyperechoic mucosal-gas interface can be seen along the anterior wall and several ring-down artifacts commonly obscure visualization of the gastric content and the posterior wall (fig. 3a). In contrast, when the subjects move to the right lateral decubitus position the gaseous content moves away from the antrum, towards the least dependent gastric areas (body and fundus), and the fluid moves towards the more dependent antrum, facilitating the examination. Initially, multiple punctuate echos may be seen within the anechoic fluid, corresponding to small air bubbles and giving the appearance of a "starry night" (fig. 3b). After several minutes, most or all of the gas separates from the fluid and moves away towards less dependent gastric areas.

Immediately after ingestion of a solid meal, a typical "frosted-glass appearance" can be seen (fig. 4). This is likely related to air mixed with solid during the pro-

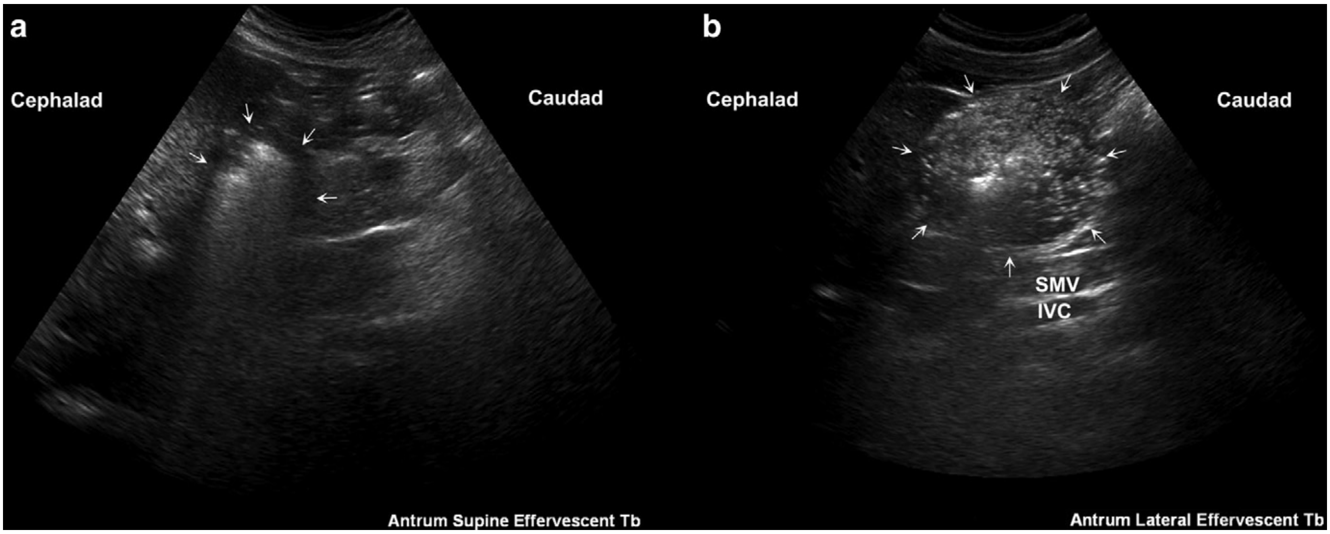

Fig. 3. Antral images after ingestion of effervescent water in the (*A*) supine and (*B*) lateral positions. Note the dirty shadow or frosted-glass appearance in the supine position at the mucosal-air interface, limiting visibility of the posterior gastric wall (*A*). Note the starry night appearance given by multiple air bubbles captured in the lateral position (*B*).

cess of chewing and swallowing, and this limits the ability to see the posterior wall of the organ, therefore making it more difficult to perform a precise quantitative assessment. Likely resulting from the semisolid consistency of the gastric content, the appearance of the antrum does not vary significantly in the two different subject positions after a solid meal (supine and right lateral decubitus).

The gastric body was imaged in an oblique parasagital plane through the left lobe of the liver. The anterior gastric wall was consistently identified in this plane, extending from the lesser to the greater curvatures (fig. 5). When empty, the body appears flat, with juxtaposed anterior and posterior mucosal surfaces. Fluid appears hypoechoic, and solid has a dirty shadow appearance resulting from to the mixed-in air. After a solid meal, significant amounts of air accumulation in the gastric body frequently impaired visualization of the posterior wall, thus limiting a reliable quantitative analysis.

