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REVIEW ARTICLE/BRIEF REVIEW

Point-of-care gastric ultrasound and aspiration risk assessment: a narrative review

Échographie gastrique au chevet et évaluation du risque d'aspiration : un compte rendu narratif

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Abstract *This narrative review summarizes the current knowledge on point-of-care ultrasound (POCUS) of gastric contents in order to inform an assessment of aspiration risk and guide anesthetic management at the bedside. An I-AIM framework (Indication, Acquisition, Interpretation, and Medical decision-making) is used to summarize and organize the content areas. This narrative review spans the breadth of the literature on pediatric and adult subjects as well as on special patient populations such as obstetric and severely obese individuals. Areas that need further investigation include the diagnostic accuracy of gastric POCUS from a Bayesian perspective and the impact of POCUS on patient outcomes, healthcare economics, and educational curricula.*

Résumé *Ce compte rendu narratif résume les connaissances actuelles concernant l'échographie au chevet (POCUS) du contenu gastrique afin de raffiner l'évaluation du risque d'aspiration et de guider la prise en charge anesthésique au chevet. Un cadre dit I-AIM (Indication, Acquisition, Interprétation, et prise de décision Médicale) est utilisé pour résumer et organiser les domaines de contenu. Ce compte rendu narratif a revu la littérature sur les sujets pédiatriques et adultes ainsi que celle portant sur des populations spéciales, telles que les patientes en obstétrique et les patients obèses morbides. Parmi les domaines qui bénéficieraient de recherches approfondies, citons la précision diagnostique de l'échographie gastrique au chevet d'un point de vue bayésien et l'impact de ce type d'échographie sur les pronostics de patients, l'économie des soins de santé, et les programmes de formation.*

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The purpose of this narrative review is to summarize the current knowledge on gastric point-of-care ultrasound (POCUS). The subject matter is geared towards an international audience with the goal to raise interest in POCUS and to provide a basic set of reference materials for use in the preparation for a "hands on" training course.

Methods

A broad literature search was performed on the MEDLINE® database from inception to May 1, 2017, including the MeSH terms *stomach*, *ultrasonography*, *pneumonia,* and *aspiration*, and combined with AND. Two authors reviewed and selected the abstracts by consensus according to relevance. The new information from the full-text articles was summarized and presented according to an I-AIM framework (Indications, Acquisition, Interpretation, and Medical decision-making).

Rationale for use

Pulmonary aspiration of gastric contents carries significant morbidity and mortality.[1-3] Aspiration is the leading cause of death from anesthesia airway events,[4] and major morbidity (including pneumonitis, acute respiratory distress syndrome, multiple organ dysfunction, and brain damage) is common among survivors.[5] Inaccurate risk assessment is often a root cause of aspiration events.[4] While a "full stomach" is a major risk factor for aspiration under anesthesia, the lack of an objective tool to assess gastric content at the bedside limits risk assessment, and patient management is usually based on patient history alone. Although the risk of aspiration is highest in emergency situations, it occasionally occurs in patients who have followed fasting guidelines and are considered at low risk.[2] This baseline risk is approximately 1:4,000.[2]

Gastric ultrasound is an emerging point-of-care tool that provides bedside information on gastric content and volume.[6-8] Similar to other more established POCUS applications, such as cardiac or lung assessment, this diagnostic modality is used to answer a well-defined clinical question in a short period of time in order to guide patient management and ultimately improve patient outcome.[9] In the case of gastric ultrasound, this is typically a dichotomous question. Is the patient's stomach "empty" or "full"? While the definition of a "full" stomach is controversial and conceivably open to interpretation, an acceptable working definition denotes any gastric content beyond what is normal for healthy fasted subjects (i.e., any solid or thick particulate content or clear fluid in excess of baseline gastric secretions of > 1.5 $mL \cdot kg^{-1}$)[10,11] Gastric ultrasound has been studied in pregnant and non-pregnant adults, severely obese subjects, elective and non-elective situations, and pediatric patients. Several recent editorials in major anesthesiology journals have called for greater adoption and teaching of gastric POCUS in anesthesia practice.[12-14] Benhamou suggested that this skill should be part of the basic armamentarium of anesthesiologists for daily practice.[12] Mahmood *et al.* reported a POCUS curriculum for anesthesiologists that includes gastric ultrasound along with other more established applications such as lung and cardiac assessment.[13] Finally, Lucas *et al.* suggested that the three most useful emerging ultrasound applications in obstetric anesthesia practice are a) ultrasound of the spine prior to neuraxial anesthesia, b) ultrasound for airway assessment, and c) gastric ultrasound.[14]

All POCUS applications are ultimately diagnostic tests. Although they are brief and focused, each needs to be studied from multiple angles. It is essential to determine their diagnostic validity (i.e., do they evaluate what needs to be evaluated?) and to establish their reliability and diagnostic accuracy. Diagnostic accuracy refers to the global accuracy (the percentage of exams with a "correct diagnosis") as well as the sensitivity, specificity, and positive and negative predictive values. Given the importance of correctly ruling out a full stomach to prevent aspiration, the negative predictive value of the test is arguably of outmost importance. Other aspects of relevance that need further study include the clinical applicability, educational aspects, and cost-effectiveness of POCUS. As an emerging diagnostic tool, some (but not all) of these aspects of the test have been studied for gastric ultrasound, and there is much room for development and change.

