Ultrasound assessment of gastric volume in the fasted pediatric patient undergoing upper gastrointestinal endoscopy: development of a predictive model using endoscopically suctioned volumes

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What is already known

- Gastric sonography has been shown to be a valid and reliable method to assess gastric content and volume in adults.

What this article adds

- Ultrasound assessment of the gastric antrum provides useful information regarding gastric content (empty versus nonempty) and volume (ml·kg⁻¹) in fasted pediatric patients.

Implications for translation

- Sonographically measured gastric antral area in pediatric patients may be used to determine preoperative gastric fluid content and assist in the management of perioperative aspiration risk.

Keywords
ultrasound; adverse events – complications; measurement; quality improvement – outcomes; research

Summary

Background: Aspiration of gastric contents can be a serious anesthetic-related complication. Gastric antral sonography prior to anesthesia may have a role in identifying pediatric patients at risk of aspiration. We examined the relationship between sonographic antral area and endoscopically suctioned gastric volumes, and whether a 3-point qualitative grading system is applicable in pediatric patients.

Methods: Fasted patients presenting to a pediatric hospital for upper gastrointestinal endoscopy were included in the study. Sonographic measurement of the antral cross-sectional area (CSA) in supine (supine CSA) and right lateral decubitus (RLD CSA) position was completed, and the antrum was designated as empty or nonempty. Gastric contents were endoscopically suctioned and measured. Multiple regression analysis was used to fit a mathematical model to estimate gastric volume.

Results: One hundred patients (aged 11–216 months) were included. The gastric antrum was measured in 94% and 99% of patients in the supine and RLD positions, respectively. Gastric antral CSA correlated with total gastric volume in both supine ($\rho = 0.63$) and RLD ($\rho = 0.67$) positions. A mathematical model incorporating RLD CSA and age ($R^2 = 0.60$) was...
Introduction

Pulmonary aspiration of gastric contents is a serious complication of sedation and anesthesia. The overall incidence of anesthetic-related pulmonary aspiration in the pediatric population has been estimated to be 0.04–0.1% (1,2). An empty stomach carries a negligible aspiration risk, while elevated preoperative gastric volume is a risk factor for severe aspiration pneumonitis (3,4). Pediatric patients presenting for urgent procedures under sedation or general anesthesia are at risk of pulmonary aspiration due to delayed gastric emptying secondary to various factors including congenital disorders, pain, trauma, acute abdomen, and medications. In a study of infants with pyloric stenosis, more than 80% of patients had >1.25 ml·kg⁻¹ of gastric fluid volume at the time of pyloromyotomy (5). Other than the patient’s reported fasting time, there traditionally has been no widely available, noninvasive, and easily accessible method to estimate gastric fluid content. Bedside gastric sonography has been used to assess the presence, character (fluid or solid), and volume of gastric contents in adults (6,7). Ultrasound can accurately predict gastric fluid volume in adults using a mathematical model validated against endoscopic-guided measurements (8). Developing a similar model for pediatric patients would have a significant clinical impact by identifying patients with significant volumes of gastric contents who would be at higher risk of regurgitation and pulmonary aspiration prior to interventions requiring deep sedation or anesthesia, particularly when the prandial status is unknown.

The primary objective of this prospective study was to investigate the relationship between the sonographically measured antral cross-sectional area (CSA) and endoscopically suctioned gastric volumes in fasted pediatric patients presenting for upper gastrointestinal endoscopy under general anesthesia. A secondary objective was to assess whether a previously published three-point grading system based on qualitative sonographic assessment of the gastric antrum correlates with endoscopically suctioned gastric volumes in the pediatric population (6).

determined as the best-fit model to predict gastric volumes. Increasing gastric antral grade (0–2) was associated with increasing gastric fluid volume.

Conclusion: The results suggest that sonographic assessment of the gastric antrum provides useful information regarding gastric content (empty versus nonempty) and volume (ml·kg⁻¹) in pediatric patients. Results suggest that the three-point grading system may be a valuable tool to assess gastric ‘fullness’ based on a qualitative exam of the antrum.

