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Point-of-Care Ultrasound to Assess Gastric Content

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Abstract: Gastric ultrasound (US) is a growing modality within the point-of-care ultrasound (POCUS) field. It provides the ability to directly measure an individual patient's gastric content and has potential use as both a clinical and a research tool. Here, we review the historical development of current gastric US models and their clinical application within the field of general anesthesia, describe the US findings and technique for using POCUS to assess gastric content, and discuss the current and potential applications of gastric POCUS within the emergency department.

Key Words: point-of-care ultrasound, gastric content, fasting, NPO, procedural sedation

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MODEL DEVELOPMENT

Ultrasound (US) has been used for over 30 years to assess gastric volume and emptying.[1,2] Over the past 10 years, several groups primarily within the field of general anesthesia have developed the use of point-of-care ultrasound (POCUS) to assess gastric content as a surrogate for aspiration risk in preoperative general anesthesia planning for adults,[3–9] pediatrics,[10–13] pregnancy,[14–17] and obesity.[18,19]

The most robust of these models was developed in adults by the Canadian group led by Dr Perlas.[3–7] In a series of 3 studies, they identified the gastric antrum as providing the most consistent imaging plane,[3] developed a qualitative grading system based on visible contents in supine versus right lateral decubitus (RLD) positions,[4] and generated a model to predict gastric volume from measured cross-sectional area (CSA),[3] which they subsequently refined and validated[5] to produce the model currently used.[6,7] In addition to the Perlas model, the French group led by Dr Bouvet[8,9] developed a model of gastric US assessment. In comparison to the Perlas model, the Bouvet model used semirecumbent (supine with the head of the bed elevated at 45°) positioning rather than supine and RLD, spanned a smaller range of volumes, and generated a lower correlation between antral CSA and predicted volume. Subsequent studies by this group[20–24] have adopted the RLD position used in the Perlas model.

The current pediatric model is derived from the study by Spencer et al,[10] who performed gastric US in the supine and RLD positions with endoscopically suctioned volumes in pediatric patients undergoing scheduled endoscopy. They found that increasing qualitative gastric grade corresponded to increasing gastric volume and that a strong correlation existed between antral CSA and volume. This was used to generate an equation to predict pediatric gastric volume from CSA similar to the Perlas model for adults. Key findings for select adult and pediatric models are reviewed in Table 1.

Based on adult modeling studies,[3–5,8,9] a decision metric to define the "at-risk" stomach for purposes of preoperative general anesthesia planning has been proposed. In this algorithm, at-risk is defined as (1) any solid or thick liquid content ("high risk") or (2) clear liquid content greater than a defined volume cutoff ("suggests high risk").[6,7] There is debate among the literature regarding the appropriate at-risk volume cutoff, ranging from 0.8 to 1.5 mL/kg.[5–7,9,23,25] Within pediatric models specifically, a cutoff value of 1.2 to 1.5 mL/kg has primarily been used.[10,23,24,26] This is based largely on data by Cook-Sather et al,[27] in which gastric suctioning via orogastric tube of 611 pediatric patients undergoing elective surgery demonstrated 95% of patients to have a volume less than 1.25 mL/kg. As an alternative in cases where volume is not measured, studies in both adult[5] and pediatric[10] patients support the use of "risk" stratification based on qualitative grading as well.

CLINICAL APPLICATION

In the general anesthesia arena, these models are now being used to characterize the gastric content of elective and emergent surgical patients to identify risk factors for the at-risk stomach to better define populations in which gastric US should be routinely used.[22–24,28] Adult studies have demonstrated that only a minority of patients (roughly 5%) fasting for elective procedures have stomach content consistent with being at risk.[22,28] In contrast, in one of these same studies,[22] 56% of patients presenting for emergency surgery were found to have at-risk gastric content despite an overall average fasting time of 18 hours. On multivariate analysis, emergency surgery, diabetes mellitus, obesity, and preoperative opioid administration were identified as independent risk factors for at-risk content, whereas overall fasting duration and fasting duration for solids less than 6 hours were not. Studies in pediatric patients have similarly demonstrated a very low rate of at-risk content in fasting elective surgery patients,[23,24] whereas emergency surgery patients were shown to have at-risk content in as many as 46% of patients despite an average fasting time of 11 hours for solids in 1 study.[21]

