Digestive Diseases and Sciences, Vol. 50, No. 9 (September 2005), pp. 1654–1660 (© 2005)
DOI: 10.1007/s10620-005-2911-3

Relationships Between Gastric Accommodation and Gastrointestinal Sensations in Healthy Volunteers. A Study Using the Barostat Technique and Two- and Three-Dimensional Ultrasonography

M. W. MUNDT, MD,* T. HAUSKEN, MD, PhD,† A. J. P. M. SMOUT, MD, PhD,* and M. SAMSOM, MD, PhD*

The origin of postprandial gastrointestinal sensations and their relation to gastric accommodation remain unclear. Our aim was to investigate the relation between antral and fundal accommodation and sensations. (A) In eight healthy volunteers fundus accommodation was measured using a barostat after a 200-ml (300-kcal) liquid nutrient. Antral area (AA) was measured using ultrasound. Data on bag volumes, AA, and sensations were assessed. (B) In another eigth healthy volunteers gastric volume was measured after a 500-ml (300-kcal) liquid nutrient using 2-D/3-D ultrasound. Sensations were scored using VAS. Distal and proximal volumes were calculated from 3-D datasets. (A) Fullness was correlated with AA ($r = 0.48$, $P = 0.002$). Fullness and bag volume were not correlated. (B) Fullness was correlated with AA ($r = 0.77$, $P < 0.001$) and distal volume ($r = 0.75$, $P < 0.001$). Proximal volume was not correlated with fullness ($r = 0.10$, $P =$ NS). We conclude that fullness is related to antral volume and area rather than proximal volume. The gastric antrum may play a key role in normal appetite regulation.

KEY WORDS: three-dimensional ultrasonography; gastric volume; barostat; gastric accommodation.

Regulation of satiety and induction of upper gastrointestinal sensations are still poorly understood. Several studies have demonstrated the involvement of chemo- and mechanoreceptors at the level of the duodenum and stomach in producing upper gastrointestinal sensations (1–4). The site at which this gastric distension occurs may also play an important role (5, 6). In the physiological state the proximal stomach accommodates after meal ingestion. Gastric accommodation can be described as a reduction in gastric tone and increase in compliance. This physiological response makes it possible for solids or liquids to be ingested without a significant rise in gastric pressure. Abnormal postprandial proximal gastric accommodation has been reported in several studies. Most studies that have investigated gastric accommodation have made use of the barostat technique to quantify the increase in volume of the proximal stomach after meal ingestion in conditions (7–10) such as functional dyspepsia (11) and diabetes mellitus (8, 12). Reduced proximal gastric accommodation has been reported to be related to symptoms such as early satiety and weight loss (11), although other studies have not confirmed this relation (13). However,

Manuscript received December 15, 2003; accepted May 3, 2004.

From the *Gastrointestinal Research Unit, Departments of Gastroenterology and Surgery, University Medical Center, Utrecht, The Netherlands, and †Division of Gastroenterology, Medical Department, University of Bergen, Bergen, Norway.

Address for reprint requests: Melvin Samsom, MD, PhD, Gastrointestinal Research Unit, Department of Gastroenterology and Hepatology, University Medical Center Utrecht, P.O. Box 85500, 3508 GA Utrecht, The Netherlands; m.samsom@umcutrecht.nl.

other relevant postprandial upper gastrointestinal sensations such as nausea, fullness, and pain were found not to be related to proximal gastric dysaccommodation, underlining that the pathogenesis of these symptoms is not yet established.

Recently we reported that the presence of a barostatic bag induces an increase in antral area (AA) and proximal gastric volume, demonstrating that the intragastric bag influences the magnitude of the accommodation response after meal ingestion (14). These observations and the fact that the barostat technique does not allow quantification of the distal gastric accommodation and is unpleasant for the patient led to the development of less invasive techniques to asses change in gastric volume as a reflection of gastric accommodation. These techniques include magnetic resonance imaging (MRI) (15, 16), single-photon-emission computed tomography (SPECT) (17, 18), and two- and three-dimensional ultrasonography (2-D and 3-D US) (19). Several studies showed that 3-D US can be used to accurately estimate volumes of hollow organs including the stomach (20–25). Using 2-D US, impaired proximal gastric accommodation was observed in a large proportion of patients with diabetes mellitus and functional dyspepsia, confirming findings of barostatic studies (12, 26, 27). Recently, several studies demonstrated that both fasting and postprandial antral size are larger in patients with functional dyspepsia than healthy controls (28, 29). Using 3-D US we tested the hypothesis that the gastric antrum plays an important role in generating postprandial sensations. The aim of this study was therefore to investigate gastric accommodation using the barostat, 2-D US, and 3-D US and to assess the relationships between accommodation of the proximal and distal stomach and upper gastrointestinal sensations in healthy volunteers.

