REVIEW

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Abdominal Ultrasound for the Evaluation of Gastric Emptying Revisited

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ABSTRACT

Background & Aims: Disorders of gastrointestinal transit and motility are frequently found in the general population, impacting the quality of life and increasing the costs of health care services. Ultrasonographic assessment of gastric emptying is a method introduced in the early 1980s for the evaluation of dyspepsia. The aim of this paper was to assess the current role of abdominal ultrasound in the evaluation of gastric emptying.
Method: Using the keywords "ultrasound and gastric emptying", "echography and gastric emptying", "3D and gastric emptying" and "strain rate imaging and gastric emptying" the PubMed database was screened for publications on ultrasonography evaluating gastric emptying in adults from January 1, 2007 to December 31, 2014.
Results: 281 papers were identified, of which only 21 randomized studies, 18 comparative and 18 non-comparative studies met the inclusion criteria. Most studies were conducted on healthy subjects for research purposes. Thirteen studies were performed on patients with functional dyspepsia, of which 6 studies assessed treatment efficacy. Other indications for ultrasound gastric emptying evaluation were: diabetes mellitus, scleroderma, metabolic syndrome, asthma, Parkinson's disease, and obesity. Using abdominal ultrasound, delayed gastric emptying was found in 10% of patients with functional dyspepsia, 48.5% of patients with longstanding diabetes and 65-70% of patients with systemic sclerosis with a disease duration of more than 10 years.
Conclusion: Functional ultrasonography is a non-invasive method used for research or practical purposes that brings an insight into gastric emptying in healthy individuals, and in individuals with functional and motility gastrointestinal disorders.

Key words: abdominal ultrasound – diabetes – gastric emptying – functional dyspepsia – gastroparesis – scleroderma.

Abbreviations: CAN: cardio-vascular autonomic neuropathy; CSA: cross sectional area; EPS: epigastric pain syndrome; FD: functional dyspepsia; GE: gastric emptying; GE T50: gastric emptying half time; GER: gastric emptying rate; GET: gastric emptying total time; GLP-1 (9-36) amide: glucagon-like peptide-1; HOMA-R: homeostasis model assessment ratio; ICR: integrated antral contraction rate; IBS: irritable bowel syndrome; L-NAME: N-nitro-L-arginine-methyl-ester; MI: motility index; PDS: postprandial distress syndrome; SDF: soluble dietary fibre; UGE: upper gastrointestinal endoscopy.

INTRODUCTION

Disorders of the gastrointestinal transit and motility such as gastroparesis, constipation, irritable bowel syndrome (IBS) and functional dyspepsia (FD) are commonly encountered in the general population, impacting the quality of life and increasing the consumption of health care services [1]. These disorders are associated with delayed or accelerated transit of the stomach, small intestine or colon, causing a wide spectrum of symptoms. Gastric emptying (GE) is usually evaluated in patients with symptoms suggestive of delayed GE, such as early satiety, postprandial fullness, postprandial bloating, nausea or vomiting, which is the case of gastroparesis patients. Less frequently, GE is assessed in patients with symptoms caused by the rapid emptying of the stomach such as diarrhea, weakness, postprandial confusion or dizziness.

The current diagnostic tools for evaluating GE include: scintigraphy, which is considered the "gold standard" for GE

evaluation of solids [2], the wireless motility capsule test, GE breath test and magnetic resonance imaging. However, all these methods have technical limitations, are expensive or complex, making the evaluation of GE a challenging task in clinical practice.

Ultrasonography is a non-invasive, inexpensive diagnostic test with a good inter-observer agreement compared to scintigraphy [3], and which provides real-time structural and functional information regarding most parameters of gastric motility [4]. However, its utility is limited by its operator-dependent nature, indirect GE quantification (according to changes in antral area), difficulties in evaluating specific groups of patients and a lack of evidence for assessing GE for solid meals [5]. Ultrasonographic evaluation of GE was introduced in the early 1980s for investigating dyspepsia. The aim of this paper was to assess the current role of abdominal ultrasound in the evaluation of GE based on existing data.

METHOD

Using the keywords "ultrasound and gastric emptying", "echography and gastric emptying", "3D and gastric emptying" and "strain rate imaging and gastric emptying" the PubMed database was screened for publications on ultrasonography investigating GE in adults from January 1, 2007 to December 31, 2014. Eligibility criteria for the studies included were: a minimum of six adult subjects evaluated; studies with or without case-control design, consecutive cases or selected cases regardless of prospective or retrospective design; studies that followed the effectiveness of therapeutic interventions; studies that used ultrasound for the assessment of gastric motility.