Several studies have further demonstrated a change in anesthesia management in cases with questionable aspiration risk.[20,21,29–31] These include change in procedural timing for elective surgery patients noncompliant with fasting guidelines,[29] use of preintubation gastric decompression and choice of induction technique in infants with pyloric stenosis,[20] and choice of induction technique in pediatric patients undergoing emergency surgery.[21] In this last study, gastric US findings changed anesthesia induction technique in 67 of 130 patients and increased the total frequency of "correct" inductions, meaning rapid sequence intubation used for at-risk stomachs and standard induction for "empty" stomachs, from 49% based on clinician assessment alone to 85% with the addition of US.[21]

In addition to these studies, studies outside of preoperative anesthesia have shown promise both for assessing gastric volume[32]

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TABLE 1. Key findings of Select Adult and Pediatric Gastric US Modeling Studies

Study	Population	N	Position	Key Findings
Perlas et al, 2009[3]	Healthy adult volunteers ≥18 y	18, 36	Supine and RLD	Two-phase prospective modeling study. Phase 1 (n = 18) demonstrated the gastric antrum to be more readily imaged than the body or fundus. Phase 2 (n = 36) generated a predictive gastric volume equation (r^2 = 0.66) from RLD antral CSA against controlled ingestion volume of 0–500 mL of water.
Bouvet et al, 2009[8]	Healthy adult volunteers ≥18 y	22	SemiR	Prospective crossover modeling study. Generated receiver operating characteristic curves to determine the diagnosis of "fasting gastric content." RLD antral CSA of 320 mm^2 produced 85% sensitivity and 95% specificity in discriminating fasting versus nonfasting state (via controlled solid and non–clear ingestion).
Perlas et al, 2011[4]	Adult elective surgery patients ≥18 y	200	Supine and RLD	Prospective observational study. Defined grades 0–2 qualitative scoring system. Identified >95% of fasted patients to have grade 0 or 1 content, and that this qualitative grade system correlated well with predicted gastric volume.
Bouvet et al, 2011[9]	Adult elective and emergency surgery patients ≥18 y	183	SemiR	Prospective observational study. Generated a predictive gastric volume equation (r^2 = 0.57) from RLD antral CSA against orogastric suctioned volume. Antral CSA of 320 mm^2 had a 91% sensitivity and 71% specificity for at-risk content, defined as >0.8 mL/kg.
Schmitz et al, 2012[12]	Healthy pediatric volunteers 6–14 y	16	Supine, SemiR, and RLD	Prospective modeling study. Generated predicted gastric volume equation (r^2 = 0.60) from RLD antral CSA against MRI measured gastric volume either fasting or after controlled ingestion of liquids.
Perlas et al, 2013[5]	Adult elective UGI patients ≥18 y	108	Supine and RLD	Prospective modeling study. Generated predicted gastric volume equation (r^2 = 0.73) from RLD antral CSA against gastroscopic suctioned volume after controlled ingestion of 0–400 mL of juice. Validated prior grades 0–2 qualitative system, showing 75% of grade 1 stomachs below at-risk cutoff, defined as >100 mL.
Spencer et al, 2015[10]	Pediatric elective UGI patients ≤18 y	100	Supine and RLD	Prospective observational study. Generated predicted gastric volume equation (r^2 = 0.60) from RLD antral CSA against gastroscopic suctioned volume. Demonstrated qualitative grade 1 stomachs to have an average volume of 0.7 mL/kg with a 95% confidence interval of 0.6–0.8 mL/kg.
Schmitz et al, 2016[13]	Healthy pediatric volunteers 6–14 y	18	SemiR and RLD	Prospective crossover modeling study. Generated predicted gastric volume equation (r^2 = 0.58) from RLD antral CSA against MRI measured gastric volume either fasting or after controlled ingestion of solids and liquids.