Clinical scenario

- History of present illness: A 79-yr-old male presents for an internal fixation of a closed femoral shaft fracture that occurred 24 hr ago. The surgical procedure is relatively urgent but not immediately life-threatening. The timing of the last meal is unclear. While the patient's daughter states he has remained *nil per os*, the patient insists he had a full lunch three hours ago.

- Medical history: The patient has hemodynamically significant severe aortic stenosis with a valve area of 0.8 cm^2 with recent episodes of exertional syncope. He has severe left ventricular hypertrophy with diastolic dysfunction but preserved systolic function. He also had an episode of transient ischemic attack within the past year. He has mild carotid stenosis for which he is on antiplatelet therapy. His medications include metoprolol 25 mg twice daily, clopidogrel 75 mg daily, and atorvastatin 20 mg daily, and he received 5 mg of morphine *iv* one hour ago.
- Physical examination: He is oriented to self, place, and year but unsure of the month or exact day. He has a body mass index (BMI) of 38 $kg \cdot m^{-2}$ and the upper airway looks normal. He is currently hemodynamically stable. An electrocardiogram shows signs of left ventricular hypertrophy but is otherwise unremarkable, and routine blood work is within normal limits.
- Anesthetic plan: The first decision is whether to proceed with semi-urgent surgery in a subject with questionable *nil per os* status. The second decision pertains to the most appropriate anesthetic technique,

which may impact the higher-order decision whether to proceed. Given the contraindications for a neuraxial technique (severe aortic stenosis and current antiplatelet therapy) a general anesthetic is planned. The clinical conflict here is between a) a "full stomach", which would dictate a rapid sequence induction of anesthesia but pose a higher risk of hemodynamic instability and acute cardiac events, and b) a slowly titrated induction of anesthesia, which would be indicated for his severe aortic stenosis but possibly increase the risk of aspiration in the setting of a "full stomach".

The I-AIM framework

An I-AIM framework is a suitable paradigm for using and teaching gastric ultrasound.[15] When gastric content is unknown or uncertain based on clinical information (*Indication*), ultrasound images are acquired in a standardized manner (*Acquisition*). Once an adequate image is obtained, it is interpreted based on qualitative and quantitative findings (*Interpretation*). This interpretation of the findings is then used to guide airway or anesthetic management (*Medical decision-making*). This framework succinctly describes the main conceptual steps for the clinical use of any point-of-care diagnostic ultrasound application and is used in this review.[11]

Indication

A gastric ultrasound exam is indicated to assess individual risk of aspiration in the setting of unclear or undetermined *nil per os* status. Similar to other tests with dichotomous results (yes or no; full or empty) and following a Bayesian diagnostic framework, gastric ultrasound is likely most useful when there is true clinical uncertainty, i.e., when the pre-test probability of having a full stomach is in the order of 50%.[11,16] Such common clinical scenarios include a) uncertain or contradictory information regarding *nil per os* status (e.g., due to a language barrier or decreased level of consciousness) and b) medical comorbidities or physiologic conditions that may prolong gastric emptying despite adequate fasting (e.g., diabetic gastroparesis, achalasia, advanced renal or hepatic dysfunction, critical illness, multiple sclerosis, Parkinson's disease, substance abuse, recent trauma, and labour).[10,17] Another interesting group of patients are those presenting for non-elective procedures who may not have had an opportunity to fast or may have delayed gastric emptying related to pain, sympathetic activation, or recent opioid therapy. Bouvet *et al.* reported a prevalence of full stomach in 56% of emergency surgical patients and suggested that a preoperative ultrasound assessment of gastric content may be particularly useful in this setting.[17] The routine application of gastric POCUS in patients with a low pre-test probability of a full stomach (i.e., fasted subjects for elective surgery) is somewhat controversial. The likelihood of an unexpected "full stomach" in these scenarios is very low[16,17] and the risk of aspiration rare (1:4,000). In low-risk situations, it is likely that the number-needed-to-test to change anesthetic management and affect outcomes would be very high and probably not cost-effective, although there is a lack of current clinical data available to confirm the optimal application of this diagnostic test.

Acquisition

After adjusting the ambient light, the patient's upper abdomen is exposed and gel is used as an acoustic medium. The patient is scanned consecutively in the supine and then in the right lateral decubitus (RLD) position (Fig. 1). In the RLD position, a larger proportion of the stomach's content flows towards the more dependent distal antrum, and therefore, scanning in this position increases the test's sensitivity.[6,8] When examination in the RLD position is not possible (e.g., critically ill, trauma), a semi-recumbent position (head elevated 45°) may be an acceptable "second best", with the supine position being the least sensitive and least accurate patient position.[18-20]

In the adult patient, a curved array low-frequency abdominal probe (2-5 MHz) with abdominal pre-sets is most suited to provide sufficient penetration to identify the relevant anatomical landmarks.[6-8] In pediatric patients under 40 kg, a linear high-frequency transducer can be used.[21] The stomach is imaged in a sagittal plane in the epigastric area, immediately inferior to the xiphoid and superior to the umbilicus. The transducer is swept from the left to the right subcostal margin. Gentle sliding, rotation, and tilting of the probe are used to locate the antrum and to optimize the image while avoiding oblique views from excessive probe rotation that could overestimate the antral size. The gastric antrum (the most distal portion of the organ) is particularly amenable to ultrasound examination. This is due to its superficial and consistent location in the epigastric area with a favourable soft tissue acoustic window through the left lobe of the liver.[6-8,10] Most importantly, an evaluation of the antrum provides accurate information about the content in the entire organ.[6-8,10] The gastric body usually has a greater air content that may interfere with the exam and the gastric fundus is difficult to access with ultrasound.[6,10] The antrum appears as a superficial hollow viscus with a thick multilayered wall