The gastric fundus was the most challenging location to image because an acoustic window is difficult to obtain with a low intercostal, transplenic approach limiting transducer mobility. In addition, air commonly found in the fundus, even with an "empty" stomach, limits visualization of the entire cross-section (fig. 6).

Quantitative Analysis. Preliminary results from this pilot phase suggest that the antrum is most amenable for imaging and measurement. A complete cross-sectional view of the antrum was obtained 100% of the time at baseline or after fluid intake. In contrast, a full cross-

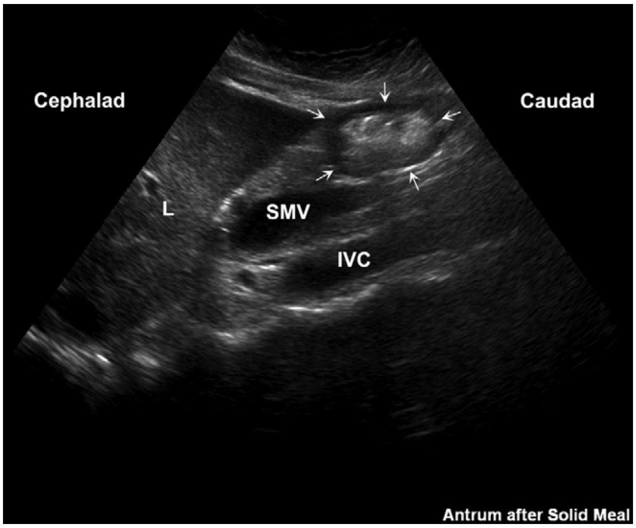

Fig. 4. The antrum after a solid meal. Note the hyperechoic, inhomogeneous content. IVC = inferior vena cava; L = liver; SMV = superior mesenteric vein.

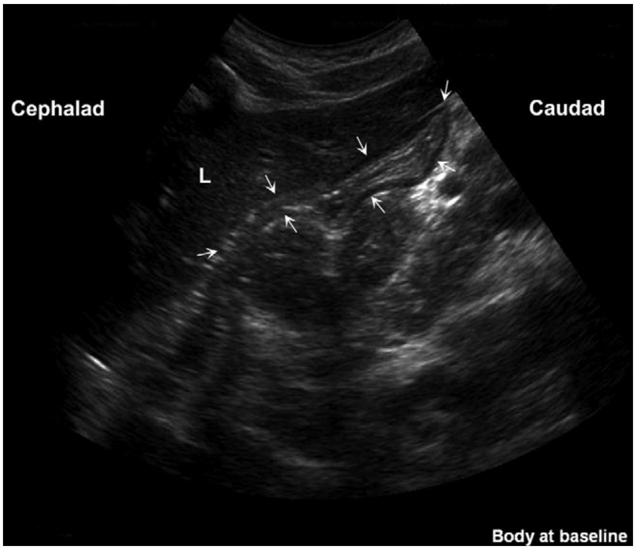

Fig. 5. The body at baseline, after 8 h of fasting. L = liver; *Arrows* = gastric body.

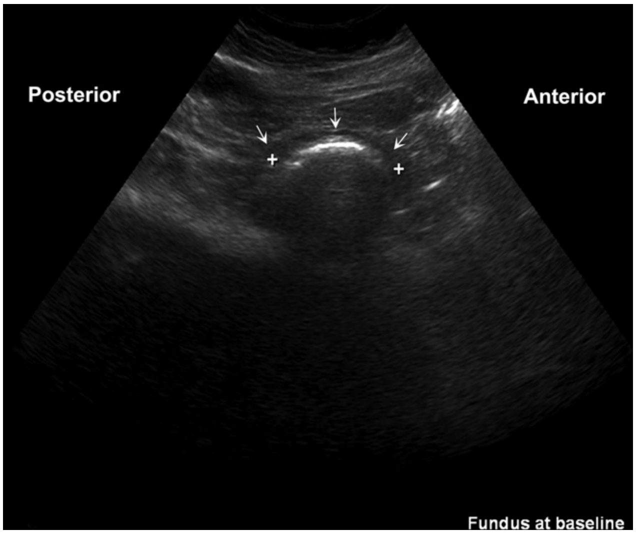

Fig. 6. The fundus at baseline, after 8 h of fasting. Note the hyperechoic line at the mucosal air interface.

section of the body was identified 77–89% of the time, and the fundus was identified 44–67% of the time, depending on subject position and type of gastric content. The success rates of imaging a full cross-section were lower in all gastric locations after ingestion of effervescent fluid or solid (table 1).