MRI indicates magnetic resonance imaging; SemiR, semirecumbent; UGI, upper endoscopy.

and in identifying the need for gastric aspiration before planned endotracheal intubation[33] in critically ill intensive care unit patients.

ULTRASOUND FINDINGS AND TECHNIQUE

Gastric POCUS can be accomplished using either a low-frequency curvilinear probe or a high-frequency linear probe based on patient habitus. Prior studies cite patients less than 40 kg as amenable to gastric imaging with the linear probe.[10,34] In our practice, we start with a curvilinear probe to establish a wide view of abdominal anatomy and transition to a linear probe when increased resolution is desired and depth of target structures is amenable. Patients are imaged first in the supine and then in the RLD position, with the semirecumbent position being used when RLD positioning is contraindicated (Fig. 1). Right lateral decubitus positioning takes advantage of the natural funnel-shaped structure of the stomach and of gravity to both increase sensitivity for measuring gastric content and reduce air interference within the stomach. This protocol can typically be completed within 5 minutes.

The probe is placed in the midline sagittal plane inferior to the xiphoid process with the probe marker toward the patient's head (Fig. 1). Subtle sliding, fanning, and tilting of the probe are then used to optimize visualization of the gastric antrum in cross section. The gastric antrum can be identified as a thick, multilayered, hollow structure typically located deep to the left lobe of the liver and proximal to the aorta. Care should be taken to avoid oblique views that result in false antral measurements and to avoid excess pressure that can compress the antrum, particularly in young, thin patients, owing to its superficial location. The antrum's thickness depends on the relative distension of the stomach. When using a high-frequency probe, the 5 layers of the gastric wall (innermost hyperechoic mucosa, hypoechoic muscularis mucosa, hyperechoic submucosa, hypoechoic muscularis propria, and outermost hyperechoic serosa) can often be visualized (Fig. 2), but when using a low-frequency probe, the individual layers of the gastric wall are not well visualized, with the thick hypoechoic muscularis propria being the most identifiable (Fig. 3).

Gastric content can be assessed qualitatively and quantitatively. Qualitative gastric content may be empty, clear liquid, or solid/thick liquid. The empty antrum appears as a small, flat to rounded, sometimes targetoid structure owing to the thickened appearance of the contracted hypoechoic muscularis surrounding the opposing anterior and posterior walls of the hyperechoic mucosal layers (Figs. 2A, 3A). Clear liquid content, including gastric secretions, can be identified as anechoic or hypoechoic material enclosed within the antrum (Figs. 2B, 3B). Depending on the

FIGURE 1. Probe placement and patient positioning for gastric POCUS. A curvilinear or linear probe is placed in the midline sagittal plane inferior to the xiphoid process with the probe marker toward the patient's head. Imaging is performed first in the supine position (A) and then the RLD position (B), with the semirecumbent position (C) being used when RLD positioning is contraindicated.

timing of ingestion or fluid agitation, small air bubbles may be admixed within this liquid, creating hyperechogenic foci in what has been termed a "starry night" pattern (Fig. 2B). Solid/thick liquid content appears as hyperechoic material within the antrum (Figs. 2C, 3C). Although relative heterogeneity of content and the presence of posterior acoustic enhancement may suggest solid versus thick liquid content, respectively, definitively differentiating between solids and thick liquid is not possible, and the two are treated similarly in proposed models. Recently ingested solid content may contain a large amount of admixed air, which can create significant "dirty shadow," resulting in obscured posterior anatomy in a "frosted glass" appearance.[3,7,35]

Obesity, air contained within the stomach, and overlying bowel gas can make interpretation of gastric content challenging,