Studies not performed on humans, studies conducted in children, studies that lacked an abstract, abstracts presented at various conferences and papers written in languages other than English and French were not taken into consideration. Reviews were also excluded. For each article included in the present study the year of publication, type of the study, country of origin, number of patients and their mean age, the method used and the main results were extracted.

RESULTS

The search strategy returned a number of 281 papers, among which 128 were duplicates. Ninety-six abstracts did not meet the inclusion criteria. The remaining 57 papers were analyzed and included in this review. Among these, 21 were randomized studies, 18 were comparative studies, and 18 were non-comparative studies (Fig. 1).

Thirty-two studies assessed ultrasound-based gastric motility in several groups of patients: FD (13 studies), diabetes mellitus (7 studies), scleroderma (2), gastroesophageal reflux disease and metabolic syndrome (1), obesity (2), asthma (1), Parkinson's disease (1), patients undergoing colonoscopy (1), frail patients (1), and pregnant women (3 studies). The remaining 25 studies were performed on healthy subjects.

Ultrasound studies assessing GE in healthy volunteers

Between 2007 and 2014, 25 studies using abdominal ultrasound assessed GE in healthy subjects. All studies included small samples, ranging between 6 and 24 subjects, and were conducted for research purposes.

Six studies investigated the effect of different nutrients and of different cereals on GE rate (GER) and on glucose metabolism. Using different meal regimens (4g oat beta-glucan, cinnamon, muesli, commercial rye whole-meal bread and white wheat bread, whole-kernel wheat bread with vinegar, cereal bran flakes), it was shown that cereal bran flakes delayed GE when compared to whole meal oat flakes (GER after cereal bran flakes: 28% vs. GER after corn flakes: 50%, p=0.02) [6-11]. Also, adding a high dose of cinnamon (6g) to the test meal delayed GE (GER after 6 g cinnamon: 34.5% vs. GER after reference meal – rice pudding: 37%, p<0.05) [7]. Similarly, inulin-enriched pasta delayed GE in young subjects by improving lipid and glucose metabolism [12, 13]. Patients with insulin resistance (HOMA-R >1.7) had delayed GE compared to patients without insulin resistance [14]. The intravenous nitric oxide synthase inhibitor, N-nitro-L-arginine-methyl-ester (L-NAME) inhibited the effects of hyperglycemia on gastric motility, without effect in subjects with normal glycemia [15].

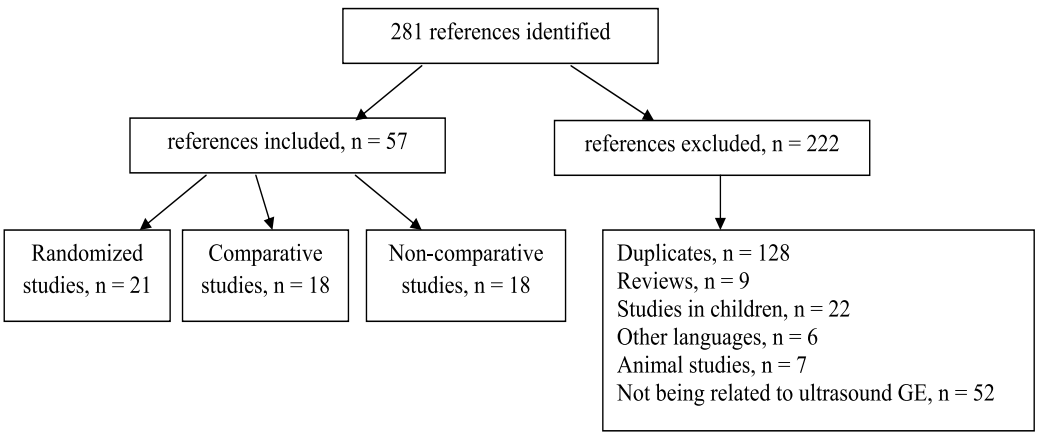

Fig. 1. Flowchart describing the selection algorithm of identified references. GE: gastric emptying.