Methods

Conjoint Health Research Ethics Board (University of Calgary, Alberta, Canada) approval was obtained (E-25160). Legal guardians and/or patients with the ability to understand the study provided written informed consent. Inclusion criteria were children and adolescents between 0 and 18 years of age presenting for elective upper gastrointestinal endoscopy under general anesthesia. Exclusion criteria included a recent (≤1 month) upper gastrointestinal bleed, previous lower esophageal or gastric surgery, nonadherence to institutional fasting guidelines, and a prolonged time (>5 min) between completion of US assessment and suctioning of gastric contents. Patients with elevated body mass index (BMI), gastroesophageal reflux, or other risk factors for aspiration were not excluded from the study.

All gastric ultrasound assessments were completed by one investigator (AS), who was an experienced user of ultrasound for regional anesthesia and vascular access procedures in pediatric patients. In preparation for the study, a 1-day gastric sonography course (ISURA US workshop, Toronto, CAN) and 3 days (>25 scans) of supervised scans were completed. Upon study completion, 30 patients’ scans were independently assessed and assigned a three-point grading score by two investigators (AS, AP) to determine interrater reliability.

Anesthetic management including type of induction and means of airway management was at the discretion of the attending anesthesiologist. Details of the technique used, including type of induction, airway device used, whether the patient was crying at induction, and the need for bag mask ventilation were documented. Demographic data recorded included indication for endoscopy, weight, height, age, and gender.

Following induction of anesthesia and application of the chosen method of airway management, sonographic examination was performed using a Philips CX50 system (Philips Healthcare, Andover, MA, USA) with a curvilinear (low frequency 2–5 MHz) or linear transducer (high frequency 7–12 MHz). The curvilinear probe was initially used; however, a linear transducer was used if the antrum was poorly defined or found to be < 3 cm from the skin surface. Patients were initially
scanned in the supine position, followed by the right lateral decubitus (RLD) position prior to endoscopy. The gastric antrum was identified in a sagittal to right parasagittal plane between the left lobe of the liver and the pancreas at the level of the aorta and superior mesenteric artery or the inferior vena cava. A minimum of one video clip and three still images of the antrum between peristaltic contractions were recorded for each patient in the supine and RLD positions.

Analysis and reporting of the quantitative (antral CSA) and qualitative (empty versus nonempty) measurements were completed at a later time without access to each patient’s measured gastric content. The cross-sectional area of the gastric antrum was measured with a free-tracing method using the internal caliper of the ultrasound unit to follow the outer margin of the antrum corresponding to the serosa. This method of antral area measurement has high intra- and interrater reliability and is equivalent to the previously reported 2-diameter method of area measurement (9). Qualitatively, the antrum was designated as empty if it appeared flat, with the anterior and posterior walls juxtaposed during a dynamic scan. The antrum was deemed to contain fluid if it appeared to have an endocavitary lumen with hypoechoic content and distended walls (6).

A grading of 0, 1, or 2 was applied as follows (6):

- Grade 0: no fluid visible in the antrum in either the supine or RLD position.
- Grade 1: antral fluid visualized only in the RLD position.
- Grade 2: antral fluid visualized in both the supine and RLD position.

After the completion of the ultrasound scan, the patient was repositioned to the left lateral decubitus position. Prior to each endoscopy, the endoscope’s air and water jet functions were tested as per standard clinical practice. The water supply was then disconnected, and all residual water in the common air/water channel was purged. The water supply remained disconnected during each patient evaluation to avoid the inadvertent instillation of extraneous water. A graduated specimen trap with 1-ml increments (MED-RX 30-4010, Oakville, ON, Canada) was attached to the endoscope by the endoscopy assistant to collect and quantify the aspirated contents.

The endoscope was then introduced transorally and advanced into the stomach. Pediatric gastroenterologists were blind to the results of the preceding ultrasound scans. The stomach was insufflated with air to maximize visualization and facilitate aspiration of all visible liquid gastric contents. Next, the endoscope was advanced into the distal stomach where the tip was retroflexed to confirm that there was no residual liquid in the gastric body or fundus. The endoscopy assistant disconnected the graduated specimen trap and recorded the measured volume of gastric content. The water supply to the endoscope was then restored, and the endoscopy resumed as per standard clinical practice.