MATERIALS AND METHODS

The study consisted of two parts. In total 16 healthy volunteers without gastrointestinal symptoms or previous gastrointestinal surgery or diseases were asked to participate in the study after giving written informed consent. Eight healthy volunteers (five male and three female; mean age, 23; age range, 18–26; mean weight, 69 kg) participated in study A, in which proximal gastric volume changes were measured using the barostat technique and distal gastric volume was studied using 2-D US. Eight other healthy volunteers (three male and five female; mean age, 23; age range, 20–37; mean weight, 63 kg) participated in study B, in which gastric volume changes were studied using 2-D and 3-D US. The protocol was approved by the ethics committee of the University Medical Center Utrecht.

Study A

Experimental Design and Barostat Measurements. In this study proximal gastric volume changes were measured using the barostat technique, and AA changes by 2-D ultrasonography. The studies commenced at 9.00 AM, after an overnight fast. The subjects were placed in bed in a sitting position, leaning slightly backward (at a 110° angle). A polyethylene bag with a maximum capacity of 1000 ml attached to a double-lumen tube (Ventrol; outer diameter, 6 mm; length, 120 cm) was introduced into the proximal stomach transorally and then slowly unfolded by manual inflation of 200 ml of air. Thereafter the bag was completely deflated and connected to the barostat device. After a 15-min rest period minimal distension pressure (MDP) was determined by increasing the pressure in the bag in 1-mm Hg increments. MDP was defined as the lowest pressure level that provided a mean intrabag pressure of 30 ml (8, 12). Thereafter intrabag pressure was set at 1 mm Hg above MDP (MDP + 1) for the remainder of the study. A 15-min equilibration period was followed by a baseline recording of 15 min. After this baseline period subjects were asked to drink 200 ml Nutridrink (1.5 kcal/ml; Nutricia; Zoetermeer, the Netherlands; 12 g protein, 11.6 g fat, and 36.8 g carbohydrates) within 3 min using a straw. Barostatic bag volumes were monitored at MDP + 1 for 60 min after liquid nutrient ingestion. Volume and pressure recordings were stored in a personal computer (sample frequency, 1 Hz). A positive accommodation response was defined as mean postprandial volume minus mean baseline volume >64 ml (11).

Measurement of Antral Area. In study A, AA was measured before bag placement, before liquid nutrient, and at 5, 15, 30, 45, and 60 min after liquid nutrient. Measurement of AA was performed with a standard duplex US scanner (Esaote AUS; Pie Medical; Maastricht, the Netherlands) with a 3.5-MHz curved probe. The AA was measured in a standardized sagittal section in which the antrum, the superior mesenteric vein, and the aorta were visualized simultaneously (30). The AA was outlined between antral contractions and with subjects suspending their breathing in expiration and calculated automatically using the built-in caliper and calculation program of the ultrasound scanner (26, 31, 32) (Figure 1). Data are expressed as square centimeters. All US measurements at each time point were performed twice. The mean of the two measurements was used for further analysis.

Sensations. Directly before each AA measurement the upper gastrointestinal sensations hunger, nausea, fullness, and pain were scored using a 100-mm-long visual analog scale (VAS).

Study B

Experimental Design. Subjects were placed in a comfortable chair leaning slightly backward. First, AA was measured using the same method as in study A. Next, a 3-D US measurement of the total stomach was performed as described below. After this fasting ultrasound scan a 500-ml, 300-kcal liquid nutrient (200 ml Nutridrink [1.5 kcal/ml; 12 g protein, 11.6 g fat, 36.8 g carbohydrate; Nutricia] mixed with 300 ml of water) was ingested within 3 min. At 5, 15, 30, 45, and 60 min after the liquid nutrient, AA and 3-D US measurements were repeated.

Sensations. Sensations were scored as in study A.

Measurements of Gastric Volumes Using 3-D US. A standard ultrasound scanner (Esaote-Pie Medical; Maastricht, the Netherlands) with a 3.5-MHz curved probe with an attached position sensor was used to perform this study. The probe was placed on the abdominal wall and the stomach was localized. With a fluent left-to-right lateral sweeping movement (20, 21, 24, 25), the total stomach was visualized from fundus to pylorus. During