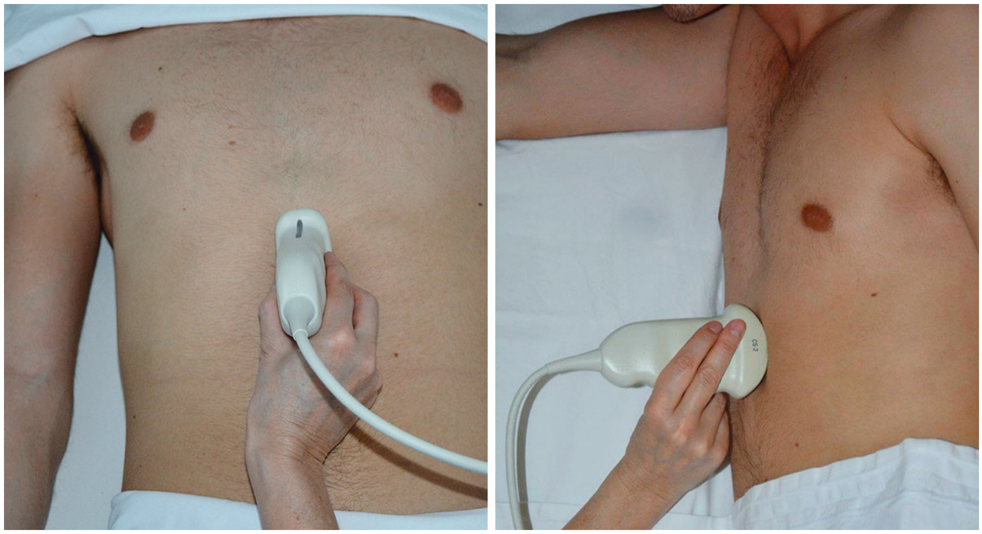

Fig. 1 "Gastric point-of-care ultrasound (POCUS) scanning of patient in the supine (left image) and right lateral decubitus position (right image) using a curved array low-frequency abdominal probe (2-5 MHz). Used with permission from gastricultrasound.org

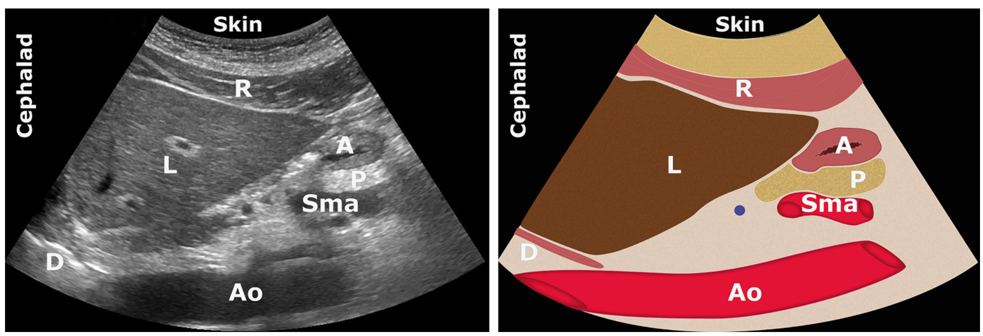

Fig. 2 Upper abdominal sonographic image showing an empty stomach antrum. A = antrum; Ao = aorta; D = diapraghm; L = liver; P = pancreas; R = rectus abdominis muscle; Sma = superior mesenteric artery. Used with permission from gastricultrasound.org

immediately inferior to the left lobe of the liver and anterior to the body of the pancreas.[7] Both the inferior vena cava and the aorta lie posterior to the antrum, and both can be identified in the course of the exam. Nevertheless, a standardized plane at the level of the aorta is used for a quantitative evaluation of the volume of gastric fluid.[8] Other vascular landmarks include the superior mesenteric artery or vein. The gastric wall is approximately 4-6 mm thick in the adult patient and has five distinct sonographic layers that are best visualized in the empty state with a high-frequency transducer. The five layers (from the inner to the outer surface) are as follows: a) mucosal-air interface, b) muscularis mucosa, c) submucosa, d) muscularis propria, and e) serosa.[7] With a low-frequency transducer, only the muscularis propria is consistently observed. This thick muscularis layer, along with the characteristic location of the antrum, allows differentiating the stomach from other portions of the gastrointestinal tract with a thinner, less prominent smooth muscle layer.

Interpretation

After identifying all relevant structures, the nature of the gastric content (empty, clear fluid, thick fluid/solid) may be established based on qualitative findings. When the stomach is empty, the antrum is either flat or round with juxtaposed anterior and posterior walls. When it is round or ovoid, its appearance has been compared with a "bull's eye" or "target" pattern (Fig. 2).[6,7,10]

Thick fluid, milk, or suspensions have a hyperechoic, usually homogenous aspect. Following the ingestion of solid food, the air content mixed with the solid bolus during the chewing process forms a mucosal-air interface along the anterior wall of the distended antrum. This large area of "ring-down" air artefacts blurs the gastric content, the posterior wall of the antrum, the pancreas, and the aorta. This is often referred to as a "frosted-glass" pattern (Fig. 3).[7] After a variable time interval, this air is displaced, and the antrum then appears distended with better appreciable content of typically mixed echogenicity (Fig. 4).

