**STOMACH**

SPECT imaging of the stomach: comparison with barostat, and effects of sex, age, body mass index, and fundoplication

E P Bouras, S Delgado-Aros, M Camilleri, E J Castillo, D D Burton, G M Thomforde, H J Chial

Background: Impaired gastric accommodation may lead to dyspeptic symptoms. A non-invasive method using single photon emission computed tomography (SPECT) has been developed to measure gastric volumes.

Aims and methods: Our aims were: to assess the accuracy of SPECT with three dimensional image analysis to measure balloon volumes in vitro; to compare gastric barostat balloon volumes measured post-meal and post-distension with total gastric volumes measured simultaneously with SPECT; to present normal gastric volume data for healthy adults; and to compare SPECT data in health with symptomatic post-fundoplication patients.

Results: In vitro balloon volumes measured by SPECT were highly accurate ($R^2=0.99$). When measured simultaneously by gastric barostat and SPECT, postprandial/fasting volume ratios (2.2 (0.12) (mean (SEM)) vs 2.3 (0.15), respectively; $p=0.6$) and post-distension volume ratios (1.4 (0.1) vs 1.3 (0.1); $p=0.2$) were highly comparable. In females, postprandial gastric volumes (675 (14) ml versus 744 (20) ml for males; $p=0.004$) and changes in gastric volumes (464 (14) ml versus 521 (20) ml for males; $p=0.01$) measured by SPECT were significantly lower than in males. No effects of age or body mass index were noted. The postprandial/fasting gastric volume ratio by SPECT was lower in post-fundoplication patients (2.7 (0.2)) than in healthy controls (3.4 (0.1); $p=0.003$).

Conclusions: SPECT provides a non-invasive estimate of the effect of a meal on total gastric volume that is comparable to changes in balloon volume observed with the gastric barostat. The SPECT technique is promising for investigation of gastric volumes in health and disease and the effects of pharmacological agents.

METHODS

Study participants

All protocols included in this paper were approved by the Mayo Institutional Review Board.

Abbreviations: SPECT, single photon emission computed tomography; $^{99m}$Tc, technecium-99m.
Simultaneous SPECT and barostat assessment

Healthy volunteers aged 18–65 years without current gastrointestinal symptoms or previous gastrointestinal illness were recruited by public advertisement. Exclusion criteria included: prior abdominal surgery other than appendectomy, tubal ligation, or caesarean section; positive symptoms on an abridged bowel symptom questionnaire; use of medications that may alter gastrointestinal function; and use of over the counter medications within seven days of the study. Eighteen healthy adults were enrolled in the study. One participant was unable to complete the study because of an inability to tolerate the intragastric balloon. A second participant was excluded from analysis due to malfunction of the gastric barostat (kinking of the tube with failed inflation of the intragastric balloon). Data for 16 volunteers (seven females, nine males; mean age 30 (2) years (range 22–48)) were available for analysis.

Normative fasting and postprandial gastric volume data using SPECT in healthy adults

Normative data for healthy adults were obtained by pooling SPECT data from healthy volunteers who had received placebo medications or served as healthy controls and received no treatment in research protocols previously conducted in our laboratory. All data were analysed by the same technologist (DDB). Healthy volunteers were aged 18–65 years and had been recruited by public advertisement. None of the healthy participants had current gastrointestinal symptoms or previous gastrointestinal illnesses. Exclusion criteria are as listed above.

Data from 73 healthy adults (48 females, 25 males; mean age 34.4 (1.1) years (range 18–57)) were included in the analysis. Average height, weight, and body mass index were 1.71 (0.01) m, 86.7 (3.2) kg, and 29 (1) kg/m², respectively.

SPECT results from patients with upper abdominal symptoms post-fundoplication

A computerised diagnostic index was used to identify adults with upper abdominal symptoms post-fundoplication who were evaluated in the motility clinic at the Mayo Clinic Rochester and had undergone measurement of gastric volume using SPECT. The study comparing these results with those of healthy controls was approved by the Mayo Institutional Review Board, and authorisation for the use of the medical records for research purposes was confirmed for each individual before accessing the records.