Sample size and statistical analysis

A sample size of 100 patients was estimated based on regression analysis using seven independent variables. Additionally, this sample size would ensure the enrollment of at least five fasted pediatric patients with gastric volumes of >1.25 ml·kg⁻¹, based on earlier work from Cook-Sather et al. (10). Patient demographic data are expressed as the mean ± standard deviation (SD), median with interquartile range (IQR), and range. Normal distribution of suctioned volumes and measured antral CSA was assessed using the Shapiro-Wilk test (P < 0.05). Nonnormally distributed data are presented as median with IQR. A Kruskal–Wallis H test was used to evaluate significant differences (P < 0.05) in median suctioned gastric volumes and measured antral CSA across the three assigned gastric grades. Post hoc pairwise comparisons were performed using Dunn’s procedure with a Bonferroni correction for multiple comparisons. A model to assess whether the qualitative view of the gastric antrum using ultrasound is predictive of true gastric volume measured by suctioning using endoscopy was developed using backward stepwise linear regression (criterion for removal of P < 0.1). Seven independent variables (age, sex, height, weight, BMI, supine CSA, and RLD CSA) were included as possible covariates. Interrater reliability of gastric grades (grades 0, 1, and 2) was evaluated using the kappa coefficient.

All statistical tests were completed using IBM SPSS Statistics 20 software (IBM, Armonk NY, USA).

Results

One hundred and five patients were enrolled in the study, five of whom were excluded. Three patients were excluded due to a prolonged time to endoscopic intubation of the stomach (>5 min) and the potential risk of gastric fluid displacement into the duodenum secondary to the cumulative amount of insufflation gas used. Two patients were excluded due to the presence of a significant amount of air-preventing visualization of the antrum in either position. The remaining 100 patients were included in the final analysis.

Patient demographics are summarized in Table 1. Participant ages and weights ranged from 11 months to 17 years (X = 11.8 years) and 8.4–114.6 kg.
(X = 41.1 kg), respectively. Fifty-five percent of patients were female. Fifty-one percent were undergoing upper endoscopy for suspected celiac disease, 12% for eosinophilic esophagitis, 9% for symptoms of gastroesophageal reflux, and 7% for inflammatory bowel disease. An additional 36% presented with miscellaneous symptoms and conditions. Fourteen patients presented with multiple comorbidities. Participant ages and weights ranged from 11 months to 17 years (X = 11.8 years) and 8.4–114.6 kg (X = 41.1 kg), respectively (Table 1).

Total gastric volume (ml) ranged from 0 to 100 ml (X = 24.6 ml), while gastric fluid volume by weight (ml/C1 kg/C0) ranged from 0 to 3.6 ml/C1 kg/C0 (X = 0.6 ml/C1 kg/C0). No patients presented with solid gastric contents.

The antrum was completely visualized in 94% and 99% of patients in the supine and RLD positions, respectively. Gastric antral CSA (cm²) correlated with total gastric volume in both supine (r = 0.63, R² = 0.40) and RLD positions (r = 0.67, R² = 0.44) (Figure 1).

Seven independent variables including age, sex, height, weight, BMI, supine CSA, and RLD CSA were subjected to backward stepwise linear regression (criterion for removal of P < 0.1) to generate a final predictive model for gastric volume estimation. Using the coefficient of determination (R²) as our fit criteria, the only significant independent predictors of suctioned volume were RLD CSA and age (months):

\[
\text{Volume} = -7.8 + (3.5 \times \text{RLD CSA}) + (0.127) \times \text{age (months)}.
\]

This model presented with a R² of 0.6 and P-values <0.05 for both independent variables (Figure 2). Age and RLD CSA presented with R² values of 0.26 and 0.44, respectively, when subjected to univariate analysis of variance, highlighting the stronger predictive power of RLD CSA. Small values of RLD CSA yield a negative volume, which indicates an empty state. Thus, the applicability of this model is restricted to positive values. Predicted gastric volumes (ml) based on RLD CSA and stratified by age are presented in Table 2. To determine whether our model presented with equivalent predictor variables upon the stratification of age into two subgroups (<8 years and >8 years), a post hoc backward stepwise linear regression was completed on each stratified group. This post hoc analysis revealed that antral CSA measured in the RLD position was a significant predictor of endoscopically suctioned volume in both subgroups. A Bland–Altman analysis, which plots the difference between predicted and observed volumes for each subject versus the mean volume of the predicted and measured values, was performed to better understand the agreement between predicted gastric volumes by the mathematical model and measured suctioned gastric volumes (Figure 3). A mathematical model bias of 0.23 ml was identified, which represents a nominal over-estimation of gastric volume.