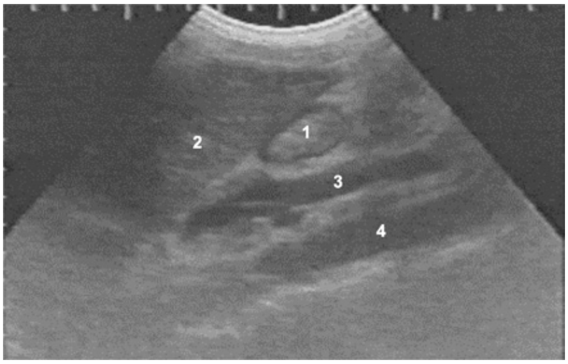

Fig 1. Example of an ultrasonographic measurement of the antral area (1) with the typical landmarks, liver, (2), superior mesenteric vein (3), and aorta (4), visualized in one sagittal plane.

this sweep approximately 400 sagittal images were digitized and stored into the PC using InVivo ScanNT software (MedCom GmbH, Darmstadt, Germany). During all sweeps the position and the orientation of the US probe were recorded continuously by a magnetic tracker system. This system consists of a transmitter generating a pulse magnetic field and a receiver (sensor) attached to the US probe, defining position and orientation in relation to the transmitter. The tracker transmitter was positioned at a maximum distance of 60 cm from the patient.

Using specialized software (InVivo; Medcom GmbH) the computer calculated images of transverse and longitudinal planes on the basis of the information in the sagittal images and the measured position and orientation of the US probe. Regions of interest (ROIs) were then drawn using the original sagittal US images. The ROIs were constructed using the outer profile of the muscularis propria of the gastric wall. After delineation of the gastric wall in the sagittal plane, the computer calculated ROIs in the other two planes and created a 3-D image of the stomach (Figure 2). Using this 3-D reconstruction the total gastric volume was calculated. In addition, partial gastric volumes were calculated. The proximal gastric volume was calculated using a dividing plane 10 cm from the diaphragm downward perpendicular to the longitudinal axis of the stomach. The gastric volume within this 10-cm region represented the proximal part. The distal volume was calculated by constructing a plane perpendicular to the antral axis at the point where the antrum, liver, superior mesenteric vein, and aorta could be seen simultaneously. The gastric volume from this plane to the pylorus represented the distal part. The volumes of the proximal and distal parts were calculated and used for further analysis.

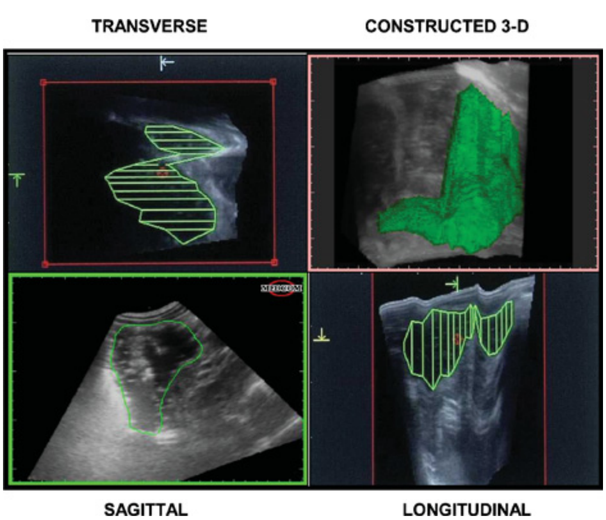

Fig 2. Example of performance of 3-D analysis software with ROIs drawn in the three planes. The lower-left panel shows the original 2-D sagittal sections, whereas the upper-left image demonstrates the transverse plane and the lower-right the longitudinal plane. The upper-right panel shows the constructed 3-D image of the stomach.

Statistical Analysis

Data are presented as mean values ±SE. Barostat and AA variables were compared using a two-sided Student's *t*-test. Relationships between gastrointestinal sensations and volume or area variables were assessed using partial correlation, controlling for subjects. The partial correlations procedure computes partial correlation coefficients that describe the linear relationship between two variables while controlling for the effects of one or more additional variables. This statistical method corrects for intrinsic correlation. Significance was accepted at the 5% level. All statistical analysis was performed with SPSS 10.0 for MS Windows (SPSS Inc.).

RESULTS

All procedures were tolerated well and all volunteers completed the study.

Antral Area and Volume Changes

Study A. MDP in the fasting state was 6.3 ± 0.3 mm Hg. The fasting volume of the barostat bag at MDP + 1 was 99.6 ± 3.9 ml. After the liquid nutrient an increase in intrabag volume of at least 64 ml was observed in all subjects. The mean maximum volume of the intragastric barostat bag was 347 ± 30.7 ml. The maximum volume was reached 30 min after ingestion of the nutrient (Figure 3A). In the fasting state, the AA was not affected by the presence of the intragastric bag at a pressure of MDP + 1 mm Hg (without intragastric bag, 2.8 ± 0.28 cm^2; with intragastric bag, 3.3 ± 0.39 cm^2; $P =$ NS.). Five minutes after nutrient ingestion the AA had increased significantly (3.3 ± 0.39 vs. 9.94 ± 1.53 cm^2; $P = 0.002$). Maximum AA was reached 15 min postprandially (11.09 ± 1.43 cm^2) (Figure 3B).