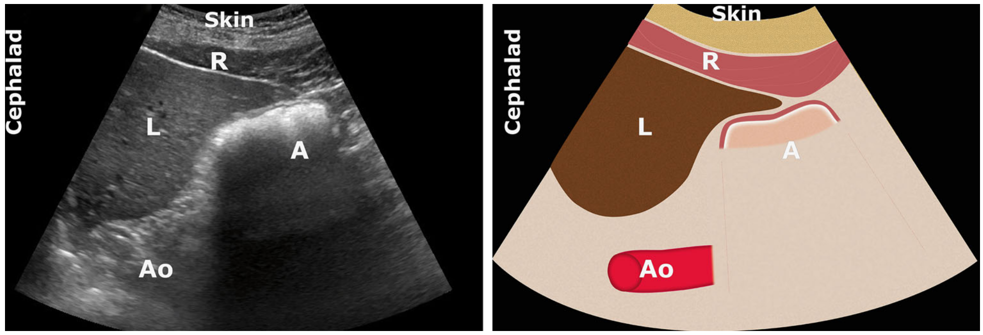

Fig. 3 Sonographic image of the stomach showing solid gastric contents with a "frosted glass" appearance. A = antrum; Ao = aorta; L = liver; R = rectus abdominis muscle. Used with permission from gastricultrasound.org

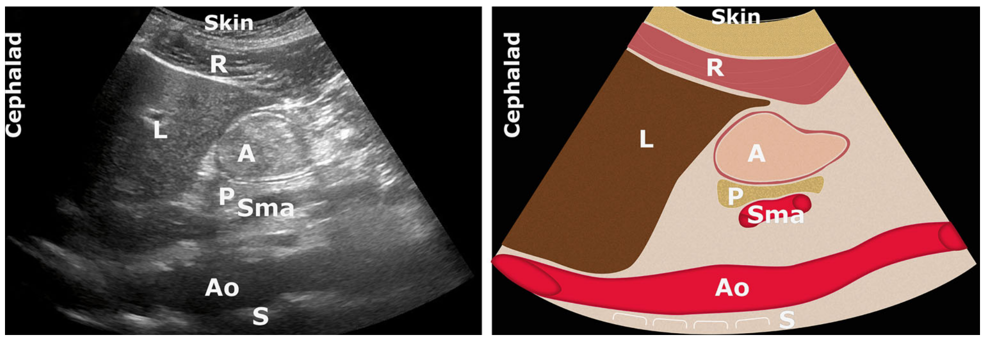

Fig. 4 Sonographic image of the stomach showing "late stage" solid gastric contents. A = antrum; Ao = aorta; L = liver; P = pancreas; R = rectus abdominis muscle; S = spine; Sma = superior mesenteric artery. Used with permission from gastricultrasound.org

Normal gastric secretions and clear fluids (e.g., water, tea, apple juice, black coffee) appear anechoic or hypoechoic. The antrum becomes round and distended with thin walls as the volumes increases (Fig. 5). Immediately after fluid intake, gas bubbles can be appreciated as small punctuate echoes, but they disappear rapidly within minutes of ingestion ("starry night" appearance, Fig. 6).[7]

Healthy subjects who have fasted for elective surgery commonly present with either a completely empty antrum, with no content visible in either the supine or the RLD position (Grade 0 antrum), or with a small, negligible volume of baseline secretions (typically $\leq$ 1.5 mL·kg^{-1}), which is usually appreciated only in the RLD position (Grade 1 antrum).[8,22] The upper limit of normal baseline gastric volume is still somewhat controversial. Nevertheless, we know that the mean value is approximately 0.6 mL·kg^{-1} and that volumes of up to 100-130 mL (about 1.5 mL·kg^{-1}) are common in healthy fasted subjects and do not pose a significant risk for aspiration.[23-25] Previously suggested thresholds of "risk" (0.4 mL·kg^{-1} and 0.8 mL·kg^{-1})[26,27] were extrapolations from volumes of hydrochloric acid directly instilled into the tracheas of animals. These values are not supported by a plethora of human data demonstrating that such volumes of gastric secretions are well within the normal range for healthy fasted individuals with a low risk for aspiration.

Conversely, a volume of clear fluid in excess of 1.5 mL·kg^{-1} or any amount of solid or particulate content in the stomach suggests a non-fasting state (or a "full stomach"), likely increasing the risk of aspiration. A Grade 2 antrum (defined as an appreciable amount of clear fluid in both the supine and the RLD postions) is associated with greater fluid volumes, is uncommon in fasted healthy individuals, and suggests a non-fasting state.[8,16,22]

Therefore, when the stomach contains clear fluid (homogeneous, hypoechoic, or anechoic), a volume assessment can help differentiate a negligible volume consistent with baseline secretions *vs* a higher-than-baseline volume.[8,10,11]