Five studies assessed the influence of different drugs (amytriptiline, orlistat, acarbose, intravenous erythromycin, mosapride citrate, GLP-1 (9-36) amide) on GE. It was demonstrated that orlistat accelerated GE for high fat liquids, acarbose delayed GE [16], intravenous erythromycin [17] and mosapride citrate enhanced GE [18], while amytriptiline [19] and GLP-1 (9-36) amide, a metabolite of glucagon-like peptide-1 (7-36) amide, a hormone that was thought to inhibit gastric secretion and emptying, had no effect on GE of liquids [20].

In the other five studies, it was hypothesized that adding various substances (i.e. milk, xylose, glucose, monosodium glutamate - a flavor enhancer, alcoholic beverages or ginger) might influence GE [21-25]. Only ginger accelerated GE and stimulated antral contractions (GE T50 after ginger: 13.1±1.1 min vs. GE T50 after placebo: 26.7±3.1 min, p<0.01) [25].

Two studies searched for the influence of the caloric content or volume on GE. One study showed that there was no intra-individual variability of GE in response to energy intake [26]. The other one showed that the caloric content, more than the volume of the test meal influenced the GE of liquids. Liquids with high amount of calories delayed GE [27].

Gastric emptying was also evaluated in patients with postprandial hypotension. It was found that intragastric water administration (via a nasal cannula) corrected the hypotension caused by intraduodenal glucose administration (via a nasal cannula), due to gastric distention. Infusion of glucose intraduodenally delayed GE when compared with saline solution infusion (GE T50 77.7 ± 8.3 min vs. 41.0 ± 4.0 min, p= 0.006) [28].

Most studies assessed GE using different test meals (liquid/semisolid/solid) by measuring the antral cross-sectional area (antral CSA) and thus calculating GER and GE T50. More rarely, other ultrasound parameters were used, such as GE total time (GET), frequency of antral contractions and motility index (MI).

Ultrasound studies assessing GE in functional dyspepsia

We identified 13 studies conducted in FD patients. Of these, 4 evaluated gastric motility (Table I), 6 assessed treatment efficacy in FD (Table II) and 3 studies evaluated proximal GE [39-41]. In 2 of these studies, abdominal ultrasound identified several parameters suggestive of delayed GE: reduced GE fraction, a reduced number of antral contractions and a lower MI [29, 32]. They evaluated 33 FD patients (20 women), with a mean age of 36.3 years. However, these studies used different parameters for the assessment of GE in these patients and no firm conclusions could be established.

Ultrasound studies assessing treatment efficacy in patients with functional dyspepsia

Among the studies conducted in FD patients, 6 studies assessed the efficacy of several therapeutic methods (Table II). Four studies compared a therapeutic agent (acotiamide, ginger, metoclopramide, ondansetron) with placebo [34, 35, 37, 38], one compared Xiao Pi-II (a plant extract with nine

Table I. Summary of ultrasound studies evaluating gastric motility in patients with functional dyspepsia

Study	Number of patients Mean age	Ultrasound parameters / test meal	Results
Manabe [29] 2011 Comparative Japan	**19 PDS patients** (ROME III criteria), 48.2 years **26 healthy subjects**, 45.0 years	- Chinese noodles (4.4 g of protein, 10.0 g of fat, and 25.8 g of carbohydrate, 211 kcal) - US- frequency antral contraction; 15-min integrated antral contraction rate (ICR).	- PDS - fewer antral contractions than HS; - ICR: in PDS (12.9 ± 4.6) and in the HS (68.9 ± 5.8), p < 0.01.
Matsumoto [30] 2008 Non-comparative Japan	**198 FD patients** (ROME III criteria), 53.1 years - H. pylori-positive n=39 - H. pylori negative n=39	- 400 ml of consommé soup (0.38 g protein, 0.25 g fat, 2.3 g sugar, 13.1 kcal) - US – antral area, MI, RI, GER - UGE + gastric biopsies	- MI was lower in H. pylori-positive patients (6.78+/-2.17) compared to H. pylori negative patients (7.63+/-2.35, p<0.05), and the RI was higher (5.64+/-4.70 vs. 2.13+/-2.58, p<0.01). - no difference with respect to the GER.
Kamino [31] 2008 Non-comparative Japan	**40 FD patients** (ROME II criteria), 53.7 years - group A improvement of symptoms with treatment; n=21. - group B persistence of symptoms; n=19.	- 400 ml consommé soup (0.38 g protein, 0.25 g fat, 2.3 g sugar, 54.8 kJ) - US – antral CSA, GER, MI	- abnormal GER at baseline in 50% of patients. - Follow-up GER and MI values were significantly higher in group A than baseline values, but not in group B.
Lunding [32] 2008 Comparative Random Norway	**14 FD patients** (ROME II criteria), 24.5 years **14 healthy subjects**, 27 years	- 500 mL clear meat soup (20 kcal) or sham feeding - US – sagittal section of the antrum, MI (US 2D), volume of the stomach (US 3D)	Without sham feeding, FD patients had lower MI than HS (4.4 +/- 1.0 min^{-1} vs. 8.0 +/- 1.2, p = 0.04).With sham feeding, FD patients had an increased MI (3.5 ± 1.5 min^{-1}, p = 0.04), but not in HS.

