Gastric accommodation and motility are influenced by the barostat device: assessment with Magnetic Resonance Imaging

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Abstract

Background: The barostat is considered the gold standard for evaluation of proximal gastric motility especially for the accommodation response to a meal. 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 itself may influence motility. Nowadays Magnetic Resonance Imaging (MRI) is able to measure several aspects of gastric motility non-invasively.

Aims: To evaluate whether the accommodation response of the stomach, observed with barostat, is present during MRI and whether the barostat interferes with gastric physiology.

Materials and Methods: Gastric accommodation, motility and emptying were studied twice in fourteen healthy subjects with MRI using 3D-volume scans and 2D-dynamic scans once in the presence of a barostat bag and once when the barostat bag was not present.

Results: Fasting and postprandial intragastric volumes were significantly higher in the experiment with barostat versus without barostat (fasting: 350±132 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, NS) 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.

Conclusions: 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 non-physiological barostat-induced phenomenon.

Key Words: Gastric motility, barostat, magnetic resonance imaging, meal accommodation.
Introduction

Assessment of gastric motility and gastric emptying is important for the diagnosis of gastric motor disorders, such as gastroparesis, functional dyspepsia and post-surgical 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, 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 vagally 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. validated MRI as a tool for the analysis of gastric emptying (9). 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 we compared MRI with the barostat for the evaluation of proximal gastric motility during simultaneous recording (8). 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. compared Single Photon Emission Computed Tomography (SPECT) with the barostat for concurrent validity and more recently, Simonian et al. described a new technique using SPECT to simultaneously measure gastric volumes and gastric emptying (4; 22).

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 years; 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.

Gastric barostat

An electronic barostat (Visceral Stimulator, Medtronic, Skovlunde, Denmark) was used to distend the stomach. A polyethylene bag (1000 ml maximum capacity) was connected to the end of a multilumen catheter (16 F). 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 F). In a previous publication (8) we have 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 seconds 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/sec.

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 (TFE), TE = 3.5 ms, TR = 10 ms, field of view 450 mm, rectangular field of view 55%, symmetric reduction 50%, flip angle 25°, 256X256 pixels, slice thickness 10 mm, total scan duration 30 seconds) was performed to determine the momentary gastric volume. To assess dynamic activity of the stomach two dimensional dynamic MRI (semi-coronal slice orientation, Turbo
Field Echo, 300 images per scan, temporal resolution: 1 second, TE = 3.6 ms, TR = 10 ms, field of view 450mm, 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 hours. 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 semi-supine position (30°). In one of two experiments a barostat bag was present and MRI and barostat recording were performed simultaneously, while 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 mm Hg), 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. Minimal distending pressure (MDP), the pressure needed to overcome the intra-abdominal pressure, was determined. MDP is arbitrary defined as the first pressure level that provides an intragastric bag volume of more than 30 ml and 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 real-time 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, USA). The liquid meal was labeled with meglumine gadoterate (Dotarem®, Laboratoire Guerbet, Roissy CdG Cedex, 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 (Figure 1).
Data analysis

Volumes measured with the barostat are given as average values over 30 seconds periods. In all volume images, the stomach was outlined manually by one observer (I.M.d.Z.). 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, 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,

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. Based on 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 Inc., Chicago, USA). All data are given as mean ± SD. A linear mixed model analysis and 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 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 Figure 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, due 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 Figure 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 to 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 (Figure 3). However, the rate of gastric emptying from 15 to 90 min was not significantly different between the two experiments (88 ± 41 ml/h vs. 97 ± 40 ml/h, with vs. without bag; NS).