We identified 15 patients (eight females, seven males; mean age 47.9 (3.0) years (range 31–74)) with upper gastrointestinal symptoms post-fundoplication who underwent clinical evaluation and SPECT assessment of gastric volumes.

SPECT–ANALYZE technique to measure gastric volumes

All tomographic images were acquired using the same large field of view dual headed gamma camera system (SMV SPECT System) equipped with low energy high resolution collimators. Subjects were positioned supine on the imaging table with detectors over the upper and mid abdomen to insure imaging of the stomach. Imaging was started 10 minutes after intravenous injection of 10 mCi ⁹⁹ᵐTc pertechnetate. Using the dual headed gamma camera, the system performed a complete 360° orbit around the patient over 16 minutes. Images were acquired into a 128x128 matrix every 6° at five seconds per image. After completion of the acquisition, images were summed to improve counting statistics and reconstructed using filtered back projection (Ramp-Butterworth filter, order 10, cutoff 0.45 Nyquist) to produce transaxial images of the stomach.

For estimations of gastric volumes, the transaxial SPECT images were transferred via Interfile to a dedicated Unix workstation. Stomach volume measurements were obtained using the ANALYZE PC 2.5 (Biomedical Imaging Resource, Mayo Foundation, Rochester, Minnesota, USA) software system, which has been used previously in volumetric imaging studies. To measure gastric volume, it was necessary to identify the stomach on the transaxial SPECT images and separate it from the background noise. This was accomplished using a semiautomated segmentation algorithm (Object Extractor, ANALYZE PC 2.5) that requires the user to identify an appropriate seed point and greyscale threshold. Three dimensional renderings of the stomach were produced (fig 1). Any extraneous structures, such as the upper duodenum or a kidney, in close proximity to the posterior aspect of the stomach (which had not been removed in the segmentation algorithm) were removed manually.

Radiation exposure was within permissible ranges for research and clinical studies. The effective radiation dose to the body was 619 mrem, which is approximately 2.7 times the radiation exposure from a full gastrointestinal transit measurement by scintigraphy. Organ exposures and effective dose equivalents have been published elsewhere.

SPECT measurements of defined balloon volumes in vitro

An infinitely compliant polyethylene balloon was filled with known volumes of ⁹⁹ᵐTc DTPA labelled water (range 150–800 ml) and placed in a water bath. Tomographic images were acquired using the large field of view dual headed gamma camera system (SMV SPECT System) described above. The gamma camera performed a 360° orbit around the balloon suspended in the water bath, and volume measurements were performed as outlined above. Volume measurements by SPECT were then compared with the known volumes in the balloon.

Simultaneous assessment of stomach function using gastric barostat and SPECT

Measurements were performed simultaneously using a barostatic balloon within the stomach and the SPECT imaging technique described above (fig 2).

Following an overnight fast, a double lumen barostat assembly with an infinitely compliant polyethylene balloon (maximum volume 1000 ml) was placed such that the balloon was in the proximal stomach. The balloon was tied onto two metal rings incorporated into the tube assembly. The tube was inserted to 60 cm, and the participant assumed the supine position. The barostat balloon was inflated to 300 ml, and the
A gastric barostat balloon was inserted into the stomach. Ten minutes after intravenous injection of 10 mCi $^{99m}$Tc pertechnetate, SPECT imaging was performed during fasting and over 32 minutes (two camera orbits) following ingestion of a 300 ml Ensure drink through a straw. Transaxial images of the stomach were rendered with ANALYZE to reconstruct three dimensional images and to measure gastric volumes during the fasting and postprandial periods. The two postprandial volume estimates were averaged. In all cases, the volumes measured over 0–16 and 17–32 minutes differed by less than 10%. Volume changes and ratios between the fasting and postprandial periods were calculated.