CSA: cross sectional area; FD: functional dyspepsia; GER: gastric empting rate; HS: healthy subjects; ICR: integrated antral contraction rate; MI: motility index; PDS: postprandial distress syndrome; RI: reflux index; UGE: upper gastrointestinal endoscopy.

Table II. Summary of ultrasound studies evaluating gastric empting for treatment efficacy in patients with functional dyspepsia

Study	Number of patients Mean age	Method used	Results
Liu [33] 2013 Random China	**180 FD patients**, 42±14 years	- Xiao Pi-II or mosapride - 3D US - gastric motility	- GER before and after: -Xiao Pi-II group: 47±7 vs. 56±10 % (p<0.001) - mosapride group: 48±7 vs. 50±7% (p=0.38).
Kusunoki [34] 2012 Randomized Japan	**42 FD patients** (ROME II criteria), 40.4 years	- acotiamide or placebo -US - liquid test meal 400 mL (13.1 kcal) - US: GER, MI, RI	- Acotiamide accelerated GER (p = 0.012).
Hu [35] 2011 Random Taiwan	**11 FD patients** (ROME III criteria)	- ginger or placebo, - 500 mL low-nutrient soup 118.6 kcal. -US – antral area, GE T50	- Median GE T50: after ginger 12.3 min vs. placebo 16.1 min, p≤0.05.
Kusunoki [36] 2010 Non-comparative Japan	**16 FD patients** (ROME III criteria), 45 years	- Rikkunshito - US - liquid meal up to 400-mL - US: antral area, GER, amplitude and frequency of antral contractions, MI	- GER before and after treatment with Rikkunshito: 57.9±5.7 vs. 72.3±5.4, p=0.010.
Banani [37] 2008 Random Iran	63 DLD patients (ROME II criteria), 39 years	- metoclopramide tablets 5 mg or metoclopramide oral solution 2 mg or placebo - test – 400 ml chicken broth (20 kcal) -US – antral CSA, final GET -UGE + biopsies	- GET before and after: 1. metoclopramide tablets: 61.2±14.9 vs. 58.1±12.8; p=0.04. 2. metoclopramide solution: 59.7±14.2 vs. 54.9±12.2 min; p=0.02 3. placebo: 58.9±13.7 vs. 57.6±13.4 min; p>0.05
Dizdar [38] 2007 Random Norway	**22 IBS patients (including 15 FD) with Giardia negative stools,** 35 years **19 healthy subjects,** 31 years	- ondansetron orally or placebo - 3D US – liquid test meal (500 ml meat soup)	- GE did not differ in ondansetron group vs. placebo (43.16 ± 22.30 mL vs. 38.07 ± 18.71 mL; p>0.05).

CSA: cross sectional area; DLD: dysmotility-like dyspepsia; FD: functional dyspepsia; final GET: final gastric emptying time; GE: gastric emptying GE T50: gastric emptying half time; GER: gastric empting rate; IBS: irritable bowel syndrome; GET: gastric emptying total time; UGE: upper gastrointestinal endoscopy.

Chinese herbs) with mosapride [33], and one study evaluated the efficacy of rikkunshito (a traditional Japanese medicine from 8 plants) [36]. Using abdominal ultrasound, several parameters were evaluated in these studies: GER, GET, GE T50. Except for ondansetron, all these studies demonstrated a small improvement in GE.

Ultrasound studies evaluating GE in patients with diabetes mellitus

Seven studies were performed in patients with diabetes, of which 5 were comparative studies (Table III). These 5 studies included 166 patients (76 women) with type 2 diabetes mellitus, who were compared with 156 healthy subjects (82 men). The mean age was 60 years in diabetic patients and 55.2 years in healthy subjects. The mean duration of diabetes was 12.2 years, the mean fasting plasma glucose 153.3 mg/dl and mean HbA1c 8.58 %.