It has been consistently shown that a single cross-sectional area (CSA) of the gastric antrum measured in a standardized manner correlates with the total gastric volume and this correlation is stronger in the RLD position.[6,28-32] Several mathematical models have been reported that describe this numerical relationship.[6,8,29,33-37] One such model has been validated against endoscopically guided gastric suctioning for non-pregnant adults with a wide range of ages and weights. This model accurately predicts gastric volume up to 500 mL as follows (Fig. 7):

$$\text{Gastric volume (mL)} = 27.0 + 14.6 \cdot \text{ Right-lat CSA} - 1.28 \cdot \text{ age}^{8}$$

This model has high intra-rater and inter-rater reliability.[38] For a volume evaluation, the antral area is obtained at the level of the aorta, with the antrum at rest (i.e., between peristaltic contractions), and measured using a free-tracing tool of the equipment following the serosa (or outer

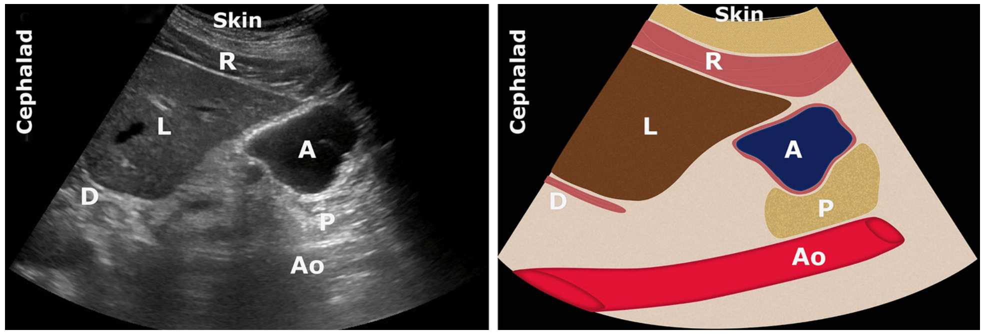

Fig. 5 Sonographic image of the stomach showing clear fluid gastric contents. A = antrum; Ao = aorta; D = diaphragm; L = liver; P = pancreas; R = rectus abdominis muscle; Sma = superior mesenteric artery. Used with permission from gastricultrasound.org

surface) of the antrum. Similar to other ultrasound measurements for other applications, a mean of three readings is recommended to minimize measurement error.

Medical decision-making

Point-of-care gastric ultrasound is used to stratify individual risk for aspiration and to tailor airway and anesthetic management in situations of clinical equipoise where prandial status is unclear.

An "empty" stomach (Grade 0 antrum) or a low volume of clear fluid within the range of baseline gastric secretions (Grade 1 antrum or $\leq$ 1.5 mL·kg^{-1}) is consistent with a fasting state and suggests a low risk (Fig. 8). In the absence of other risk factors, the ultrasound confirmation of an empty stomach would indicate that no special airway management precautions (intubation, rapid sequence induction) are required, and that supraglottic airway devices or deep sedation without airway protection may be appropriate management choices. Conversely, solid content or a high volume of clear fluid that is not in keeping with a fasting state suggests a higher-than-baseline risk for aspiration. These findings would indicate that the airway needs to be protected from aspiration with endotracheal intubation and possibly a rapid sequence induction of anesthesia.

The clinical context of each individual patient needs to be taken into account when making a medical decision.[11] Specific risk factors for aspiration need to be considered, such as the patient's history and physical exam, type of procedure (elective or urgent), nature of the last meal, time interval since the last meal, as well as other risk factors for aspiration.[39] Ultrasound findings can help turn a 50% pre-test probability of a "full stomach" into a "likely full" or "likely empty" situation, thus guiding anesthetic management accordingly. A growing body of evidence suggests that the addition of point-of-care gastric ultrasound to a patient's history and physical exam can modify aspiration risk assessment and anesthetic management in a substantial proportion of cases when clinical data alone are uncertain.[16,17,40-42] A prospective study of 38 elective surgical patients who had not complied with fasting instructions reported a change in anesthetic management in 72% of the cases with point-of-care gastric ultrasound *vs* with management based on history alone and a trend towards a lower incidence of surgical delays.[40]

Morbidly obese patients

The incidence of obesity is growing globally. Obese subjects are usually considered to be at increased risk of aspiration and are therefore of particular interest. Although the greater depth of the antrum (around 7 cm) and the increased visceral adiposity can make the examination more challenging, gastric sonography is feasible in 95% of severely obese individuals.[43,44] The previously mentioned mathematical model for the assessment of gastric volume has been shown to be reasonably accurate in severely obese subjects (BMI $>$ 40 kg·m^{-2}), with a trend towards an overestimation of the volume, particularly at low volume states (mean overestimation of 35 mL).[44] Overall, obese patients presented significantly larger baseline antral CSA and total gastric volumes than their non-obese counterparts.[43,44] Nevertheless, the gastric volume per unit of body weight (0.57-0.7 mL·kg^{-1} and the relative distribution of antral grades were similar to those observed in non-obese subjects.[22,43,44]

Pediatric patients

For children weighing $<$ 40 kg, a linear high-frequency transducer provides the best images through improved spatial resolution, while a low-frequency curvilinear transducer is recommended for best imaging in larger pediatric patients.[21] Similar to the adult population, most fasted children have either a Grade 0 or a Grade 1 antrum. The range of fasting gastric volume per unit of body weight is remarkably constant across all ages and body habitus, with an upper limit of normal in the range of 1.2-1.5 mL·kg^{-1} for pediatric patients.[21,30] A linear correlation between the antral CSA and the gastric volume was