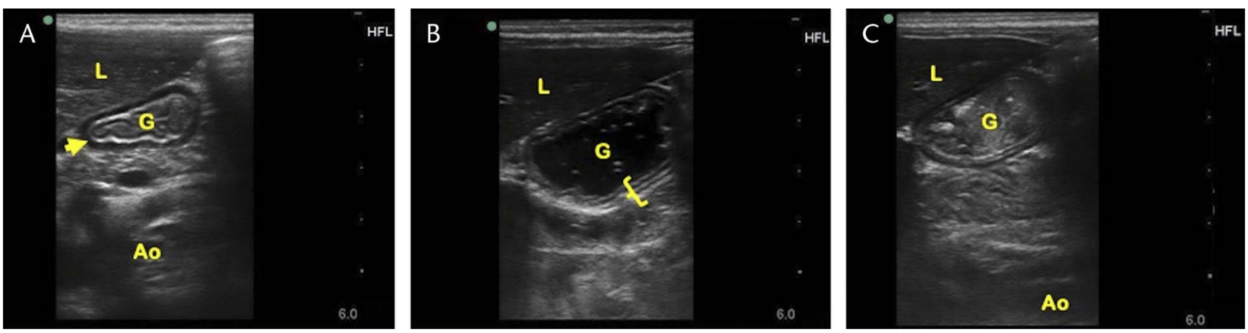

FIGURE 2. Gastric content visualized with the linear probe. A, The empty antrum appears as a small flattened structure with opposing layers of inner hyperechoic mucosa and a prominent thickened hypoechoic muscularis propria (arrow). B, Clear liquid content appears as hypoechoic or anechoic content with associated posterior acoustic enhancement and, in this case, excellent visualization of the 5 gastric wall layers (bracket): innermost hyperechoic mucosal-air interface, hypoechoic muscularis mucosa, hyperechoic submucosa, hypoechoic muscularis propria, and outermost hyperechoic serosa. A few scattered hyperechoic foci can be seen within the hypoechoic liquid consistent with small air bubbles in a starry night pattern. C, Solid and/or thick liquid content appears as heterogeneous hyperechoic material. The presence here of posterior acoustic enhancement suggests at least some liquid content. Ao indicates aorta; G, gastric antrum; L, liver.

FIGURE 3. Gastric content visualized with the curvilinear probe. A, The empty antrum appears as a small targetoid structure with a thickened hypoechoic muscularis propriae (arrow). B, Clear liquid appears as hypoechoic or anechoic content. C, Solid content appears as heterogeneous hyperechoic material. Note that the 5 layers of the gastric wall are poorly visualized using the curvilinear probe, with the hypoechoic muscularis propriae (arrows) being the most prominent. Ao indicates aorta; G, gastric antrum; L, liver.

if not impossible, in some cases. Overlying bowel gas may partially or completely limit visualization of the antrum. This can often be addressed with positional changes and variations of probe pressure to redistribute bowel gas similar to other abdominal US applications. Admixed air within gastric liquids can create a hyperechoic appearance that mimics solid content sometimes with only minimal dirty shadow, making differentiation from solids challenging. In larger-volume states, waiting a few minutes to allow air content to disperse or rise to the nondependent portion of the stomach may clarify this content, although this is less helpful in small-volume states. Variations in probe pressure, panning left to right to obtain broader qualitative views of stomach content, and use of the increased resolution of the linear probe can be used to help differentiate content in these situations. Despite these limitations, most studies report the ability to successfully identify gastric content in more than 90% of patients, with high intra- and interrater reliability,[36] and learning curves akin to other POCUS modalities.[37]

Gastric content can be quantified (Supplementary Fig. 1, Supplemental Digital Content, http://links.lww.com/PEC/A475), ideally with the patient in the RLD position, via measurement of the antral CSA, expressed in square centimeters, in a standardized plane including the liver, antrum, and aorta using either a free-traced circumference or 2 perpendicular diameters and the standard equation for the CSA of an ellipse[1]:

$$\text{CSA}\left(\text{cm}^2\right) = (\text{D1 (cm) x D2 (cm) x } \pi)/4$$

Care should be taken to capture these measurements between peristaltic contractions when the antral volume is at its maximal size. Typically, a series of 3 independent measurements are taken and averaged. This average CSA value can then be used to estimate the corresponding gastric volume using equations for adult[5] (18 years and older) and pediatric[10] (17 years and younger) patients:

$$\text{Adults: Volume (mL)} = 27.0 + \left(14.6 \text{ x RLD CSA}\left(\text{cm}^2\right)\right) - (1.28 \text{ x age (years)})$$

$$\text{Pediatrics: Volume (mL)} = -7.8 + \left(3.5 \text{ x RLD CSA}\left(\text{cm}^2\right)\right) + (0.127 \text{ x age (months)})$$