Median and mean endoscopically suctioned volumes and median antral CSA measured in the supine (supine CSA) and right lateral decubitus (RLD CSA) positions as a function of qualitative gastric grade are summarized in Table 3. Ninety-one percent were classified as grade 0 or 1. The antrum appeared empty in 88% and 37% of views in the supine and RLD positions, respectively. Significant differences (P < 0.05) were found between

<table>
<thead>
<tr>
<th>Table 1 Patient demographics (n = 100)</th>
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<tr>
<td>Mean (± SD)</td>
</tr>
<tr>
<td>Age (years)</td>
</tr>
<tr>
<td>Weight (kg)</td>
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<tr>
<td>BSA (m²)</td>
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<td>BMI</td>
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</table>
gastric grade and absolute gastric volume and volume per unit of weight ($P < 0.05$) (Table 3). Significant differences ($P < 0.05$) were also found in the measured antral CSA in both supine and RLD positions between each of the qualitative grading groups (Table 3). The interrater agreement for qualitative grading of 30 patients was excellent ($k = 0.88$).

### Technical data for gastric sonography

The best views of the antrum were achieved using a curvilinear transducer in 64 patients ($\bar{X} = 13.7$ years, $\bar{X} = 48.8$ kg), compared with 37 patients ($\bar{X} = 8.4$ years, $\bar{X} = 27.7$ kg) where the linear probe was superior. Although it was not quantified, a respiratory effect was noted as the antral size appeared to decrease with expiration. An attempt was made to save clips between peristaltic contractions and without respiratory effect.

### Discussion

Our study compared antral CSA to endoscopic aspiration of gastric contents collected under direct visualization, which to our knowledge, has not been described heretofore in the pediatric population. We present a prediction model to estimate total gastric volume using
sonographically measured gastric antral area in the RLD position and age of the patient in months. Our data suggest that the gastric antrum can be consistently identified and the gastric antral CSA can be measured in the majority of pediatric patients, similar to previous adult studies (6,11). In addition, significant differences are noted in absolute gastric volumes (ml) and total gastric volumes by weight (ml kg⁻¹) between antral grades (0–2), which suggests that the qualitative grading system may be a valuable tool to provide timely information at the bedside based on antral appearance alone.

**Multiple regression model**

We studied the correlation between sonographically measured gastric antral CSA in both supine and RLD positions, and gastric volume suctioned under direct endoscopic visualization in a pediatric population. A recent pediatric study (12) found moderate correlation between sonographically measured gastric fluid volume and magnetic resonance (MR) determined gastric fluid volumes. They concluded that sonographically measured antral CSA in the RLD does not accurately predict total gastric volume in pediatric patients. Their study was limited by a small sample size (n = 16), narrow age range, and a lack of blinded investigators. In addition, MR imaging of gastric content volume, which was their gold standard, is still relatively new and has been shown to have low reliability with a variation coefficient up to 32% in interrater testing (13). In comparison, this study included a larger number of pediatric patients undergoing endoscopic suctioning allowing us to evaluate multiple potential factors and produce a more accurate model.

Similar to adult studies using a comparable methodology (7,14), the best-fit mathematical model presented in this study suggests that RLD and age are the best predictors of gastric volume in the pediatric population. Our study protocol was comparable to Perlas et al. (14), as antral sonography was completed in supine and RLD position and gastric contents were suctioned under direct vision, whereas in Bouvet et al. (7), gastric contents were blindly suctioned via a gastric tube. Our adjusted $R^2$ of 0.6 was slightly lower than 0.73 as reported by Perlas et al. (14), but similar to Bouvet et al. (7) who reported a value of 0.57. The lower $R^2$ value in this study may be due to the cohort’s varied demographics (Table 1). Although gender, height, weight, BMI, and antral CSA measured in the supine position were studied as possible covariates, they contributed little to the strength of the model and were subsequently removed during stepwise regression.

**Qualitative grading system**

We further assessed whether a previously validated 3-point qualitative grading system could be accurately used to predict small versus larger gastric volumes in pediatric patients presenting for surgery (14). Our results showed that there was a significant difference in total gastric volumes between the three groups. This suggests the potential benefit of using a grading system to quickly provide valuable information at the bedside as awareness of an approximate gastric volume could influence a provider’s choice of sedation, anesthetic, and airway management.