Ultrasonography was used to assess antral CSA, proximal CSA, whole stomach cylinder or full stomach area using different parameters, such as GE T50 of distal or proximal stomach, GER, MI, antral contractions or food emptying rate. The main findings of these studies are presented in Table III.

Gastric emptying in other disorders

Abdominal ultrasound was found to be useful in assessing several other conditions. Delayed GE was demonstrated in more than 50% of patients with systemic sclerosis with a long disease duration compared with patients with FD and healthy subjects (GE T50 42±4 min vs. 47 ±3 min and 26±3 min respectively, p<0.001) [47, 48]. Abnormal GE was also found in patients with Parkinson's disease (GE T50: 167.4±28.4 min) compared to elderly healthy controls (120±14.0 min), p<0.001 [49], in patients with gastroesophageal reflux disease and metabolic syndrome (decreased GER, OR 2.32, CI 95% 1.36-5.48) [50] and in obese adult patients (GE T50: 36±2 min) compared to lean adult subjects (26±1 min), p<0.001 [51]. Using a solid meal test, one study conducted in 30 asthma patients demonstrated delayed GER 210 minutes after ingestion, compared with healthy subjects (71.8±2.1% vs. 75.0±2.2%, p<0.05) [52]. Another study performed in frail patients (undernourished elderly subjects) showed enhanced postprandial emptying when compared with younger adults (GE T50: 32.9±26 min vs. 43.9±29 min, p=0.065), a larger antral area at rest and impaired antral compliance [53].

Gastric emptying in obstetrics

Three studies were performed in pregnant women [54-56]. One study showed that during labour performed under epidural anesthesia, antral area decreased from 319 mm^2 at epidural insertion to 203 mm^2 at full cervical dilatation, with a median between the two measurements of 188 min; gastric motility was preserved during labor [54]. Another study showed that high-protein drink supplementation improved patient satisfaction compared to ice chips/water, while GE

Table III. Summary of ultrasound studies that evaluated gastric motility in patients with diabetes mellitus

Study	Number of patients Mean age	Method used	Results
Chiu [42] 2014 Comparative Taiwan	**11 patients with longstanding diabetes type 2**, 58±2 years **11 healthy subjects**, 51±5 years	- 500mL of chicken and corn soup, 118.6 kcal (2.6g protein, 2.6g fat, 21.2g carbohydrate) - UGE - US – antral area, GE T50, antral contractions	- GE T50 in diabetic patients vs. HS: 46.3 min vs. 20.8 min, p ≤ 0.05. - Antral area in diabetic patients vs. HS: 15.6±2.3 cm^2 vs. 12.6 ±2.4 cm^2, p=0.014.
Shen [43] 2014 Comparative China	**36 patients with diabetes type 2 and gastropathy**, 46.5±8.6 years **92 healthy subjects**, 44.7±8.5 years	- US- whole stomach cylinder measurement, antral area, antral volume, GER, GE times – T1 (25%), T2 (50%), T3 (75%) - scintigraphy (contrast agent + 400 ml water)	- GE T50 (stomach cylinder) in diabetic patients vs. HS : 46.5±7.2 min vs. 41.6±8.2 min, p<0.05
Yu [44] 2014 Comparative Randomized Prospective China	**30 patients with type 2 diabetes,** 65.7±6.2 years **10 healthy subjects,** 62.3±3.5 years	- SDF-free liquid (500 mL, 500 Kcal) and isoenergetic SDF liquid (oat β-glucan 7.5 g, 500 mL, 500 Kcal) protein 15%, fat 30%, carbohydrate 55% - US – proximal CSA of the stomach, antral CSA, GE T50.	- GE T50 after SDF free vs. SDF: - HS: 72.1±19.5 min vs. 85.5±16.5 min, p=0.037, - diabetic patients : 91.0±16.8 min vs. 114.5±34.4 min, p=0.001.
Bian [45] 2011 Comparative China	**71 patients with diabetes**, 68.2 ± 6.8 years **30 controls** 68.1 ± 6.3 years	- US – full stomach area, FER at 120 min -^{13}C-octanoic acid breath test	- higher incidence of DGE in diabetic patients 48.5% vs. controls 10.7%, p = 0.001. - area of empty stomach in HS vs. diabetic patients : 3.81 ± 0.72 cm^2 vs. 4.36 ± 0.96 cm2 (p=0.005) - FER120% HS vs. diabetic patients: 86.1 ± 7.1 vs. 69.1 ± 12.5 p< 0.001 - CAN was present in 66.7% of diabetic patients with DGE.
Sogabe [46] 2007 Comparative Japan	**18 diabetic patients with gastroparesis,** 61.6±11.4 years **13 healthy subjects,** 50.3±6.5 years	- 400 mL of consommé soup (0.38 g protein, 0.25 g fat, 2.3 g sugar, 13.1 kcal) -US - antral CSA, antral contractions, MI, GER	- GER was 73.7±12.4 % in HS, 45.0 ± 13.7% in diabetic patients with metabolic syndrome and 39.1 ± 11.9% in patients without metabolic syndrome. - GE delayed in diabetic patients compared to controls (p<0.001).