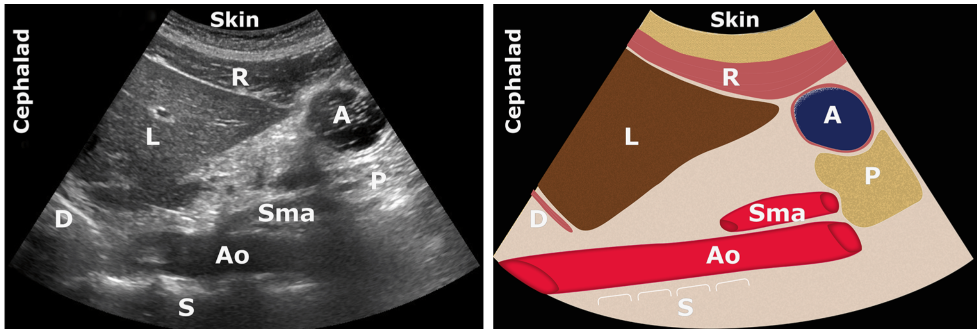

Fig. 6 Sonographic image showing the "starry night appearance" of the stomach represented by clear fluid mixed with gas bubbles. A = antrum; Ao = aorta; D = diaphragm; L = liver; P = pancreas; R = rectus abdominis muscle; S = spine; Sma = superior mesenteric artery. Used with permission from gastricultrasound.org

described in a study of 100 fasting children, and this correlation was again stronger when measured in the RLD position.[30] Point-of-care gastric ultrasound has been used to determine the most appropriate anesthetic technique for the management of hypertrophic pyloric stenosis.[45] In addition, a bedside gastric examination has been reported in children for a different diagnostic application-i.e., the detection and monitoring of ingested foreign bodies (batteries, hairclips, coins, etc.).[46-49] In this context, it has been noted that the additional ingestion of water may aid in the positive identification of the foreign body as a hyperechoic structure within a hypoechoic background of clear fluid.[47]

Critically ill patients and emergency medicine

Two pilot studies have investigated the use of gastric POCUS in critically ill patients.[19,20] A preliminary proof-of-concept study reported that novice examiners could identify the antrum in 65% of patients in the supine position following only four hours of training, and that antral CSA correlated well with the assessment of tomographic volume.[19] It has also been suggested that a craniocaudal diameter may be a simple surrogate of CSA and residual gastric volume.[20]

Gastric ultrasound may be used for indications other than assessment of content and risk of aspiration. Confirmation of nasogastric tube placement in the stomach or duodenum has been reported by either direct imaging of the tip or indirect confirmation through air instillation ("dynamic fogging"), and it has also been used for the diagnosis of gastric outlet obstruction.[50,51]

Obstetric patients

Pulmonary aspiration remains one of the most feared complications in obstetric anesthesia.[52] Regardless of the planned anesthetic technique, an empty stomach is highly desirable prior to anesthetic induction. Gastric emptying in healthy non-labouring pregnant women is similar to that of non-pregnant patients, but it is significantly prolonged once labour begins and appears to return to normal only many hours after delivery.[53,54] There are several clinical situations in obstetric anesthesia where knowing the status of the gastric content may be critical for clinical management.[11] Therefore, real-time ultrasound assessment may allow an opportunity to improve patient safety.[55] Although the general principles and anatomical landmarks of the ultrasound examination of pregnant women are similar to those of non-pregnant subjects, some technical details may differ. Identification of the gastric antrum can be more difficult in pregnant patients due to the gravid uterus and the moving fetus. The stomach is displaced more cephalad and to the right compared with non-pregnant subjects, and dynamic characteristics, such as a fast shallow breathing and hyperdynamic circulation, may pose additional challenges to the exam.[31,32,56] Finally, the presence of the gravid uterus will determine a slightly steeper angle between xiphoid and abdomen, which may make probe placement more difficult.[31,32]

In 1992, a novel study by Carp *et al.* evaluating the nature of gastric contents for a qualitative ultrasound assessment rendered promising but less than optimal results. Their findings showed that only a markedly distended stomach was appreciable and an empty stomach could not be consistently identified.[54] Recent advances in ultrasound imaging, such as multibeam technology and improved engineering, now allow a much higher special resolution. Arzola *et al.* showed substantial agreement and reliable diagnosis when evaluating various gastric contents after a conventional fasting period of solids and clear fluids in the third trimester of pregnancy.[31] Although Barboni *et al.* suggested an initial slower gastric emptying of solid contents after a standardized meal in patients scheduled for elective Cesarean deliveries, no ultrasound examination was carried out beyond six hours.[56] Nevertheless, after following current fasting guidelines (six to eight hours for solids and two hours for clear fluids), no solid gastric contents were found in two cohort studies in term pregnant women before elective Cesarean delivery. These results suggest that these guidelines to ensure an empty stomach are equally effective as in the non-pregnant

Fig. 7 Predicted gastric fluid volume as determined based on a cross-sectional area of the gastric antrum measured in the right lateral decubitus position and the validated model by Perlas *et al.*[8] Used with permission from gastricultrasound.org