Gastric volume

The influence of the barostat bag on total gastric volume and gastric contents is shown in Figure 4. Ingestion of the meal caused a significant (p<0.0001) increase over basal in total gastric volume in both experiments (Figure 4A and 4B). Total gastric volume was significantly (p<0.0001) larger in the experiment with the barostat bag (Figure 4A) compared to the experiment without the barostat bag (Figure 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 versus the decrease in volume of gastric contents (Figure 4A). Such a difference was not observed during the experiment without the barostat bag (Figure 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 (Figure 5A). However, in the experiment without the barostat bag, total air volume did not change significantly after meal ingestion (Figure 5B). Total gastric volume during the experiment with the barostat bag in situ consisted of free air, that is air outside the barostat bag, and air inside the barostat bag, that is barostat bag volume (Figure 5C 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 to the total air volume in the experiment without barostat bag (Figure 5D 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 Figure 6. We observed that the peristaltic contraction pattern became irregular with the barostat bag in situ. However, contraction frequency (Figure 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 barostat bag and 14.9 ± 1.1 per 5 min without 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 to the experiment without 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. As 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 due to a smaller secretory area exposed to nutrients.

While gastric emptying was not influenced in the presence of an intragastric barostat bag total gastric volume and gastric accommodation to the meal were affected, while 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 (Figure 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). In order 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 (Figure 4B) and we did not observe any accommodation response over that of the meal volume. In the presence of the barostat bag, however, a significant accommodation response was observed. One could argue that the increase in air volume, as shown in figure 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 (Figure 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 minutes after completion of the meal ingestion and is maintained at maximum level for at least 30 minutes. This effect was present in the experiment with the barostat bag, but absent 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 minute 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 non-invasive character. Furthermore, MRI provides additional information about peristaltic contractions (8) and evaluates both the proximal and distal stomach simultaneously, whereas the barostat data reflect the function of the only proximal stomach. In contrast to SPECT, MRI does not expose patients to ionizing radiation and provides “real time” volumes: acquisition time 30 seconds for MRI versus approximately 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. have shown that gravity had a
major influence on the intragastric distribution of the meal, although there was relatively little effect on gastric emptying (13).

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 non physiological barostat-induced phenomenon, 3) apart from gastric volume changes additional information on motility and emptying are 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 it’s clinical relevance.
References


**Legends to figures**

Figure 1  This figure summarizes the protocol of the study. Every 15 min, a volume scan and dynamic scan were acquired.

- Volume measurement
- Motility measurement
- Barostat: isobaric distention (MDP+2 mmHg)
Figure 2  Transversal T1-weighted TFE images (3.5/10; flip angle, 25°) of the stomach in the same subject without barostat bag (a + b) and with barostat bag (c + d), before ingestion of the gadolinium labeled meal (a + c) and immediately after ingestion of the meal (b + d). Gastric contents consisting of a mixture of the gadolinium labeled meal and gastric secretions are shown by black arrows. Total gastric volume consists of both gastric contents and air (white arrow indicates air). The air-filled barostat bag cannot be visualized separately from "free air". Note that gastric volume is larger in the barostat experiment, both before and after meal ingestion.
Figure 3  Gastric emptying of the meal with and without the barostat bag in situ. Changes in volume of gastric contents after meal ingestion are shown for the experiments without the barostat bag and with the barostat bag set at isobaric pressure (MDP + 2 mmHg) in 14 healthy subjects. *p>0.0001: volume of gastric contents without barostat bag in situ vs. with bag in situ (mean ± SD).
Figure 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 (4A) and without barostat bag (4B). Fig 4A: *p>0.0001: for total volume vs. volume of gastric contents and for rate of volume decrease. Fig 4B: *p>0.0001: for total volume vs. volume of gastric contents.
Figure 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
Figure 6 Example of the effect of barostat bag on contraction pattern. A graphical representation of the contraction pattern of one healthy volunteer during 5 min before introduction of the intragastric barostat bag (a) and after introduction of the intragastric barostat bag (b). In the graphs, time runs from left to right; the upper part of the graph represents the gastric fundus, and the lower part of the graph represents the antrum. Yellow represents a wide gastric diameter and black and white a narrow gastric diameter. In graph a, the red lines represent 15 peristaltic contractions. Note that without the bag, the contraction pattern is regular. After introduction of the bag, the contraction pattern becomes less regular, whilst the frequency of contractions is preserved. This pattern was seen in all volunteers. Immediately after meal ingestion, the contraction pattern became even more disturbed with the intragastric barostat bag in situ versus without the barostat bag.
Figure 7  Number of contractions per 5 min (mean ± SD) in the session with and without the barostat bag in situ in 14 healthy subjects.