**Study limitations**

We recognize that it may not be possible to generalize these results to other pediatric populations, as our cohort was limited to children with gastrointestinal complaints undergoing endoscopy with standardized fasting times. However, studying this specific population had several advantages. This approach provided the opportunity to use aspirated gastric contents obtained under direct visualization as the gold standard measure for comparison. We believe this is superior to other methods such as blindly suctioned samples, which may result in an underestimate, and

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**Table 3** Qualitative grading system and suctioned gastric volumes. Volumes are presented as median with interquartile range (IQR) and mean with 95% confidence intervals (CI). Antral cross-sectional areas (CSA) are presented as median with interquartile range (IQR)

<table>
<thead>
<tr>
<th>Grade 0</th>
<th>Grade 1</th>
<th>Grade 2</th>
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<tbody>
<tr>
<td>Volume (ml, IQR)</td>
<td>13.0** (16.0)</td>
<td>26.0** (22.2)</td>
</tr>
<tr>
<td>Volume (ml, 95% CI)</td>
<td>14.0 (10.8–17.2)</td>
<td>26.3 (22.5–30.0)</td>
</tr>
<tr>
<td>Volume (ml·kg⁻¹, IQR)</td>
<td>0.3** (0.2)</td>
<td>0.7** (0.4)</td>
</tr>
<tr>
<td>Volume (ml·kg⁻¹, 95% CI)</td>
<td>0.3 (0.3–0.4)</td>
<td>0.7 (0.6–0.8)</td>
</tr>
<tr>
<td>Supine CSA (cm², IQR)</td>
<td>1.9* (0.9)</td>
<td>1.9* (0.9)</td>
</tr>
<tr>
<td>RLD CSA (cm², IQR)</td>
<td>2.6** (1.3)</td>
<td>4.0* (2.5)</td>
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</table>

**Significant difference (adjusted P < 0.05) in medians between graded groups using Dunn’s procedure with a Bonferroni correction.**

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other imaging modalities, which are indirect measures with unproven reliability (13). Furthermore, there was no additional risk to patient welfare using endoscopically obtained gastric aspirates because the patients were already scheduled to undergo elective esophagogastroduodenoscopy.

We believe that the age range and indications for endoscopy included in our study cohort provided a reasonable representation of the general pediatric population presenting with gastrointestinal issues. There was an expected underrepresentation of younger patients (< 24 months old), as the indication for upper gastrointestinal endoscopy is less frequent in this age group. However, associated with this wide range in ages (11 months to 17 years) are large differences in suctioned gastric volumes and measured antral CSA. Table 2 shows progressively increasing total gastric volume at a given RLD CSA with increasing age. For example, a 4-year-old child (17 kg) with a measured RLD CSA of 4 cm² will have an estimated total gastric volume of 12 ml (0.7 ml·kg⁻¹), whereas a 10-year child (29 kg) with a RLD CSA of 4 cm² will have an estimated total gastric volume of 21 ml. Children under the age of 24 months rarely undergo gastroscopy and this was reflected in our patient demographics. Only two patients were < 24 months, and five were < 48 months. Our mean gastric fluid volumes (0.63 ± 0.47 ml·kg⁻¹) were slightly larger when compared to a previous study by Schwartz et al. (15) who also obtained gastric volumes under direct endoscopic visualization (0.35 ± 0.45 ml·kg⁻¹) in a group of fasted patients presenting with a variety of gastrointestinal symptoms. They concluded that this patient population did not have increased gastric fluid volumes compared with healthy fasted children. As this study population was limited to fasting patients, there was a minority of subjects with higher volume states (six patients >1.25 ml·kg⁻¹, six between 1.0 ≤ ml·kg⁻¹ ≤ 1.25). Further research is required in nonfasted pediatric patients, especially those presenting for emergency surgery that are likely to present with higher gastric volumes and an increased risk of aspiration. It could be argued that anesthetists need to identify whether a stomach is empty or full; this may require distinguishing between a normal fasting volume (<1.0 ml·kg⁻¹) and an abnormal amount of gastric contents (>1.5 ml·kg⁻¹) (10).

Conclusion
Our results suggest that sonographically measured gastric antral area in pediatric patients may be used to determine preoperative gastric fluid content and assist in the management of perioperative aspiration risk. This promising bedside noninvasive tool needs to be further validated in nonfasted patients at increased risk of higher gastric volumes before using results to guide clinical decision making.

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Conflict of interest
No conflicts of interest.

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References
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