Antral CSA increased proportionally to intragastric fluid volume within the range of volumes studied, after a linear correlation curve. This correlation was stronger in the right lateral decubitus (r = 0.86) than in the supine position (r = 0.72) (fig. 7). This is expected because fluid within the gastric cavity moves towards the more dependent areas (*i.e.*, the antrum in the right lateral decubitus position).

Imaging a full cross-section of the body was possible 78–89% of the time at baseline or with fluid content, but far less consistently with gas or solid content (6–70% of the time; table 1). The values of body CSA showed a much wider baseline variability than antral CSA values, and a weaker correlation to intragastric volume when compared to antral CSA values.

Table 1. Success Rates of Imaging a Full Cross-section by Subject Position, Gastric Location, and content

	Antrum % (count), n = 18	Body % (count), n = 18	Fundus % (count), n = 18
Supine			
0 mL	100 (18)	83 (15)	44 (8)
250 mL of water	100 (18)	83 (15)	56 (10)
500 mL of water	100 (18)	89 (16)	67 (12)
500 mL of effervescent water	72 (13)	44 (8)	28 (5)
Solid meal	72 (13)	22 (4)	22 (4)
Lateral			
0 mL	100 (18)	78 (14)	44 (8)
250 mL of water	100 (18)	89 (16)	61 (11)
500 mL of water	100 (18)	89 (16)	50 (9)
500 mL of effervescent water	89 (16)	72 (13)	17 (3)
Solid meal	28 (5)	6 (1)	22 (4)

A quantitative analysis of fundal data was not performed because CSA was not obtainable in up to 66% of the subjects for some of the volumes studies (table 1).

Phase II Study Results: Development of a Quantitative Model

Demographics are presented in table 2. Two data sets were considered missing because it was not possible to visualize the entire cross-section of the antrum. In one subject, this was the result of the presence of a significant amount of gas in the stomach itself (subject 11, session 1), and in a second subject (subject 17, session 2) the interposition of the transverse colon made the exam suboptimal. Therefore, analysis was based on the remaining 70 data sets. As expected, we found a high correlation between (log-transformed) CSA-supine and volume (rho = 0.659, $P < 0.0001$), between CSA-lateral and volume (rho = 0.731, $P < 0.0001$), and between CSA-supine and CSA-lateral (rho = 0.759, $P < 0.0001$).

Boxplots in figure 8 and 9 illustrate a monotone relationship between CSA measurements (for supine and lateral position) and volume. It appears to be a close-to-linear relationship between volume and CSA, with lateral position measurement having a closer fit. Also, the relationship between volume and CSA-lateral seems to be deviating from a linear form for volume values greater than 300 mL. This finding was also confirmed by the results of our inverse regression model building, where models based on data with volume values smaller or equal to 300 mL gave a better fit. It was therefore decided to exclude from the prediction model observations with volume values larger than 300 mL. Table 3 presents the results for the selected inverse regression models for CSA-lateral and CSA-supine measurements. On the basis of the adjusted R-square statistic, lateral measurements give a more accurate model for CSA. Formulae were constructed for the prediction of volume values given a measurement of CSA and given a set of values for the demographic variables. The equations are:

$$\text{Volume (ml)} = 1199.99 + 483.09 * \log(\text{CSA-supine}) - 5.84 * \text{age} - 9.94 * \text{Height}$$

$$\text{Volume (ml)} = -372.54 + 282.49 * \log(\text{CSA-lateral}) - 1.68 * \text{Weight}$$

