Gastric accommodation and motility are influenced by the barostat device: assessment with magnetic resonance imaging

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Gastric accommodation and motility are influenced by the barostat device: assessment with magnetic resonance imaging. The procedure is invasive because it involves the introduction of an intragastric catheter and bag and is not always well tolerated. Moreover, the barostat bag may influence motility. Nowadays magnetic resonance imaging (MRI) is able to measure several aspects of gastric motility noninvasively. To evaluate whether the accommodation response of the stomach, observed with the barostat, is present during MRI and whether the barostat interferes with gastric physiology, gastric accommodation, motility, and emptying were studied twice in 14 healthy subjects with MRI using three-dimensional volume scans and two-dimensional dynamic scans once in the presence of a barostat bag and once when the barostat bag was not present. Fasting and postprandial intragastric volumes were significantly higher in the experiment with barostat vs. without barostat (fasting: 350 ± 123 ml vs. 37 ± 21 ml, P < 0.0001; postprandial: 852 ± 126 ml vs. 361 ± 62 ml, P < 0.0001). No significant differences were found in gastric emptying (88 ± 41 vs. 97 ± 40 ml/h, not significant) and contraction frequency between both experiments. The accommodation response observed in the presence of the barostat bag was not observed in the absence of the barostat bag. In conclusion, the presence of an intragastric barostat bag does not interfere with gastric emptying or motility, but the accommodation response measured with the barostat in situ is not observed without the barostat bag in situ. Gastric accommodation is a nonphysiological barostat-induced phenomenon.

gastric motility; meal accommodation; gastric emptying; single photon emission computed tomography; ultrasound

ASSESSMENT OF GASTRIC MOTILITY AND gastric emptying is important for the diagnosis of gastric motor disorders, such as gastroparesis, functional dyspepsia, and postsurgical conditions (19, 20, 26, 27). These disorders are characterized by changes in gastric motor function that may vary from antral hyper- or hypomotility, impaired postprandial accommodation, or changes in pyloric tone, to alteration in coordination of antroduodenal motility. Recognition of these characteristics may contribute to a better understanding of the various gastric motor disorders.

Several techniques are currently applied to study gastric motility but they measure or evaluate only one of the various aspects. The barostat technique is used to study proximal gastric sensory and motor function, including gastric accommodation (20, 27). Accommodation is considered to be a vagal mediated reflex that occurs postprandially resulting in a reduction of tone, providing a reservoir for the meal (7). Impaired gastric accommodation is present in a considerable subset of patients with functional dyspepsia or following surgery (16, 24). Disadvantages of the barostat technique are the time-consuming procedure and the invasive nature requiring oral intubation with intragastric positioning of a polyethylene bag (27). Questions have been raised about interference of the barostat with gastric physiology (11, 14, 18).

In recent years, magnetic resonance imaging (MRI) has been used to investigate gastric motility and emptying (3, 9, 10, 15, 17, 28). Feinle et al. (9) validated MRI as a tool for the analysis of gastric emptying. A major advantage of MRI is that several aspects of gastric motility such as contractions and emptying can be measured simultaneously. In a recent publication, our laboratory (8) compared MRI with the barostat for the evaluation of proximal gastric motility during simultaneous recording. Evidence was provided that MRI is as accurate as barostat measurements in determining changes in gastric volume and gastric contractions in response to glucagon (known to relax the stomach) and erythromycin (known to contract the stomach). Previously, Bouras et al. (4) compared single photon emission computed tomography (SPECT) with the barostat for concurrent validity, and more recently Simonian et al. (22) described a new technique using SPECT to simultaneously measure gastric volumes and gastric emptying.

The present study was undertaken to evaluate whether 1) an accommodation response observed in the presence of a barostat bag is also present during MRI when the barostat bag is not present and 2) the barostat interferes with gastric physiology. These questions were addressed by simultaneous MRI + barostat recording vs. MRI alone in response to meal ingestion in the same group of volunteers.

MATERIALS AND METHODS

Subjects. Fourteen healthy volunteers (8 women, 6 men; mean age 23 ± 5 y; body mass index 23.0 ± 1.2 kg/m²) participated in the study. None of the volunteers had a history of gastrointestinal disease or abdominal surgery and none were using any medication. The medical ethics committee of the Leiden University Medical Center had approved the protocol of the study, and written, informed consent was obtained from each subject.

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**Gastric barostat.** An electronic barostat (Visceral Stimulator, Medtronic, Skovlunde, Denmark) was used to distend the stomach. A polyethylene bag (1,000 ml maximum capacity) was connected to the end of a multilumen catheter (16 Fr). Since the barostat device had to be placed outside the MRI investigation room, the multilumen catheter was elongated with a 3-m-long catheter (16 Fr). In a previous publication (8), our laboratory has shown that elongation of the multilumen catheter does not influence minimal distending pressure (MDP), nor does it influence intragastric bag volume; however, elongation does result in a delay of 5 s in reaching maximum bag volume. The barostat device keeps the pressure in the intragastric bag at a preselected level. This means that the system injects air into the bag when the stomach relaxes and aspirates air when the stomach contracts (1). Maximal air flow was 20 ml/s.