Study B. Using the 3-D US technique the fasting gastric volume was 35.9 ± 4.1 ml. At 5 min after the liquid nutrient a significant increase in gastric volume was observed (488 ± 6.4; $P < 0.001$). During the postprandial hour a 37% linear decrease in gastric volume (Figure 4) to 336.7 ± 4.1 ml occurred. The mean fasting AA was 3.26 ± 0.41 cm^2, which was comparable to that in study A ($P =$ NS). AA also increased significantly after liquid

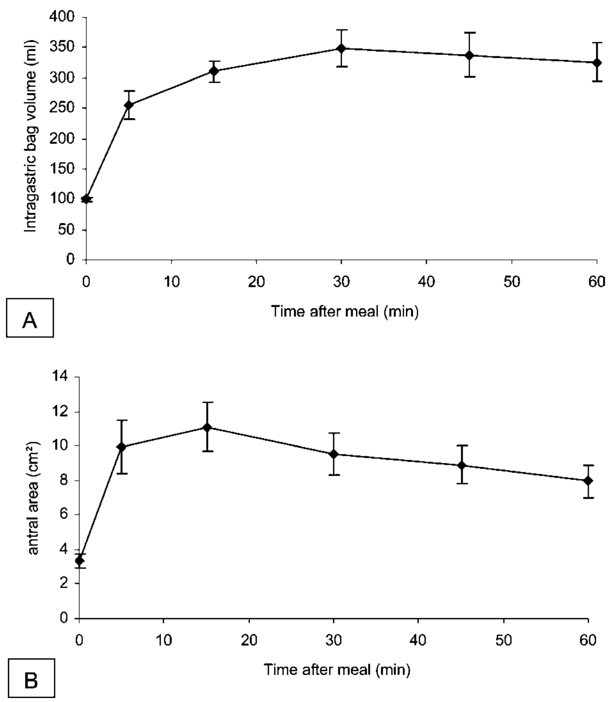

Fig 3. Mean intragastric bag volume as measured by gastric barostat (A) and mean antral area (B) before (time 0) and after administration of a mixed liquid meal. Ingestion of the meal induces a rapid and sustained increase in intragastric bag volume as well as antral area.

nutrient ingestion (3.26 ± 0.47 vs. 13.9 ± 1.37 cm^2; $P < 0.001$). Maximum AA occurred 5 min after the liquid nutrient. Calculated distal volumes changed significantly after the liquid nutrient (2.85 ± 0.42 vs. 24.1 ± 2.0 ml; $P < 0.001$). Proximal gastric volumes could not be measured in the fasted condition.

Gastrointestinal Sensations

Study A. Five minutes after the liquid nutrient a significant increase in sensation fullness (15.4 ± 5.2 vs. 41.3 ± 5.7; $P < 0.001$) was observed as well as a significant decrease in sensation hunger (63.5 ± 6.8 vs. 37.3 ± 8.0; $P = 0.02$) (Figure 5). There were no significant changes in scores for the sensations pain (11.1 ± 7.1 vs. 13.8 ± 7.7; $P =$ NS) and nausea (14.1 ± 8.3 vs. 12.0 ± 6.2; $P =$ NS).

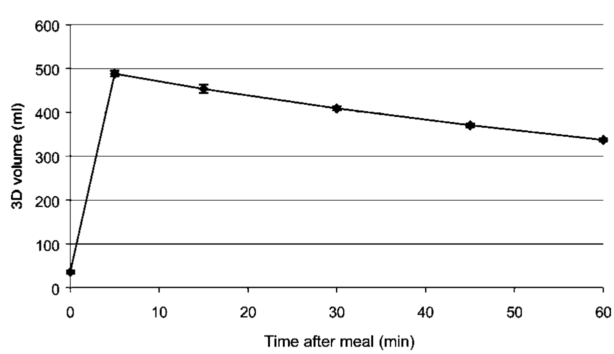

Fig 4. Mean measured gastric volume using the 3-D US technique. A linear decrease can be observed during the first postprandial hour.