**Statistical analysis**

Linear regression analysis and computed $R^2$ were used to assess the accuracy of SPECT in measuring balloon volumes in vitro. Linear regression analysis was also used to compare in vivo postprandial changes in intragastric balloon volume obtained with the barostat with changes in total gastric volume detected by SPECT. The Wilcoxon signed rank test was used to compare simultaneous barostat and SPECT estimates. The postprandial volume response is presented as the difference between postprandial and fasting volumes measured by barostat and SPECT, and as the ratio of postprandial to fasting volumes. Descriptive statistics were used to summarise gastric volumes in the cohort of healthy volunteers. The Wilcoxon signed rank test was used to compare absolute (fasting and average postprandial) volumes and volume changes between males and females, and to compare volumes in healthy adults with those in postfundoplication patients. We compared gastric volume responses for three age ranges (18–30, 31–40, and 41–60 years) in healthy subjects using one way analysis of covariance including sex and body mass index as covariates.

**RESULTS**

**SPECT measurement of defined balloon volumes in vitro**

Figure 3 shows the actual volumes and SPECT volume estimates for the water filled balloons. SPECT derived volume estimates were highly accurate and showed a near perfect linear relationship with actual balloon volumes ($R^2=0.99$).

**Simultaneous SPECT and barostat assessment of the stomach**

Table 1 shows fasting and postprandial intragastric balloon and total gastric volumes measured by the barostat and SPECT techniques, respectively. As expected, total gastric volumes measured by SPECT were larger than intragastric balloon volumes obtained for the barostatically controlled balloon. Mean ratios of postprandial to fasting balloon and total gastric volumes measured by barostat and SPECT, respectively, were...
highly comparable (p=0.6). Figure 4 plots the postprandial ratios, as measured by both techniques ($R^2=0.7$). Significant positive linear relationships were noted for volume estimates between barostat and SPECT.

Postprandial balloon volumes were 512 (25) ml; the additional balloon distension resulted in a volume increase within the balloon of 157 (78) ml. Balloon distension was associated with an increase in whole stomach volume measured by SPECT. Distension was associated with a mean increase in stomach volume of 333 (49) ml, approximately double the average volume increase measured within the balloon, suggesting the whole stomach responded to the additional distension volume. Post-distention ratios assessed by the barostat and by SPECT were comparable (p=0.2) (table 1).

Normative data for healthy adults
Fasting gastric volumes did not differ between males and females. Postprandial gastric volumes (p=0.004) and postprandial gastric volume changes (p=0.01) were significantly greater in males than females (table 2). Age and body mass index did not influence fasting or postprandial gastric volumes. Specifically, gastric volumes and the postprandial response were not significantly different for healthy volunteers aged 18–30 years (n=27), 31–40 years (n=28), and 41–60 years (n=18). Body mass index did not significantly impact on the effect of sex on postprandial gastric volumes.

Symptomatic post-fundoplication patients
Gastric volumes and volume ratios in patients with upper gastrointestinal symptoms post-fundoplication were quite variable (table 3). Fasting gastric volumes were higher in post-fundoplication patients relative to healthy controls (p<0.005). As shown in fig 5, the postprandial to fasting gastric volume ratios were significantly lower in the post-fundoplication group compared with healthy controls (p=0.003). However, it is worth noting that gastric volumes and volume ratios of several of the post-fundoplication patients were well within the normal range.

Table 1 Gastric volumes by single photon emission computed tomography (SPECT) and barostat effects of meal and distension

<table>
<thead>
<tr>
<th></th>
<th>Barostat</th>
<th>SPECT</th>
<th>Correlation coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting and postprandial volumes (ml) (n=16)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fasting volume</td>
<td>238 (14)</td>
<td>627 (37)</td>
<td>0.60 (p=0.02)</td>
</tr>
<tr>
<td>Postprandial volume</td>
<td>512 (25)</td>
<td>1380 (37)</td>
<td>0.64 (p=0.008)</td>
</tr>
<tr>
<td>Difference</td>
<td>274 (20)</td>
<td>753 (47)</td>
<td>0.68 (p=0.003)</td>
</tr>
<tr>
<td>Postprandial ratio</td>
<td>2.2 (0.12)</td>
<td>2.3 (0.15)</td>
<td>0.8 (p=0.0001)</td>
</tr>
<tr>
<td>Postprandial and post-distension volumes (ml) (n=14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before distention</td>
<td>515 (27)</td>
<td>1387 (39)</td>
<td></td>
</tr>
<tr>
<td>After distention</td>
<td>672 (11)</td>
<td>1720 (51)</td>
<td></td>
</tr>
<tr>
<td>Ratio</td>
<td>1.33 (0.07)</td>
<td>1.25 (0.04)</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean (SEM).