For example, on the basis of the first model, a patient with CSA-supine measurement of 5 cm^2, age of 26 yrs, and height of 168 cm, the predicted mean value for the volume is 155.4 mL. For the second model, a patient with CSA-lateral measurement of 10 cm^2 and weight of 70 kg will be predicted to have a mean volume value of 160.5 mL. It is important to mention here that these equations can only be applied for cases in which variable values are inside the ranges of the data based on which

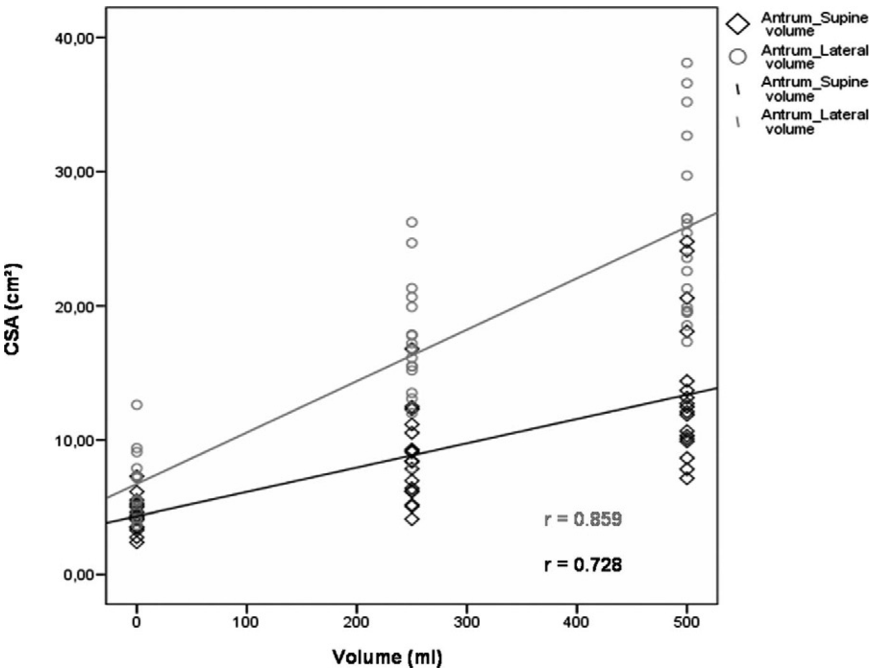

Fig. 7. Phase I pilot study results. Correlation of antral cross-sectional area (CSA) with gastric fluid volume in the supine and right lateral decubitus positions.

those models were built (19 yrs ≤ age ≤ 58 yrs, 45 kg ≤ weight ≤ 105 kg, 150 cm ≤ height ≤ 192 cm, 2.3 cm^2 ≤ CSA-supine ≤ 16.27 cm^2, 4.88 cm^2 ≤ CSA-lateral ≤ 20.18 cm^2).

Each subject was randomized twice, so we also performed a random effects models analysis, taking into account potential correlation between measurements of the same subject. The estimates from the random effects models (data not shown) are in general very similar to those from the linear regressions, with the exception of the estimates for weight in the CSA-lateral model, which is not significant in the random effects model.

In addition to these equations, confidence intervals can be calculated for the true volume value given CSA measurement and demographic values.[5] Here, we focus on the CSA-lateral model, and we calculate the confidence bands for volume given CSA-lateral. For simplicity, and in accordance with the results from the random effect model, we do not adjust for weight in the inverse regression model (fig. 10).

Table 2. Phase II Demographics

	Median/Frequency	IQR/Percentage
Age, yrs	26	21–42
Gender, M/F ratio	1.25	N/A
Height, cm	168	162–177
Weight, kg	70	58.4–80
BMI, kg/cm^2	23.5	20.5–26

BMI = body mass index; F = female; IQR = interquartile range; N/A = not applicable; M = male.