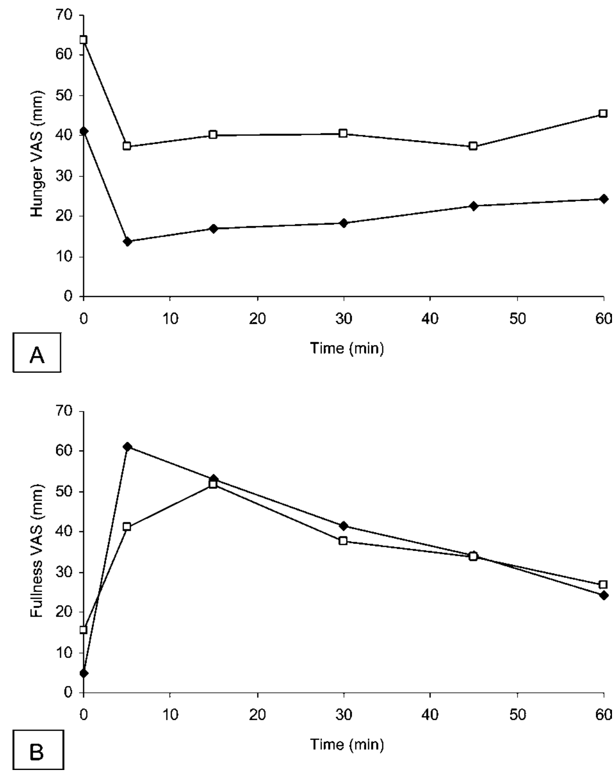

Fig 5. Mean hunger (A) and fullness (B) sensation scores in studies A (squares) and B (diamonds) measured using the VAS. In both studies a significant decrease in hunger and increase in fullness are seen directly after liquid nutrient ingestion.

Study B. Immediately after the liquid nutrient a significant increase in sensation fullness was observed (7.2 ± 3.5 vs. 53 ± 5.1; $P < 0.001$) as well as a decrease in sensation hunger (43.4 ± 8.3 vs. 20 ± 7.2; $P = 0.03$) (Figure 5). No changes were found in the sensations pain (10.2 ± 7.2 vs. 8.8 ± 4.8; $P = NS$) and nausea (0.8 ± 0.49 vs. 1.0 ± 0.42; $P =$ NS).

Relation Among Antral Area, Gastric Volume Data, and Gastrointestinal Sensations

Study A. The increase in AA showed a moderate but significant relation with the increase in sensation fullness after the liquid nutrient ($r = 0.48$, $P = 0.002$). In contrast, a negative, nonsignificant relation was observed between change in barostat bag volumes and change in sensation fullness ($r = -0.21$, $P =$ NS). Other sensations were not related to gastric volume data.

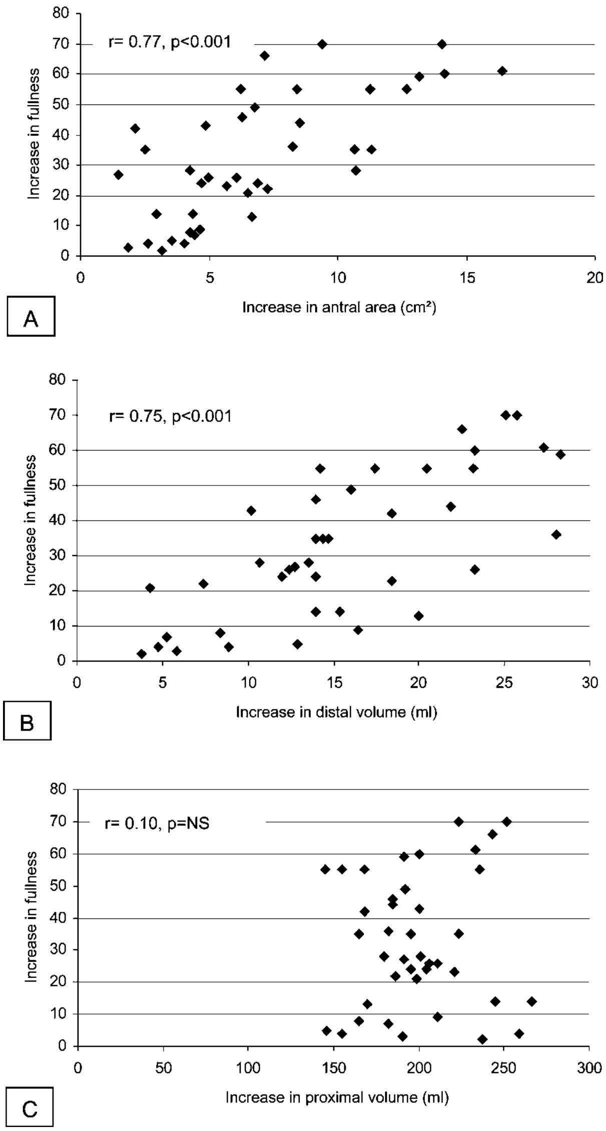

Fig 6. Scatter plots demonstrating the relation between increase in fullness and increase in antral area (A), increase in distal volume (B), and proximal volume (C).