Right lat CSA	Age(y) 20	30	40	50	60	70	80
2	**31**	**18**	**5**	**0**	**0**	**0**	**0**
3	**45**	**32**	**20**	**7**	**0**	**0**	**0**
4	**60**	**47**	**34**	**21**	**9**	**0**	**0**
5	**74**	**62**	**49**	**36**	**23**	**10**	**0**
6	**89**	**76**	**63**	**51**	**38**	**25**	**12**
7	103	**91**	**78**	**65**	**52**	**40**	**27**
8	118	105	**93**	**80**	**67**	**54**	**41**
9	133	120	107	**94**	**82**	**69**	**56**
10	147	135	122	109	**96**	**83**	**71**
11	162	149	136	123	111	**98**	**85**
12	177	164	151	138	125	113	100
13	191	178	165	153	140	127	114
14	206	193	180	167	155	142	129
15	220	207	194	182	169	156	143
16	235	222	209	200	184	171	158
17	249	236	224	211	198	185	173
18	164	251	239	226	213	200	187
19	278	266	253	240	227	214	202
20	293	281	268	255	242	229	217
21	307	295	282	269	256	244	231
22	323	310	297	284	271	259	246
23	337	324	311	298	285	273	260
24	352	339	326	313	301	288	275
25	366	353	340	327	315	302	289
26	381	368	355	343	330	317	304
27	395	382	369	357	344	331	318
28	410	397	385	372	359	346	333
29	424	411	398	386	373	360	347
30	439	427	414	401	388	375	363

population.[32,57] Clear fluids were initially assessed by Wong *et al.* in obese and non-obese pregnant women, confirming normal gastric emptying during pregnancy.[58,59] Volume estimation based on a CSA of the gastric antrum has been the focus of multiple recent investigations. Several mathematical models have been described in various examining positions and different clinical scenarios.[60-63] Based on these models, there is currently a search for cut-off values of antral CSA to discriminate different levels of risk.[60-63] While a cut-off value has been reported to discriminate a completely empty stomach (Grade 0 antrum) from one with low fluid volume (Grade 1 antrum), this type of threshold is of limited clinical applicability, as both the Grade 0 and the Grade 1 antrum are common in fasted individuals and carry no significant risk. A more clinically relevant "cut-off" value of CSA would be one that differentiates a baseline volume (Grade 0 or Grade 1 antrum or ≤ 1.5 mL·kg^{-1}) from a greater-than-baseline condition (Grade 2 antrum or > 1.5 mL·kg^{-1}). Although Bataille *et al.*[60] and Jay *et al.*[61] reported antral size during labour, patients were not allowed to take any oral intake, which deviates from most current recommendations in obstetric practice.[60] In contrast, Zieleskiewicz *et al*. based their report on women who were allowed to drink water at their convenience during established labour under effective epidural analgesia.[62] Arzola *et al*. proposed a mathematical model to estimate gastric volume in pregnant women in the third trimester.[63] Although the ingested volume of fluid rather than suction under gastroscopic examination was used as the reference standard, the resulting model very closely resembles the previous predictive model described by Perlas *et al.* in adult non-pregnant subjects.[8] Based on these data, an antral CSA of 9.6 cm^2 in the semi-recumbent right

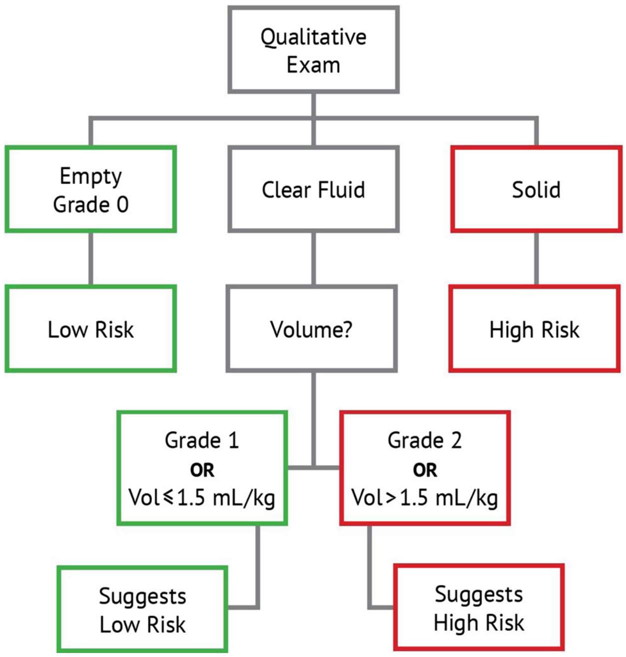

Fig. 8 Flow chart for interpretation of findings and medical decision-making based on gastric point-of-care ultrasound findings. Used with permission from gastricultrasound.org

lateral position can discriminate a low from a high gastric volume (> 1.5 $mL \cdot kg^{-1}$).[63] This value of antral CSA could be a simple surrogate measure that could facilitate the interpretation of examination findings when clear fluid is observed in the antrum. Further research is warranted to develop decision-making strategies based on peripartum gastric ultrasound assessment.

Limitations and areas of further research

It is important to consider both the technical limitations of this diagnostic test as well as the conceptual framework within which it is used. From a technical standpoint, gastric ultrasound has been validated in patients with normal gastric anatomy and may therefore not be reliable or accurate in subjects with previous gastric surgery (e.g., partial gastrectomy, gastric bypass) or large hiatus hernias. Information on the nature of gastric content (clear fluid, solid) could still be useful in these settings, but volume estimation, in particular, will likely be inaccurate in these subjects.