One interesting note regarding these 2 equations is the differing effect of age within the 2 populations for a given CSA, with adults having decreased predicted volumes and children increased predicted volume with increasing age for a given CSA.

Once gastric content and volume have been determined, this information can be used to categorize gastric Perlas grade and risk status (Fig. 4). Grade (0–2) is assigned based on visible contents in supine versus RLD positions: grade 0, empty in both positions; grade 1, empty in supine, clear fluid in RLD; and grade 2, clear fluid in both positions.[4] Risk status, as proposed by the Perlas models for use in general anesthesia, can then be assigned into 1 of 4 categories: high risk, any solid or thick liquid content; suggests high risk, clear liquid content greater than a defined volume cutoff, or alternatively grade 2 in the absence of volume measurement; suggests low risk, clear liquid content below a defined volume cutoff, alternatively the grade 1 stomach; and low risk, the empty grade 0 stomach.[6,7] When volume is measured, cutoffs ranging from 0.8 to 1.5 mL/kg have been debated,[5–7,9,23,25] with

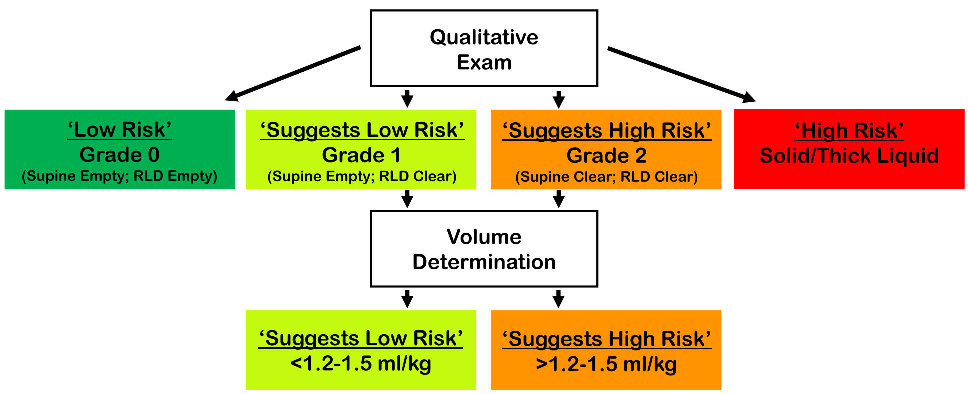

FIGURE 4. The Perlas model of gastric content interpretation. Gastric content is assigned a qualitative grade (0–2) based on the presence or absence of clear liquid in supine and RLD positions. Clear liquid content can be further quantified in the RLD position via measurement of CSA to extrapolate a gastric volume, expressed as milliliters per kilogram. A subsequent assignment of risk stratification for use in operative anesthesia can then be made based either on the qualitative grade or quantified volume. Solid or thick liquid content in either position is assigned as high risk.

recent pediatric studies using a value of 1.2 to 1.5 mL/kg.[10,23,24,26] It should be noted that the language and implications associated with this categorization have been the subject of debate[38] and remain fluid, with prior categorizations of "full" versus "empty" being replaced with the above risk categories.