Pressure (mmHg), volume (ml), and compliance (ml/mmHg) were constantly monitored, recorded, and analyzed on a personal computer connected to the barostat (Polygram for Windows, SVS module, Medtronic).

**MRI.** The subjects underwent 1.5-T MRI (ACS-NT; Philips Medical Systems, Best, The Netherlands) using a multi-receive parallel body-synergy-coil. The protocol consisted of two acquisitions: three-dimensional volume MRI (20 slices with a transverse orientation, turbo field echo, echo time 3.5 ms, repetition time = 10 ms, field of view 450 mm, rectangular field of view 55%, symmetric reduction 50%, flip angle 25°, 256 × 256 pixels, slice thickness 10 mm, total scan duration 30 s) was performed to determine the momentary gastric volume. To assess dynamic activity of the stomach, two-dimensional dynamic MRI (semicoronal slice orientation, turbo field echo, 300 images per scan, temporal resolution 1 s, echo time = 3.6 ms, repetition time = 10 ms, field of view 450 mm, rectangular field of view 55%, symmetric reduction 50%, flip angle 25°, 256 × 128 pixels, slice thickness 10 mm) was performed. Both acquisitions were performed during free breathing. These MRI techniques have been used and validated previously (8, 9, 15).

**Study design.** Each subject participated in two experiments performed on separate days in random order with an interval of at least 7 days. Each experiment started at 8:30 AM after a fast of at least 10 h. The catheter with bag was introduced through the mouth and positioned in the fundus of the stomach as described previously (8). Correct position was checked by fluoroscopy. Subjects underwent MRI in a right-sided semisupine position (30°). In one of two experiments a barostat bag was present and MRI and barostat recording were performed simultaneously, whereas in the other experiment a barostat bag was not present and only MRI was performed.

In the combined experiment the barostat catheter with bag was introduced through the mouth and positioned in the fundus of the stomach. Correct positioning was checked with fluoroscopy. To unfold the bag, air (300 ml) was manually inflated with controlled pressure (<20 mmHg), and the catheter was pulled back carefully until its passage was restricted by the lower esophageal sphincter. Then the catheter was introduced 2 cm further. Thereafter, the bag was deflated and connected to the barostat device. MDP, the pressure needed to overcome the intra-abdominal pressure, was determined. MDP is arbitrarily defined as the first pressure level that provides an intragastric bag volume of more than 30 ml and is determined by increasing the intrabag pressure in 1 mmHg steps every minute. Thereafter, the barostat was set to maintain a pressure of 2 mmHg above MDP throughout the experiment.

Three-dimensional volume MRI and two-dimensional dynamic MRI were obtained before and at regular intervals (15 min) after ingestion of a 200-ml (300 kcal, 12.5 g protein, 40.4 g carbohydrate, 9.84 g fat) liquid meal (Ensure Plus, Abbott). The liquid meal was labeled with meglumine gadoterate (Dotarem, Laboratoire Guerbet, Roissy, France) for contrast enhancement. Hereafter the mixture of the meal and gastric secretions will be referred to as “gastric contents.” Total duration of each experiment was 110 min (Fig. 1).

Data analysis. Volumes measured with the barostat are given as average values over 30-s periods. In all volume images, the stomach was outlined manually by one observer (I. M. de Zwart). Volumes were obtained by adding the calculated surfaces of all outlined areas multiplied by the slice thickness using the MASS software package (Medis, Leiden University Medical Center, Leiden, The Netherlands).

The following volumes were analyzed: 1) total gastric volume, defined in the experiment without the barostat bag in situ as volume of gastric contents + volume of air; in the experiment with the barostat bag in situ, total gastric volume was defined as volume of gastric contents + volume of air + barostat volume; 2) volume of gastric contents, defined as the volume of the gadolinium-labeled meal plus gastric secretions; 3) total volume of air, defined as the total amount of air inside the stomach; 4) barostat volume, defined as the volume of air inside the barostat bag, measured by the barostat device; and 5) free air volume, defined as total amount of air minus barostat bag volume of air. Gastric emptying rate was defined as the decrease in gastric content volume (ml) over time (min). To obtain gastric motility parameters, gastric diameters were calculated at 10 equally distributed points perpendicular to the stomach axis. On the basis of this diameter calculation, peristaltic contractions were detected and their frequency was calculated (8, 9, 15). By color coding the 10 diameter lines, the peristaltic contraction pattern was visualized in a graph.