Study B. In this part a relation between increase in AA and distal gastric volume and increase in fullness was observed (0.77, $P < 0.001$, and $r = 0.75$, $P < 0.001$, respectively) (Figure 6A and B). In contrast, increase in fullness was not related to proximal gastric volume ($r = 0.10$, $P =$ NS) (Figure 6C). Pain, hunger, and nausea were not related to AA or gastric volume data.

DISCUSSION

Many studies have focused on the relation between upper gastrointestinal sensations and different aspects of gastric function. Most recent studies investigated this relationship using the barostat technique. In the present study we used three different techniques to measure accommodation responses of the stomach. In study A the barostat technique was used to measure proximal gastric accommodation and 2-D US was used to measure AA, which reflects the volume of the distal stomach. No relation could be demonstrated between changes in barostatic bag volume and the upper gastrointestinal sensations fullness, pain, hunger, and nausea, which is in concordance with findings of others in healthy volunteers and patients with functional dyspepsia (11, 13). On the other hand, AA did show a moderate, but statistically significant correlation with sensation fullness. In study B we solely applied noninvasive 2-D and 3-D US techniques to measure accommodation. Three-dimensional ultrasound has been developed to enhance accuracy in volume estimation (19, 24, 25, 33). With this method not only the total stomach volume can be calculated, but also partial gastric volumes and intragastric distribution of the meal (21). Intragastric air can potentially limit visualization of the gastric outline by ultrasound. However, in our studies, which were carried out with subjects in seated position, air–fluid interfaces were not encountered. This observation is in concordance with the results presented by Gilja *et al.* (27, 34, 35) and encourages the use of 3-D US in studies of the stomach. Future studies should investigate if 3-D US can be used in studies using solid meals. In this study a total gastric volume decrease of 37% within the first postprandial hour was observed. If we equate this volume decrease to gastric emptying, 37% of the liquid nutrient was emptied within this hour. Within the first 5 min after the nutrient mean of 536 (mean fasting volume + meal volume) − 488 (mean volume at 5 min) = 48 ml had emptied from the stomach. This represents an emptying rate of about 6 ml/min. Since the energy density of our liquid nutrient was 0.6 kcal/ml (300 kcal/500 ml), this means an emptying rate of 3.6 kcal/min, which is comparable with findings of Hunt *et al.* (36) during the early gastric emptying phase. The results of our study demonstrate a clear relation between increase in AA and increase in fullness, as was previously demonstrated by Jones *et al.* (37). This relation was stronger in the absence of a barostat bag in the proximal stomach. The most likely explanation for this phenomenon is that the intragastric bag influences the gastric physiology and therefore interferes with sensation rating. Recently we demonstrated that presence of an intragastric bag in the proximal stomach has an effect on both proximal and distal gastric accommodation after a liquid nutrient (14). These observations make clear that the barostat technique is not ideal to measure gastric accommodation.

Since 2-D US only reflects the gastric volumes, we developed a method to measure partial volumes. Proximally we drew a 10-cm downward line to calculate proximal volume. The proximal volume thus obtained did not correlate with any of the scored gastrointestinal sensations. However, the calculated distal volume did show a clear relation with fullness. Although gastric borders were drawn somewhat arbitrarily, the method provides more insight in the functional behavior of different parts of the stomach.

Our findings suggest that the gastric antrum plays an important role in symptom generation and might be involved in physiological appetite regulation. It has already been suggested that antral distention might play a major role in triggering the sensation fullness (37) as our study results confirm. Up to now it is not clear how this mechanism is mediated. It is, however, conceivable that this regulation is modified by multiple factors such as sympatic nerve activity and humoral activity (38–40). Antral distention will stimulate visceral mechanoreceptors. Mechanoreceptors in different regions of the stomach show different patterns of phasic contractile activity. It has been suggested that increased antral activity during antral distention gives rise to gastric discomfort (41, 42).

Future studies using the 3D ultrasound technique are likely to increase an understanding of the pathophysiology of functional gastric disorders, especially functional dyspepsia. Several studies reported a larger AA in a subgroup of patients with functional dyspepsia (28, 43, 43). Those findings taken together with our observations suggest that the gastric antrum plays an important role in symptom generation and might be involved in the impaired relaxation response of the proximal stomach in patients with functional dyspepsia.

In conclusion, this study, using three techniques to measure accommodation, has shown that postprandial fullness is related to antral volume and AA rather than to proximal gastric volume. This suggests that the gastric antrum is more important in functional gastric disorders than hitherto assumed. Our findings imply that the total stomach should be included in studies investigating accommodation and sensations in patients.

ACKNOWLEDGMENT

Dr. M. Samsom is a fellow of the Royal Netherlands Academy of Arts and Sciences.