GASTRIC US WITHIN THE EMERGENCY DEPARTMENT

Within general anesthesia, gastric POCUS is being used to determine optimal preoperative anesthetic and airway management in cases with questionable aspiration risk. Parallels to use in emergency department (ED) airway management should be made cautiously. Unlike the controlled environment of operative anesthesia, ED patients are critically ill and rarely electively intubated, and the urgency of airway management in the ED likely precludes routine use of gastric POCUS in this setting. In the rare instances where the need for airway management is adequately anticipated, gastric POCUS may help guide use of preintubation gastric decompression,[20,33] choice of induction agent (avoid agents with esophageal relaxing effects), and preoxygenation technique (minimize gastric inflation from aggressive positive pressure ventilation), but no evidence yet exists for these indications in the ED setting.

Implications for use within the ED extend beyond those patients requiring airway manipulation, and several studies have evaluated the potential clinical importance of determining ED patient prandial status via gastric POCUS.[26,39–41] These studies have demonstrated that emergency physicians with US training can accurately determine gastric content using POCUS,[40] that patient-reported oral intake is inconsistent with gastric US findings in about a quarter of pediatric ED patients,[41] and that the majority of pediatric patients undergoing procedural sedation have gastric content that would be assigned as being at risk via anesthesia models.[26] In this last study, Leviter et al[26] prospectively evaluated the stomach content of 116 pediatric patients at the time of procedural sedation using a modified version of the Perlas model. They were able to quickly determine both qualitative and quantitative gastric content in 93% of patients with good interrater reliability. There were 69% of patients who demonstrated at-risk gastric content with a mean *nil per os* (NPO) time of 5.8 hours and no reported serious adverse events.

The potential for assessing gastric content in patients undergoing procedural sedation and analgesia (PSA) is of particular importance given the frequency of this procedure and the debate regarding delayed PSA based on NPO timing. The American Society of Anesthesiologists provides NPO guidelines for patients before elective procedures.[42] Although these guidelines are not meant for application to nonelective, emergent situations, they have been applied to PSA despite the fact that fasting status has been shown to portend no increase in adverse events in pediatric PSA[43–48] with reported rates of clinically apparent aspiration lower for pediatric PSA[45] than for pediatric general anesthesia.[49] Multiple guidelines including a 2007 ED consensus–based practice advisory[50] and the American Academy of Pediatrics[51] endorse a balanced risk-benefit approach to NPO timing and PSA, and the American College of Emergency Physicians includes within its clinical policy on procedural sedation a level B recommendation to not delay PSA based on fasting time,[52] which was further reemphasized in the newest American College of Emergency Physicians guidelines regarding unscheduled procedural sedation.[53] Despite these recommendations, the practice of delaying PSA based on NPO status is still ingrained in many institutions, and recently published studies that have changed their practice still report using a 3-hour NPO rule for solids.[48] No data exist as to whether delaying PSA based on NPO timing actually reduces gastric content and corresponding risk status, and such delays are not without harm to both patients and ED workflow.

Until the study by Leviter et al,[26] no data existed as to the actual stomach content of patients at the time of PSA. The findings of a high percentage of patients with at-risk content is not surprising, however, as prior studies of adult[22] and pediatric[21] nonelective surgery patients demonstrated high rates of at-risk stomachs despite average fasting times well beyond those from the study by Leviter et al[26] or recommended for elective surgery.[42] Although the study by Leviter et al[26] was a single-center study, their reported sedation practice is on par with other reported studies[48] as well as our own sedation practice. Further studies are needed to replicate and expand upon these findings and have the potential to identify predictors of patients with at-risk content, how this content changes over time, and what, if any, safety implications the presence of at-risk content has upon PSA. This information could help inform optimal PSA patient selection, medication regimen, and NPO timing. Given the very low rate of adverse events with pediatric PSA, such studies will require many patients across multiple institutions to provide sufficient power for any conclusions to be made.

CONCLUSIONS

Gastric POCUS provides a simple, accurate, and rapid tool to assess an individual patient's gastric content. It is being used with increasing frequency by anesthesiologists to guide preoperative general anesthesia planning. As proposed, such categorization is meant to be incorporated into the medical decision-making process to better inform, rather than dictate, general anesthesia procedural planning. How this information should be used outside of the general anesthesia arena, including within the field of emergency medicine, has yet to be determined and is the subject of active investigation.

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