**Functional Ultrasonography**

Two-dimensional (2D) ultrasonography (US) has been used to assess antral wall motion, patterns of transpyloric flow, and GE based on changes in the 2D cross-sectional area or diameter of the gastric antrum (1). It has been validated in comparison to GES in healthy adults (2) and in patients with insulin-dependent diabetes (3). However, 2D US relies on the observation that retention of contents in the distal stomach is related to GE rate and requires assumptions about the geometric shape of the antrum prior to volume calculation. In patients with diabetes, intragastric distribution of contents may be abnormal and, thus, GE measurement may be subject to error (1,4). More recently, 3D ultrasonographic techniques have been developed and shown to be more accurate and less variable than 2D data (5), and have been validated in comparison to GES among healthy individuals (1) and in patients with gastroparesis (4).

Functional US utilizing duplex Doppler techniques may also be used to visualize movement of gastroduodenal contents and transpyloric flow of liquid meals (6,7). An episode of GE is defined as flow across the pylorus with a mean velocity of >10 cm/sec for at least 1 second (8). Transpyloric passage of gastric contents and postprandial upper GI symptoms can be studied with great temporal and spatial resolution using this method, including during assessment of pharmacological intervention (8,9).

**Preparation and Procedure:** Similar to other tests of GI motility, US testing begins after an overnight fast. Patients consume a test meal which may consist of a high or low caloric nutrient drink (10) or a standard solid-liquid meal (3,11). The transducer is placed vertically over the upper abdomen to visualize the antrum in cross-section with the aorta and superior mesenteric vein in order to standardize the location and axis of the ultrasound beam in all images. The diameter of the gastric antrum at each time point is measured. Though varying methods have been described, measurements typically are acquired more frequently within the first hour of testing, followed by decreased frequency during the later stages of the test (3,10,11).

For the 3D technique, US measurements are performed using an US system and a pulsed magnetic field system attached to the US probe (5). Data are acquired with patients in the seated position immediately before and after meal ingestion, followed by images at 10- to 15-minute intervals for the first hour and 30-minute intervals for the remainder of the study, for a maximum of 180 minutes. Patients are instructed to hold their breath at the end of inspiration, and the stomach is scanned by continuous translational movement across the long axis, starting at the left subcostal margin and ending in the region of the gastroduodenal junction (1,4).

**Pitfalls and Precautions:** Bubbles within the meal may produce artifact. It has been proposed that heating the test meal to the boiling point followed by cooling lessens the bubbles in the stomach compared to a meal served at room temperature. The ideal patient positioning is seated and leaning slightly back. With the 3D system, the laboratory environment and magnetic interference causing spatial distortion are critically important. Objects with metallic components such as watches, belts, and jewelry must be removed from both the patient and the operators (5).

**Calculations and Interpretation:** During evaluation with 2D US, the mean of three readings is calculated at each observation and the antral section is calculated using the formula: 
\[ S = \pi \cdot d_1 \cdot d_2 / 4, \]
with S representing the area of the antral cross-section, d1 the longitudinal and d2 the anteroposterior diameter. The antral cross-sectional area is plotted against time and the T_{1/2} and total emptying time are set at the points where the line crosses the 50% and basal (fasting) values, respectively (3,11).

When using the 3D technique, data acquisition is transferred to a work station, and computerized volume estimation is performed with custom software (5). The volume of content in the stomach is expressed as a percentage of the original volume at time 0 minutes. GE curves are expressed as percent retention over time, and T_{1/2} is determined (1,4).

**Merits:** US is noninvasive, safe, widely available, allows for bedside monitoring, does not expose the patient to ionizing radiation, and shows reasonably good interobserver agreement in the evaluation of liquid GE (12).
**SUPPLEMENTARY DATA**

*Limitations:* US is unable to distinguish between the solid and liquid components of a meal (1) and is best utilized for assessment of liquid GE, thus limiting its clinical utility. US also requires an experienced technician, is user dependent, may be influenced by the presence of intragastric air or posture (1,5), and is generally considered impractical for prolonged observations (reference 34 in paper). Specialized equipment based on magnetic scan head tracking is required for the 3D US technique (5).

**Magnetic Resonance Imaging**

Magnetic resonance imaging (MRI) has been used to document delayed GE (13), volume change, and gastric contractile activity (14). Due to the small number of centers which use MRI, we have not included a discussion on MRI in our review.

**Additional Techniques**

Older techniques for GE assessment include radiopaque markers and paracetamol (acetaminophen) absorption testing. The use of radiopaque markers involves the acquisition of hourly abdominal x-rays for a maximum of six hours after ingestion of barium pellets incorporated into a solid meal. However GE of the non-digestible pellets occurs with the return of phase III of the migrating motor complex (MMC), rather than with the emptying of digestible food (15, 16). Unlike the situation with wireless motility capsule testing, the exact time of GE of markers cannot be ascertained using this method.

Paracetamol absorption testing is based on the principle that the rate-limiting step of absorption is GE. However, this test is only validated for liquid emptying (17), does not directly assess GE, requires repeated blood sampling, and may be limited by drug interactions (18).

Gastric motor functions may also be evaluated by tests such as antroduodenal manometry (ADM) and cutaneous electrogastrography (EGG). ADM utilizes water perfusion or solid state sensors and allows for characterization of gastric and small-intestinal phasic contractions, and may be used in select cases of documented gastric or small bowel dysmotility to determine the underlying pathophysiology (e.g. neuropathic vs. myopathic vs. mechanical obstruction). Limitations are that it is mainly available at tertiary referral centers, is invasive, time-consuming and technically demanding (19), with potential for artifacts (such as respirations, pulsations of major vessels and artificially high-pressure zones due to catheter angulation with resistance to water perfusion) to complicate the interpretation (20).

EGG provides information about gastric myoelectric frequencies and has been shown to correlate with scintigraphy (21), manometry (22), and US (23). It may be used as a complement to GE testing and ADM to assess unexplained upper GI symptoms or gastric motor functions in patients with chronic constipation or history of fundoplication with retching and nausea. Its use is limited by cost, technical needs, ongoing debate regarding clinical indications for use, optimal lead placement, and interpretation of findings (19).
References:

5. Gilja OH, Detmer PR, Jong JM, Leotta DF, Li XN, Beach KW, Martin R, Strandness DE, Jr. Intragastric distribution and gastric emptying assessed by three-dimensional ultrasonography. Gastroenterology 1997;113:38-49