REFERENCES

1. Horowitz M, Jones K, Edelbroek MA, Smout AJ, Read NW: The effect of posture on gastric emptying and intragastric distribution of oil and aqueous meal components and appetite. Gastroenterology 105:382–390, 1993
2. Greenberg D, Smith GP, Gibbs J: Intraduodenal infusions of fats elicit satiety in sham-feeding rats. Am J Physiol 259:R110–R118, 1990
3. Schwartz MP, Samsom M, Berge Henegouwen GP, Smout AJ: Effect of inhibition of gastric acid secretion on antropyloroduodenal motor activity and duodenal acid hypersensitivity in functional dyspepsia. Aliment Pharmacol Ther 15:1921–1928, 2001
4. Schwartz MP, Samsom M, Smout AJ: Chemospecific alterations in duodenal perception and motor response in functional dyspepsia. Am J Gastroenterol 96:2596–2602, 2001
5. Caldarella MP, Azpiroz F, Malagelada JR: Antro-fundic dysfunctions in functional dyspepsia. Gastroenterology 124:1220–1229, 2003
6. Houghton AD, Liepins P, Clarke S, Mason R: Role of the antrum in the gastric emptying of a non-nutrient liquid in the rat. Scand J Gastroenterol 27:748–752, 1992
7. Azpiroz F, Malagelada JR: Gastric tone measured by an electronic barostat in health and postsurgical gastroparesis. Gastroenterology 92:934–943, 1987
8. Samsom M, Salet GA, Roelofs JM, Akkermans LM, Vanberge-Henegouwen GP, Smout AJ: Compliance of the proximal stomach and dyspeptic symptoms in patients with type I diabetes mellitus. Dig Dis Sci 40:2037–2042, 1995
9. Thumshirn M, Camilleri M, Hanson RB, Williams DE, Schei AJ, Kammer PP: Gastric mechanosensory and lower esophageal sphincter function in rumination syndrome. Am J Physiol 275:G314–G321, 1998
10. Wijnhoven BP, Salet GA, Roelofs JM, Smout AJ, Akkermans LM, Gooszen HG: Function of the proximal stomach after Nissen fundoplication. Br J Surg 85:267–271, 1998
11. Tack J, Piessevaux H, Coulie B, Caenepeel P, Janssens J: Role of impaired gastric accommodation to a meal in functional dyspepsia. Gastroenterology 115:1346–1352, 1998
12. Undeland KA, Hausken T, Aanderud S, Berstad A: Lower postprandial gastric volume response in diabetic patients with vagal neuropathy. Neurogastroenterol Motil 9:19–24, 1997
13. Boeckxstaens GE, Hirsch DP, Kuiken SD, Heisterkamp SH, Tytgat GN: The proximal stomach and postprandial symptoms in functional dyspeptics. Am J Gastroenterol 97:40–48, 2002
14. Mundt MW, Hausken T, Samsom M: Effect of intragastric barostat bag on proximal and distal gastric accommodation in response to liquid meal. Am J Physiol Gastrointest Liver Physiol 283:G681–G686, 2002
15. Marciani L, Gowland PA, Spiller RC, Manoj P, Moore RJ, Young P, Fillery-Travis AJ: Effect of meal viscosity and nutrients on satiety, intragastric dilution, and emptying assessed by MRI. Am J Physiol Gastrointest Liver Physiol 280:G1227–G1233, 2001
16. Schwizer W, Maecke H, Fried M: Measurement of gastric emptying by magnetic resonance imaging in humans. Gastroenterology 103:369–376, 1992
17. Kim DY, Delgado-Aros S, Camilleri M, *et al.*: Noninvasive measurement of gastric accommodation in patients with idiopathic nonulcer dyspepsia. Am J Gastroenterol 96:3099–3105, 2001
18. Kuiken SD, Samsom M, Camilleri M, Mullan BP, Burton DD, Kost LJ, Hardyman TJ, Brinkmann BH, O'Connor MK: Development of a test to measure gastric accommodation in humans. Am J Physiol 277:G1217–G1221, 1999
19. Gilja OH, Hausken T, Odegaard S, Berstad A: Three-dimensional ultrasonography of the gastric antrum in patients with functional dyspepsia. Scand J Gastroenterol 31:847–855, 1996