Regarding the conceptual framework for the use of gastric POCUS, it is first important to consider that this test evaluates only one of the determinants of aspiration risk-i.e., gastric content, nothing more or less. The risk of clinically important aspiration is partly determined by the presence of gastric content at the time of anesthetic induction, but it is also influenced by other independent factors, such as a) co-existing diseases of the upper gastrointestinal tract (e.g., achalasia and gastroesophageal reflux disease), b) the anesthetic technique, and c) the events related to airway management (e.g., unexpected difficult intubation requiring prolonged manual ventilation). So, point-of-care gastric ultrasound evaluates an important, but not the only, determinant of risk.

A second significant issue is that, like any ultrasound examination (and any diagnostic test for that matter), gastric POCUS is not infallible. In fact, up to 3-5% of all exams may be inconclusive, and the diagnostic accuracy of gastric ultrasound to detect a full stomach (i.e., the sensititvity, specificity, and positive and negative predictive values of gastric POCUS) remains to be studied.[6,8,43]

Although both the positive and negative predictive values are important attributes of a test, given the implications of a correct "empty" stomach diagnosis for aspiration prevention, the negative predictive value of gastric POCUS is arguably of utmost importance. Furthermore, the diagnostic accuracy of the test will be related to the experience of the sonographer. It has been established that, on average, approximately 33 practice examinations followed by expert feedback are needed for anesthesia fellows learning to perform gastric ultrasound to obtain an accurate diagnosis in 95% of cases. Nevertheless, the optimal way to learn and teach this skill has yet to be established.[64] Gastric content is dynamic and changes quickly over time. Therefore gastric POCUS gives information that may be accurate only at the time of the test. For example, a stomach that is found to be "full" prior to induction of anesthesia may not be so at the end of a surgical procedure and vice versa. So, the test may be repeated as dictated by the clinical situation. Along those lines, ensuring an empty stomach prior to extubation in questionable cases (e.g., difficult airway; critically ill subjects) may be an appropriate additional indication.

A third important limitation is the difficulty to prove conclusively that the introduction of this test will lead to a reduction in episodes of clinically important aspiration and tangible improvements in patient outcomes. A randomized-controlled trial of patients with unclear prandial status with enough power to answer this question would need to be very large and would be logistically difficult to accomplish. This limitation is shared by other POCUS applications, and many current clinical recommendations are based on observational data. For example, the addition of lung ultrasound to a Focused Assessment with Sonography in Trauma (FAST) protocol for evaluating trauma victims is based on the fact that bedside ultrasound is more sensitive than chest *x-ray* to diagnose pneumothorax. Nevertheless, there is a lack of clinical evidence that FAST improves survival or other important patient outcomes. Similarly, the

American Heart Association currently recommends that bedside ultrasound may be considered during resuscitation to identify potentially reversible causes of cardiac arrest. This is suggested despite inadequate evidence to evaluate whether there is any survival benefit of cardiac ultrasound during Advanced Cardiovascular Life Support (ACLS). Furthermore, although the performance of a diagnostic test is not a therapeutic intervention itself, every diagnostic test is potentially destined to lead to clinical interventions that may themselves be beneficial or harmful. So far, we have scant evidence of the effect of gastric ultrasound on important clinical outcomes. The assertion that gastric ultrasound is beneficial in the management of perioperative patients is currently a hypothesis that needs to be tested with properly designed clinical studies examining clinical outcomes rather than just surrogate outcomes.

Given the above limitations and knowledge gaps, further research is needed to define the diagnostic accuracy of gastric POCUS from a Bayesian perspective, including determination of sensitivity, specificity, positive and negative predictive values, and cost-effectiveness considerations. The above information will help define the clinical role of this test, including the determination of appropriate indications. This knowledge is particularly relevant within the current "Choosing Wisely Canada" initiative.

Back to the clinical scenario

In our case scenario, an "empty" test result (no content at all or $\leq$ 1.5 mL·kg^{-1} of clear fluid) would be compatible with a fasting state. It would suggest that ingestion did not in fact occur, and the "memory" of it may be related to confusion or delirium, which is highly prevalent in this clinical context. This negative result would suggest that the risk of aspiration is low, and it may be safe to proceed with surgery with a slowly titrated induction of anesthesia as dictated by the patient's cardiac condition.

Conversely, the documentation of solid or particulate content or a grossly distended stomach with >1.5 mL·kg^{-1} of clear fluid would suggest that the ingestion did likely take place, the stomach has not fully emptied, and the risk of aspiration is higher than baseline. This finding would support postponing the surgery until either a) a recommended fasting interval has been achieved or b) the stomach is confirmed to have emptied on a repeat examination.

Conclusions

Gastric POCUS is an emerging application of sonography increasingly used in anesthesia education and practice. Its validity and reliability have been evaluated for a variety of patient populations, including pregnant and non-pregnant adults, severely obese patients, and pediatric patients. It is likely most useful to define risk and guide patient management when prandial status is uncertain or unknown. Further research is warranted to establish the diagnostic accuracy of gastric POCUS from a Bayesian perspective, determine the impact of this test on patient outcomes and on healthcare economics, and establish how best to incorporate this new skill into existing educational curricula.[64-66]

Conflict of interest None declared.

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