Table 2 Normative data for gastric volumes measured in 73 healthy volunteers

<table>
<thead>
<tr>
<th>Volume (ml)</th>
<th>All (n=73)</th>
<th>Males (n=25)</th>
<th>Females (n=48)</th>
<th>p Value (males v females)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting</td>
<td>213 (6)</td>
<td>215 (11)</td>
<td>211 (7)</td>
<td>0.5</td>
</tr>
<tr>
<td>Postprandial</td>
<td>698 (12)</td>
<td>744 (20)</td>
<td>675 (14)</td>
<td>0.004</td>
</tr>
<tr>
<td>Postprandial minus fasting</td>
<td>483 (12)</td>
<td>521 (20)</td>
<td>464 (14)</td>
<td>0.01</td>
</tr>
<tr>
<td>Postprandial/fasting volume ratio</td>
<td>3.4 (0.1)</td>
<td>3.6 (0.2)</td>
<td>3.4 (0.1)</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Table 3 Post-fundoplication patients

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value (SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting volume (ml)</td>
<td>281 (25)*</td>
</tr>
<tr>
<td>Postprandial volume (ml)</td>
<td>717 (37)</td>
</tr>
<tr>
<td>Postprandial minus fasting</td>
<td>436 (25)</td>
</tr>
<tr>
<td>Postprandial/fasting ratio</td>
<td>2.7 (0.2)*</td>
</tr>
</tbody>
</table>

*p<0.005 versus controls.
DISCUSSION
We have shown that the novel SPECT-ANALYZE technique accurately measures known volumes, as demonstrated by the results of the in vitro volume validation protocol. In vivo, SPECT measures total gastric volumes post-meal and post-distension, which are larger than intragastric balloon volumes measured using the barostat method. Postprandial and post-distension ratios (which estimate volume changes) measured by gastric barostat and SPECT techniques were highly comparable. SPECT does not directly measure gastric tone as it does not evaluate intragastric pressure. Intragastric pressure is homeostatically controlled by changes in gastric tone/tension and equilibrium with outside pressure by venous through the belch reflex which accommodate the hydrostatic pressure from intragastric content and other causes of change in intra-abdominal pressure. As the volume and caloric density of the meal were standardised and intra-abdominal pressure is relatively constant within an individual, an increase in gastric volume indirectly reflects a change in gastric tone. In fact, the postprandial to fasting volume ratios measured with SPECT (without knowledge of intragastric pressure) were highly comparable with those measured with the barostatic balloon.

Our previous studies suggested that non-invasive measurement of gastric volume may be a practical surrogate for the invasive assessment of tone with the barostat: SPECT documents as volume changes the expected effects of pharmacological agents on gastric tone, as measured by the barostatic balloon with nitrates, the motilide erythromycin, and the 5-HT3 antagonist alosetron. Finally, in patients with idiopathic non-ulcer dyspepsia, SPECT showed that approximately 40% had lower volume increases in response to the standard Ensure meal, and this proposition coincides with Tack’s observation obtained with the barostatic balloon. Techniques that do not require intubation to measure gastric volume have no direct effect on gastric relaxation, either by triggering of the swallowing reflex by the tube and swallow induced relaxation or by distension of the stomach with the balloon. A potential advantage of the less invasive SPECT method is the absence of any interference of external imaging with the physiological functions of the stomach. It has been suggested that the gastric barostat balloon may function as a foreign object and could interfere with physiological assessment of gastric function. Data from our study confirm the observations of Samsom and colleagues as fasting and postprandial gastric volumes measured by SPECT in healthy subjects in the presence of an intragastric balloon were 2 to 3 fold higher than volumes measured in other healthy subjects in the absence of the balloon. Relaxation within an organ or in anatomically adjacent organs in response to distension at one site is a well established reflex. The experiments in this study were performed with participants in the supine position because of physical limitations imposed by the SPECT camera. However, fasting and postprandial volumes and ratios measured by the gastric barostat in this study were consistent with values reported from other gastric barostat studies performed in the seated position. These data suggest that meal induced changes in intragastric balloon volume measured by barostat were in the physiological range. Simultaneously performed SPECT identified gastric volume changes with a nutrient liquid meal.