20. Gilja OH, Hausken T, Berstad A, Odegaard S: Measurements of organ volume by ultrasonography. Proc Inst Mech Eng [H] 213:247–259, 1999
21. Tefera S, Gilja OH, Olafsdottir E, Hausken T, Hatlebakk JG, Berstad A: Intragastric maldistribution of a liquid meal in patients with reflux oesophagitis assessed by three dimensional ultrasonography. Gut 50:153–158, 2002
22. Gilja OH, Hausken T, Olafsson S, Matre K, Odegaard S: In vitro evaluation of three-dimensional ultrasonography based on magnetic scanhead tracking. Ultrasound Med Biol 24:1161–1167, 1998
23. Hausken T, Sondenaa K, Svebak S, Gilja OH, Olafsson S, Odegaard S, Soreide O, Berstad A: Common pathogenetic mechanisms in symptomatic, uncomplicated gallstone disease and functional dyspepsia: volume measurement of gallbladder and antrum using three-dimensional ultrasonography. Dig Dis Sci 42:2505–2512, 1997
24. Gilja OH, Smievoll AI, Thune N, Matre K, Hausken T, Odegaard S, Berstad A: In vivo comparison of 3D ultrasonography and magnetic resonance imaging in volume estimation of human kidneys. Ultrasound Med Biol 21:25–32, 1995
25. Gilja OH, Thune N, Matre K, Hausken T, Odegaard S, Berstad A: In vitro evaluation of three-dimensional ultrasonography in volume estimation of abdominal organs. Ultrasound Med Biol 20:157–165, 1994
26. Undeland KA, Hausken T, Gilja OH, Aanderud S, Berstad A: Gastric meal accommodation studied by ultrasound in diabetes. Relation to vagal tone. Scand J Gastroenterol 33:236–241, 1998
27. Gilja OH, Hausken T, Wilhelmsen I, Berstad A: Impaired accommodation of proximal stomach to a meal in functional dyspepsia. Dig Dis Sci 41:689–696, 1996
28. Hausken T, Berstad A: Wide gastric antrum in patients with non-ulcer dyspepsia. Effect of cisapride. Scand J Gastroenterol 27:427–432, 1992
29. Ricci R, Bontempo I, La Bella A, De Tschudy A, Corazziari E: Dyspeptic symptoms and gastric antrum distension. A ultrasonographic study. Ital J Gastroenterol 19:215–217, 1987
30. Bolondi L, Bortolotti M, Santi V, Calletti T, Gaiani S, Labo G: Measurement of gastric emptying time by real-time ultrasonography. Gastroenterology 89:752–759, 1985
31. Hveem K, Hausken T, Berstad A: Ultrasonographic assessment of fasting liquid content in the human stomach. Scand J Gastroenterol 29:786–789, 1994
32. Hveem K, Jones KL, Chatterton BE, Horowitz M: Scintigraphic measurement of gastric emptying and ultrasonographic assessment of antral area: relation to appetite. Gut 38:816–821, 1996
33. Berstad A, Hausken T, Gilja OH, Thune N, Matre K, Odegaard S: Volume measurements of gastric antrum by 3-D ultrasonography and flow measurements through the pylorus by duplex technique. Dig Dis Sci 39:97S–100S, 1994
34. Gilja OH, Hausken T, Bang CJ, Berstad A: Effect of glyceryl trinitrate on gastric accommodation and symptoms in functional dyspepsia. Dig Dis Sci 42:2124–2131, 1997
35. Gilja OH, Hausken T, Odegaard S, Berstad A: Monitoring postprandial size of the proximal stomach by ultrasonography. J Ultrasound Med 14:81–89, 1995
36. Hunt JN, Stubbs DF: The volume and energy content of meals as determinants of gastric emptying. J Physiol 245:209–225, 1975
37. Jones KL, Doran SM, Hveem K, Bartholomeusz FD, Morley JE, Sun WM, Chatterton BE, Horowitz M: Relation between postprandial satiation and antral area in normal subjects. Am J Clin Nutr 66:127–132, 1997
38. Hebbard GS, Samsom M, Sun WM, Dent J, Horowitz M: Hyperglycemia affects proximal gastric motor and sensory function during small intestinal triglyceride infusion. Am J Physiol 271:G814-G819, 1996
39. Iovino P, Azpiroz F, Domingo E, Malagelada JR: The sympathetic nervous system modulates perception and reflex responses to gut distention in humans. Gastroenterology 108:680-686, 1995
40. Paintal AS: A study of gastric stretch receptors; their role in the peripheral mechanism of satiation of hunger and thirst. J Physiol 126:255-270, 1954
41. Andrews PL, Grundy D, Scratcherd T: Vagal afferent discharge from mechanoreceptors in different regions of the ferret stomach. J Physiol 298:513–524, 1980
42. Davison JS, Grundy D: Distribution of gastrointestinal mechanoreceptors mediating excitation or inhibition of vagal efferent activity in the rat [Proceedings]. J Physiol 280:46P–47P, 1978
43. Ricci R, Bontempo I, Corazziari E, La Bella A, Torsoli A: Real time ultrasonography of the gastric antrum. Gut 34:173–176, 1993