Discussion

Aspiration of gastric contents can be a serious perioperative complication with a high prevalence in certain groups of patients (*e.g.*, up to 38% of patients with severe trauma who require surgery) and leading to significant morbidity and mortality.[6] Mortality after aspiration pneumonia can be as high as 5%,[1] and it accounts for up to 9% of all anesthesia-related deaths.[2] At the present time, there are no widely available tools to reliably assess gastric content in the acute care setting. Paracetamol absorption,[7] electrical impedance tomography,[8] radiolabeled diet,[9] polyethylene glycol dilution,[10] and aspiration of gastric content[11] are all invasive meth-

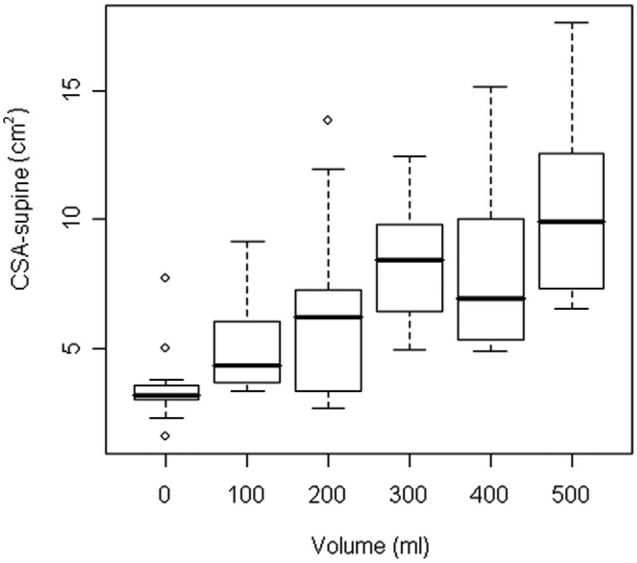

Fig. 8. Box plots showing median and interquartile ranges for cross-sectional area (CSA)–supine for different volume values.

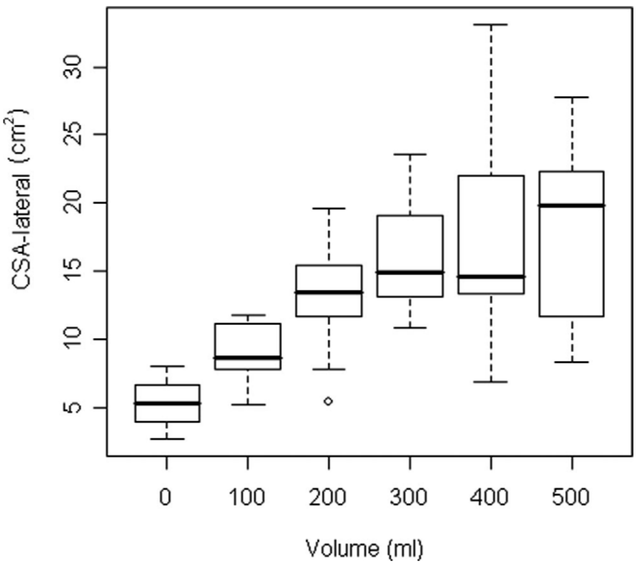

Fig. 9. Box plots showing median and interquartile ranges for cross-sectional area (CSA)–lateral for different volume values.

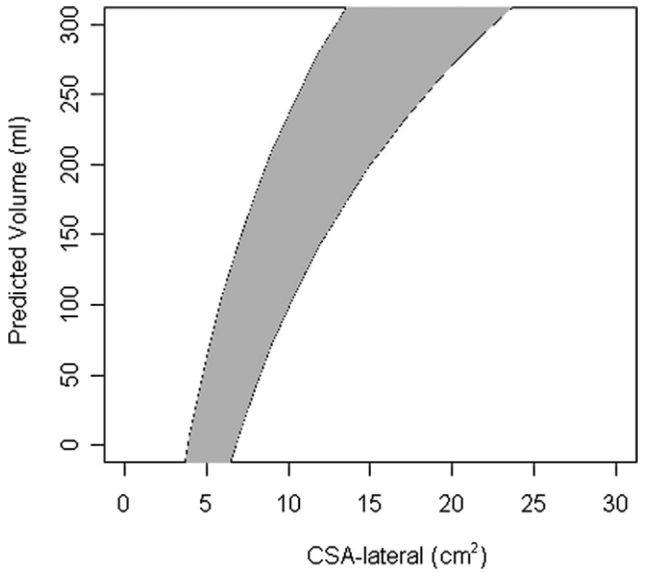

Fig. 10. 95% confidence band of predicted volume values based on an inverse regression model for cross-sectional area (CSA)–lateral.