A potential limitation of the SPECT technique is radiation exposure which could limit the number of studies in individual patients. Other techniques such as ultrasound, magnetic resonance imaging, and volumetric fluid loading have been proposed as alternative methods to measure gastric accommodation but they have not been completely validated to date.

The present study also characterised normative SPECT data for fasting and postprandial gastric volumes in 73 healthy adults. Females have a significantly lower postprandial volume compared with males, and this difference is not influenced by body mass index in the range tested. The average 10% sex related difference in postprandial volume is unlikely to be biologically important but it has important implications in planning studies of perturbations for which sex should be included in the randomisation plan. There were no significant differences in gastric volumes for adults up to 60 years of age.

We have also characterised the postprandial change in gastric volume in patients with prior fundoplication and upper gastrointestinal symptoms. As a group, post-fundoplication patients manifested a significant reduction in the postprandial response, confirming results from a study with an intragastric barostatic balloon. However, several patients had normal volume responses and alternative explanations such as gastric hypersensitivity should be considered in evaluating the cause of symptoms in these patients.

In conclusion, the SPECT-ANALYZE technique accurately measures volume in vitro and can characterise changes in gastric volume in response to a meal and gastric distension. Volume changes (expressed as ratios) with SPECT are comparable with those identified using the gastric barostat. The SPECT technique allows non-invasive visualisation and measurement of the entire stomach volume. This technique should facilitate evaluation of the effects of pharmacological agents on gastric volume and comparisons between health and disease states.

ACKNOWLEDGEMENTS
This study was supported in part by the General Clinical Research Center Grant No RR00883 (Physiology Core) from National Institutes of Health. Dr Bousar received support from the American College of Gastroenterology. Dr Camilleri is supported by grants R01-DK54681 and K24-DK02638 from National Institutes of Health. We thank Ms Cindy Stanislaw for secretarial support.

This paper was presented in part at the Annual Meeting of the American Gastroenterological Association (May 2001, Atlanta, GA) and appears in abstract form in Gastroenterology 2001;120:A97, and at the International Symposium for Neurogastroenterology and Motility (November 2001, Madison, WI) and appears in abstract form in Neurogastroenterology and Motility 2001;13:378.

Authors’ affiliations
E P Bousar, S Delgado-Aros, M Camilleri, E J Castillo, D D Burton, G M Thomforde, H J Chial, Clinical Enteric Neuroscience Translational and Epidemiological Research Program, Mayo Clinic and Mayo Foundation, Rochester, Minnesota, USA

REFERENCES
1 Azpiroz F, Malagelada JR. Gastric tone measured by an electronic barostat in health and postgastroparesis. Gastroenterology 1987;92:534–43.
Gut through the ages

Browse the Archive

Gut online has an archive of content dating back to 1966.
Full text from 1997; abstracts from 1975; table of contents from 1966

www.gutjnl.com
SPECT imaging of the stomach: comparison with barostat, and effects of sex, age, body mass index, and fundoplication

E P Bouras, S Delgado-Aros, M Camilleri, E J Castillo, D D Burton, G M Thomforde and H J Chial

Gut 2002 51: 781-786
doi: 10.1136/gut.51.6.781

Updated information and services can be found at:
http://gut.bmj.com/content/51/6/781

These include:

References
This article cites 30 articles, 10 of which you can access for free at:
http://gut.bmj.com/content/51/6/781#BIBL

Email alerting service
Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

Topic Collections
Articles on similar topics can be found in the following collections
Stomach and duodenum (1689)

Notes

To request permissions go to:
http://group.bmj.com/group/rights-licensing/permissions

To order reprints go to:
http://journals.bmj.com/cgi/reprintform

To subscribe to BMJ go to:
http://group.bmj.com/subscribe/