**Statistical analysis.** Data were analyzed using a statistical software package (SPSS for Windows release 12.0.1, SPSS, Chicago, IL). All data are given as means ± SD. A linear mixed-model analysis and a paired-samples t-test were used to detect differences in data between the experiments. For linear mixed-model analysis, data were analyzed in the model by using a fixed time and intervention effect. The level of significance was set at P < 0.05.

**RESULTS**

**Example.** A typical example of the images obtained during the experiments is given in Fig. 2. This figure shows images of the stomach of one of the subjects with (c and d) and without (a and b) the barostat bag in situ. The gastric contents are white, owing to the presence of the paramagnetic contrast agent in the meal, whereas air, both inside and outside the barostat bag, is black. The barostat bag itself could not be visualized.

**Gastric emptying.** Gastric emptying with and without the barostat bag in situ is shown in Fig. 3. The volume of gastric contents measured 15 min after ingestion of the meal was significantly smaller for the experiment with the barostat bag compared with the experiment without the barostat bag (225 ± 46 ml vs. 266 ± 34 ml; P < 0.02). This difference in volume of gastric contents remained significant throughout the study (Fig. 3). However, the rate of gastric emptying from 15 to 90 min was not significantly different between the two experi-
Gastric volume. The influence of the barostat bag on total gastric volume and gastric contents is shown in Fig. 4. Ingestion of the meal caused a significant ($P < 0.0001$) increase over basal in total gastric volume in both experiments (Fig. 4). Total gastric volume was significantly ($P < 0.0001$) larger in the experiment with the barostat bag (Fig. 4A) compared with the experiment without the barostat bag (Fig. 4B), both before meal ingestion (350 ± 132 ml vs. 37 ± 21 ml, $P < 0.0001$) and immediately after meal ingestion (852 ± 126 ml vs. 361 ± 62 ml, $P < 0.0001$). These differences remained significant throughout the experiment.

In addition to the significant difference in total stomach volume between the two experiments, we also noticed a difference in the rate at which total stomach volume decreased during the experiments. During the experiment with the barostat bag in situ, a significant ($P < 0.0001$) difference was shown between the rate at which the total stomach volume decreased vs. the decrease in volume of gastric contents (Fig. 4A). Such a difference was not observed during the experiment without the barostat bag (Fig. 4B; $P = 0.15$).

Gastric air volume. In the experiment with the barostat bag in situ, the total air volume (= total gastric volume minus volume of gastric contents) increased significantly ($P < 0.01$) over basal (time 0 min) from 15 to 45 min after meal ingestion (Fig. 5A). However, in the experiment without the barostat bag, total air volume did not change significantly after meal ingestion (Fig. 5B). Total gastric volume during the experiment with the barostat bag in situ consisted of free air, that is air outside...
Fig. 4. Total gastric volume and volume of gastric contents (mean ± SD) before and after meal ingestion in 14 healthy subjects with barostat bag (at MDP + 2 mmHg) in situ (A) and without barostat bag (B). A: *P < 0.0001, total volume vs. volume of gastric contents and for rate of volume decrease. B: *P < 0.0001, total volume vs. volume of gastric contents.

Fig. 5. Volumes of air (mean ± SD) before and after meal ingestion in 14 healthy subjects with barostat bag in situ (A, C, D) and without barostat bag (B). A: total air volume (MRI); *P < 0.01 over time 0 min. B: total air volume, from experiment without barostat bag. C: volume of barostat bag (barostat); *P < 0.05 over time 0 min. D: free air volume: total air volume minus volume of barostat bag.
the barostat bag, and air inside the barostat bag, that is barostat bag volume (Fig. 5, C and D). An increase in free air volume during the experiment was not observed, although the volume of free air was significantly ($P < 0.05$) higher compared with the total air volume in the experiment without the barostat bag (Fig. 5, D and B, respectively).

**Gastric accommodation.** Barostat bag volume increased significantly ($P < 0.05$) at 15 and 30 min after administration of the liquid meal. This “accommodation” did not result from an increase in meal or free air volume. No change in gastric air volume was observed in the experiment with barostat, indicating that the accommodation measured with the barostat technique is a phenomenon that could not be observed when the barostat bag was not present.

**Contractions.** The barostat bag influences the contraction pattern. A typical example of the contraction pattern before (a) and after introduction of the barostat bag (b) is shown in Fig. 6. We observed that the peristaltic contraction pattern became irregular with the barostat bag in situ. However, contraction frequency (Fig. 7) before ingestion of the meal was similar in the experiments with and without the barostat bag (14.4 ± 0.7 and 14.6 ± 0.8 per 5 min, respectively). After ingestion of the meal, the number of contractions was 13.6 ± 1.0 per 5 min with the barostat bag in situ and 14.1 ± 1.7 per 5 min without the barostat bag (NS). At the end of the experiment, that is 90 min after meal ingestion, the number of contractions was 15.2 ± 1.7 per 5 min with and 14.9 ± 1.1 per 5 min without the barostat bag (NS).