CAN: cardio-vascular autonomic neuropathy; CSA: cross sectional area; DGE: delayed gastric emptying; FER: food emptying rate; GE: gastric emptying; GE T50: gastric half-emptying time; GER: gastric empting rate; HS: healthy subjects; MI: motility index; SDF: soluble dietary fibre; UGE: upper gastrointestinal endoscopy.

T50 was the same in both groups (GE T50 high-protein drink: 25.5±15.9 min vs. GE T50 ice chips/water: 20.0±8.7 min; p=0.19) [56].

A study conducted in 10 obese pregnant women at term, non laboring, demonstrated that GE did not differ after the ingestion of 300 ml and 50 ml water (GE T50 after 300 ml water: 23±11 min vs. GE T50 after 50 ml water: 32±15 min; p=0.23) [55].

DISCUSSION

This systematic review summarizes the results of the 57 studies published between 2007 and 2014 on the role of abdominal ultrasound in the evaluation of GE. Given the variety of disorders in which ultrasound was used for GE evaluation, ultrasonography seems to have a large applicability for investigating gastric motility. However, based on the assessed studies, due to a lack of standardization of measured ultrasound parameters and of test meals (liquid/mixed/solid), the current role of ultrasound in GE evaluation in daily clinical practice is insufficiently established.

In 1980, Holt et al. used ultrasonography for the first time for studying the gastric contractions in response to a liquid test meal [57]. In 1982, Bateman and Whittingham quantified this method using a series of cross-sectional areas at regular intervals obtained at right angles to the long axis of stomach, and calculating GE half time of a liquid meal [58]. In 1985, Bolondi et al. simplified the method, performing measurement of GE by using a cross-sectional area of the gastric antrum at different periods of time, determining the total GE time of mixed meal [59].

Currently, the calculation of antral area or diameter is mostly used. The technique requires placing the transducer in the epigastric region, in a vertical position, in order to visualize the antrum, the superior mesenteric artery and the abdominal aorta. The antral cross-sectional area is estimated by drawing the internal edge of the mucosa with built caliper. Using different mathematic formulas, several parameters of gastric motility are calculated at different periods of time:

a) gastric emptying half time (GE T50): the point in time when 50% of a test meal is evacuated from the stomach;

b) total gastric emptying time (GET): the point in time when antral area measured after a test meal returns to the basal value;

c) gastric emptying rate (GER): [(antral cross-sectional area at 1min and 15 min after ingestion of the test meal)/antral cross-sectional area at 1 min)] x 100 [60];

d) frequency of antral contractions: the number of antral contractions per 3 minute-intervals for the first 9 minutes after ingestion [60];

e) amplitude of antral contractions: (area relaxed – area contracted) x 100/ area relaxed [60];

f) motility index (MI): mean amplitude of antral contractions x frequency of contractions [60].

Functional ultrasonography provides real-time information regarding most parameters of gastric motility [4], while scintigraphy, "the gold standard" method, provides information on only three parameters: the percentage retention, GE T50 and the lag phase for solids [1].

The test meal used for the ultrasound evaluation of GE is very important. The content of the stomach is evacuated in a different manner depending on several meal characteristics: the type of meal (liquid/semisolid/solid), the meal volume, caloric content and composition. A solid meal, after an initial lag time of 20-30 minutes, is emptied from the stomach in a second phase at an approximately linear rate. A liquid meal low in nutrients or with a large volume is emptied from the stomach at an exponential faster rate [61]. If the liquid meal is hypertonic, acidic or rich in nutrients (fat, certain amino acids), GE is delayed and non-exponential.