ods to determine gastric volume and gastric emptying time. They are not, however, readily available at the bedside or applicable in the perioperative period. Ultrasonography is fundamentally different from other imaging modalities in its accessibility and noninvasive nature. It can be used to assess patients with acute abdominal trauma[12] and respiratory compromise.[13] It is commonly used to guide central venous line placement[14] and for regional anesthesia.[15]

Some preliminary studies suggest that ultrasonography may have a role in the assessment of gastric content. Carp *et al.*[16] used ultrasonography to differentiate between liquid and solid gastric content. Bolondi[4] imaged the gastric antrum in a cross-sectional view and calculated antral CSA. Antral CSA has been shown to be larger in obstetric patients who are allowed to eat during labor *versus* those on a clear-fluid-only diet, and it decreases with time after oral intake.[17,18] Sequential measurements of antral CSA after a standardized oral intake have been used to measure gastric emptying time, correlating well with scintigraphic evaluation.[19] The current study suggests that bedside two-dimensional ultrasonography can provide reliable qualitative and quantitative information regarding gastric content.

Our results suggest that the gastric antrum and body have a distinct sonographic appearance when empty, after fluid intake, after effervescent fluid intake, and after a solid meal. Furthermore, our data suggest that the gastric antrum expands from a baseliune empty state as fluid enters the stomach, and that antral CSA as measured by ultrasonography correlates well with gastric volume in a close-to-linear manner, particularly when measured in the right lateral decubitus position. This close-to-linear relationship is limited to relatively small volumes (up to 300 ml). This is expected because the gastric antrum can only expand up to a certain limit. Volumes in excess of 300 ml result in only modest further increases in antral size, with excess volumes being accommodated by more proximal areas of the stomach. According to our model, measured CSA can be used to predict gastric content volume. For example, according to our inverse regression model curve, we can be 95% confident that an adult patient with a measured

Table 3. Inverse Regression Model Statistics for CSA-lateral and CSA-supine

	Parameter Estimate	Standard Error	T Value	*P* Value	Adjusted R^2
Model for CSA supine					
Intercept	−2.48398	0.9674	−2.57	0.0138	
Volume	0.00207	0.000472	4.38	< 0.0001	0.560
Age	0.01209	0.00471	2.57	0.0137	
Height	0.02058	0.0059	3.49	0.0011	
Model for CSA lateral					
Intercept	1.31878	0.20184	6.53	< 0.0001	
Volume	0.00354	0.000399	8.87	< 0.0001	0.665
Weight	0.00594	0.00289	2.05	0.0459	

CSA = antral cross-sectional area.

CSA-lateral of 4 cm^2 has an empty stomach, whereas a CSA-lateral of 10 cm^2 corresponds to a gastric volume of between 100 and 240 ml. Similarly, a patient with a CSA-lat of 24 cm^2 has a gastric volume of at least 300 ml (fig. 10). These findings support the use of antral CSA as a surrogate marker of intragastric volume and the use of two-dimensional ultrasonography as the first tool to assess gastric volume in a noninvasive manner. We believe that gastric ultrasonography can have significant future clinical and research applications. As an accurate, noninvasive tool, it can help better define aspiration risk both on a given individual as well as in different patient populations.[20]

There are several limitations to this study. First, it was conducted on normal, healthy adult individuals; study findings and the numerical models in particular cannot be extrapolated to other subject populations (*e.g.*, children, morbidly obese, patients with specific pathologies). Second, our predictive models are based on ingestion of water; they are only applicable to fluid gastric content. Third, for reasons discussed above, our prediction models are valid for volumes of 0 to 300 ml and cannot be used to accurately predict volumes over 300 ml. However, it is arguably this range of low volumes that are of greatest interest to the clinician. Finally, the inherent limitations of ultrasonography also apply, including the need of an appropriate soft tissue window to obtain images. In particular, the presence of a significant amount of air or gas in the gastric antrum may impair imaging of the entire cross-section of the organ.

In conclusion, our data suggest that bedside gastric ultrasonography can provide accurate qualitative and quantitative information regarding gastric content type and volume. Bedside ultrasonography could potentially become a clinically useful noninvasive tool to accurately determine gastric content and volume with significant implications for perioperative aspiration risk assessment.

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