**DISCUSSION**

The barostat has become the gold standard for the evaluation of proximal gastric motility (20, 23). Recent studies employing the barostat technique indicate that gastric accommodation is impaired in a subset of patients with functional dyspepsia who have early satiety as predominant symptom (2, 21, 24). It should, however, be noted that the barostat technique is invasive and it is not clear whether the barostat bag itself affects gastric motility and emptying. We have shown that the emptying rate of the meal was not affected by the distended barostat bag. However, we observed significant differences in postprandial gastric content volumes. In the presence of a barostat bag, gastric content volume, that is meal + gastric secretion, was significantly smaller compared with the experiment without the barostat bag. The reason for this difference in gastric content volume between the two experiments is not apparent. The meal was of identical volume and composition in both experiments. Because the difference occurred immediately after meal ingestion and did not change during the remaining experiment, it may be related to differences in gastric secretion. Gastric acid secretion may be impaired in the presence of a barostat bag owing to a smaller secretory area exposed to nutrients.

Although gastric emptying was not influenced in the presence of an intragastric barostat bag, total gastric volume and gastric accommodation to the meal were affected, and although the frequency of gastric contractions was not influenced by the barostat bag, the activity of contractions was converted from a regular pattern to a more irregular pattern (Fig. 6).

The barostat has the unique ability to evaluate gastric accommodation: a vagally mediated reflex relaxation of the stomach wall in response to a meal (7). To be able to measure gastric accommodation, the pressure in the barostat bag is set at a preselected distending pressure level. By applying this distending pressure level, the barostat bag is able to detect changes in gastric tone as increments or decrements in gastric volume. The increase in total gastric volume in the experiment without the intragastric barostat bag was nearly identical to the volume of the meal (Fig. 4B), and we did not observe any accommodation response over that of the meal volume. In the absence of the barostat bag, however, a significant accommodation response was observed. One could argue that the increase in air volume, as shown in Fig. 5B and represented by the difference in volume between total gastric volume and gastric contents, reflects an accommodation response. In our opinion this increase most likely results from the swallowing of air. This opinion is based on the finding that a similar increase in “free air volume” is observed during the experiment with the barostat bag present (Fig. 5D). The slight increase in volume seen during the course of the experiment might result from the
increased swallowing due to the presence of the gastric barostat bag. Moreover, Bouras et al. (4) describe in their publication on SPECT imaging of the stomach that the accommodation (volume) response to a meal typically reaches a peak within 10 min after completion of the meal ingestion and is maintained at maximum level for at least 30 min. This effect was present in the experiment without the barostat bag (Fig. 5A). Data we recently acquired using another protocol confirm the increase in air volume occurring already within 1 min after meal intake, providing evidence for either a receptive relaxation, as described by Cannon et al. (5) or an increase in air volume due to swallowing of air. Other authors, by comparing SPECT or ultrasonography with the intragastric barostat technique, also failed to detect any accommodation response over that of the ingested volume (18, 25). It should be noted, however, that, in the studies employing SPECT and ultrasonography, comparison with the barostat was not made during simultaneous recording, as in the present study.

Gastric barostat studies have been helpful in defining subgroups of dyspeptic patients, for instance those with early satiety and an impaired meal accommodation response (6, 24). Notwithstanding these observations, the true physiological background of gastric barostat studies should be reconsidered. Additional studies combining barostat and MRI in these subgroups of patients are required to evaluate the phenomenon of (impaired) accommodation.

A clear advantage of MRI for evaluation of gastric emptying and motility is its noninvasive character. Furthermore, MRI provides additional information about peristaltic contractions (8) and evaluates both the proximal and distal stomach simultaneously, whereas barostat data only reflect the function of the proximal stomach. In contrast to SPECT, MRI does not expose patients to ionizing radiation and provides “real-time” volumes: acquisition time 30 s for MRI vs. ~15 min for SPECT. A disadvantage of MRI is the supine position of the subject during the examination. Several studies have evaluated the effect of body position and gravity on gastric emptying and motility (12, 13). Horowitz et al. (13) have shown that gravity had a major influence on the intragastric distribution of the meal, although there was relatively little effect on gastric emptying.

We conclude that, evaluated with MRI, 1) the presence of an intragastric barostat bag does not influence gastric emptying, 2) gastric accommodation as measured with the barostat bag in situ is not observed in the absence of the barostat bag and should be considered a nonphysiological barostat-induced phenomenon, and 3) apart from gastric volume changes, additional information on motility and emptying is provided. Further study on the presence of an accommodation response under physiological circumstances in health and disease is required. These data might provide more insight into the value of impaired accommodation in disease and its clinical relevance.

REFERENCES