Ultrasound studies assessing GE in healthy volunteers

Most of the studies evaluating gastric motility included in this systematic review were performed on healthy subjects. In these studies, ultrasound was used mainly as a clinical research tool for GE evaluation, especially for assessing the influence of different meal compositions (different nutrient / caloric test meals) or specific drugs on GE. These were heterogeneous studies, which used different protocols and ultrasound parameters for the assessment of GE. Ultrasonography was able to characterize different parameters of the GE. Most parameters that were determined using the measurement of the antral area were GER, GET, and GE T50. The normal values of the ultrasound parameters reported varied between 37 and 51% for GER [7, 9, 11], and between 90.7 and 123 minutes for GE T50 [12, 24] using a solid test meal; the average normal values in the case of a liquid test meal were 58.6% for GER [14] and 26.7 minutes for GE T50 [25]. However, no common end-point for these studies was identified.

Current literature data supports the fact that real-time ultrasonography, due to its non-invasive character and relatively low cost, is a potentially valuable tool for the study of gastric motility in healthy subjects in the research field. Observations on healthy subjects could find applicability in patients with gastro-intestinal motility disorders. However, its current role in clinical practice remains limited.

Ultrasound studies assessing GE in patients with functional dyspepsia

Delayed GE is considered one of the mechanisms involved in the pathophysiology of FD, with a reported prevalence ranging between 20% and 50% [62]. A meta-analysis of 17 studies showed that 40% of FD patients had delayed GE of solids, as evaluated by scintigraphy [63].

One study that used abdominal ultrasound detected delayed GE in 10% of FD patients [40]. Another study showed that the presence of *Helicobacter pylori* infection in FD patients with severe antral inflammation was associated with delayed GE [30].

There is controversy regarding the relationship between the delayed GE and symptoms. Using strain rate imaging, Ahmed et al. showed that FD patients could be divided into two subgroups: epigastric pain syndrome (EPS) and postprandial distress syndrome (PDS). Compared to controls, patients with EPS had higher strain values during fasting, while patients with PDS had lower strain values. Postprandially, EPS patients had higher strain values compared to both PDS and controls [41]. Kamino et al. suggested that FD patients showing alleviation of symptoms had improved gastric motility [31], while van Lelyveld et al. found a lack of relationship between chronic upper abdominal symptoms and altered gastric motility [64].

Several studies were performed on FD patients for the assessment of drug influence on GE, as mentioned above [33-38]. The evaluated drugs, except ondansetron, improved GE. A study performed by Dumitrascu et al. in 1998, for evaluating the efficacy of metoclopramide in 25 FD patients, also showed that metoclopramide accelerated antral emptying and improved the symptom score [65].

Based on all these findings, it seems that abdominal ultrasound may play a role in the evaluation of GE in patients with FD. However, due to the heterogeneity of these studies (different patient inclusion criteria, different study end-points, different ultrasound parameters used for the assessment of GE), a firm conclusion regarding the role of GE in this population could not be reached. Still, abdominal ultrasound proved a viable diagnostic tool for evaluating treatment efficacy in FD patients.

Ultrasound studies assessing GE in patients with diabetes mellitus

Gastrointestinal symptoms are frequently reported in diabetic patients [42]. Delayed GE has been identified in 30-50% of patients with type 1 and 2 diabetes mellitus and is associated with upper gastrointestinal symptoms [66].

Only one study conducted in patients with type 2 diabetes with a long disease duration identified delayed GE in 48.5% of patients. In this study, ultrasound demonstrated a prolonged proximal and distal GE T50, larger antral area, lower GER and fewer antral contractions in diabetic patients [45]. Stevens et al. found that in Chinese diabetic patients with gastroparesis, GE T50 for glucose with water assessed by 3D ultrasound and 2D ultrasound was comparable to GE T50 evaluated by scintigraphy (98.8 ± 10.4 min vs. 103.3 ± 10.0 min, p=0.60; 80.7 ± 11.4 min vs. 103.3 ± 10.0 min, p=0.11). They found a significant correlation between the scintigraphic GE T50 and

3D ultrasonographic GE T50 (r = 0.67, p=0.03) [67]. Similar results regarding the good correlation between GE evaluated by scintigraphy and GE assessed by 2D ultrasound (in diabetic patients, using a semi-solid meal) were previously reported (r = 0.94; p<0.001) [68].

Hlebowicz et al. demonstrated in 10 insulin-dependent diabetic patients with gastroparesis that vinegar might worsen glycemic control in patents with type 1 diabetes [69].

According to these studies, abdominal ultrasound is a useful diagnostic tool for the diagnosis of delayed GE in patients with diabetes mellitus.

Ultrasound studies assessing GE in other disorders

Symptoms such as nausea, vomiting, early satiety and postprandial bloating are frequently seen in scleroderma patients justifying gastric motility assessment in these patients. Two studies conducted in scleroderma patients with more than 5 years disease duration found impaired motility in more than half of them. In scleroderma patients with high dyspepsia scores, delayed GE was found in about two thirds of the patients. In addition, scleroderma patients exhibited a restrictive pattern identified by a reduced fasting antral area, when compared with healthy controls [47, 48]. There are no data about gastric motility in the early stage of this disease.

Another disorder that associates gastrointestinal tract dysmotility is Parkinson's disease. Previous data showed that gastric motility was impaired in this population of patients [70]. Similar results were also reported by Fasano et al. [49].

In patients with asthma, symptoms of gastroesophageal reflux are frequently present [71]. However, there is a lack of data on gastric motility in asthma patients. Prior studies reported contradictory results. One study that used scintigraphy for GE evaluation showed that asthma patients had normal gastric motility [72], while the radionuclide study of Botts et al. demonstrated delayed GE in 2 of 6 patients [73]. Using abdominal ultrasound, Amarasiri et al. showed that asthma patients with reflux symptoms had delayed GE and antral hypomotility resulting from a hypervagal response [52].

The presence of delayed GE was also demonstrated in patients with gastroesophageal reflux disease and metabolic syndrome (low GER) [50], results that are consistent with previous data [74]. It was also shown that in adults with obesity, the major component of the metabolic syndrome, GE was delayed, the process being age-related [51]. Gastric emptying was accelerated in frail patients when compared to younger adults [53].

Ultrasound GE was also studied in patients with liver cirrhosis. The authors conducted several studies in this field showing that GE after a solid-liquid meal was delayed in cirrhotic patients [75], whereas GE of low calorie liquid meal was accelerated in patients with liver cirrhosis without portal hypertensive gastropathy [76].

Gastric emptying in obstetrics

In pregnant women, due to increased intraabdominal pressure, changes in progesterone levels and presence of labor pain, GE might be delayed [77]. There is a scarcity of data on GE in pregnant women published before 2007. One paper (2002) demonstrated that GE was not delayed after ingestion of 300 ml water in non-obese, non-laboring pregnant women [78]. Similar results were reported by Wong et al. (2007) for obese, at term, non-laboring pregnant women [55].

Two other papers included in this review showed that GE was not influenced by epidural anesthesia [54, 56]. However, since these studies included only a small number (24) of patients, firm recommendations about fasting prior to epidural anesthesia cannot be made.

Despite the current limited data on ultrasound GE evaluation in pregnant women, the method remains a valuable tool for the study of gastric motility and for the assessment of the pulmonary aspiration risk during labor.

Current role of abdominal ultrasound for GE evaluation

Compared with the "gold standard" scintigraphy for GE evaluation, ultrasound is a reliable, inexpensive, widely available, radiation-free diagnostic method. Current data support its use for evaluating GE of liquid meals in healthy volunteers, patients with type 1 and type 2 diabetes, and FD patients [5]. The main disadvantages of ultrasonography are its operator-dependent nature, the lack of evidence for GE evaluation of solid meals, and the difficulties in evaluating certain populations of patients, such as obese patients, patients with air in the stomach or with gastric resection / atypical anatomy of the stomach [5]. Despite these limitations, recent data supports the use of abdominal ultrasound in the evaluation of the preoperative aspiration risk. Current evidence also recommends its use in patients with dyspepsia, in order to identify patients who potentially could benefit from prokinetic agents.

The major limitation of the present review is that its main conclusions were drawn based on studies evaluating very heterogeneous populations. The different inclusion criteria, characteristics of the populations studied, study types (e.g. comparative/non-comparative/randomized), ultrasound methods used, different test meals (liquid, semi-solid and solid), different ultrasound parameters assessed (GER, GE T50 of proximal and distal stomach, antral and proximal CSA) made statistical analysis of the data impossible.

Another limitation is the fact that it did not include studies performed in children, due to the lack of a consensus with regard to scintigraphy being the "gold" diagnostic test for the evaluation of gastric motility in this population.

CONCLUSION

Functional ultrasonography is a non-invasive method used for research or practical purposes, that brings insight into gastric emptying in healthy individuals, in functional disorders and in motility disorders of the gastrointestinal tract.

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