VISCERAL PERCEPTION

Non-invasive measurement of gastric accommodation in humans

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Gastric accommodation describes the reduction in gastric tone and increase in compliance that follows ingestion of a meal and involves at least two responses: "receptive relaxation" which allows the stomach to accept a volume load without a significant rise in gastric pressure and "adaptive relaxation" which modulates gastric tone in response to the specific properties of the meal ingested. However, there are considerable technical difficulties in measuring the accommodation process. The current standard barostat studies, and other methods such as conventional and three dimensional ultrasound, or single photon emission computed tomography have significant disadvantages. Preliminary findings from the development and validation of a new magnetic resonance imaging technique that addresses many of the deficiencies of previous methods are presented.

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SUMMARY

Gastric accommodation is a term used to describe the reduction in gastric tone and increase in compliance that follows ingestion of a meal. It involves at least two responses: "receptive relaxation" which allows the stomach to accept a volume load without a significant rise in gastric pressure and "adaptive relaxation" which modulates gastric tone in response to the specific properties of the meal ingested. Abnormal postprandial gastric accommodation occurs in several conditions and may be involved in the pathogenesis of functional dyspepsia. However, there are considerable technical difficulties in measuring the accommodation process. The current standard barostat studies, and other methods such as conventional and three dimensional ultrasound, or single photon emission computed tomography (SPECT) have significant disadvantages. The ideal technique would be non-invasive, widely available, convenient, reliable, and would not expose the subject to ionising radiation. It would also allow measurement of gastric accommodation in response to solid as well as liquid meals. There is also a need to differentiate between responses to food, gastric secretion, and air, and to simultaneously monitor changes in gastric tone, tension, motility, emptying, and transpyloric flow. New magnetic resonance imaging (MRI) techniques are being developed to address many of these needs.

INTRODUCTION

Gastric accommodation describes the reduction in gastric tone and increase in compliance that follows ingestion of a meal. These responses provide an appropriate gastric reservoir for food and enable volume to increase without a rise in gastric pressure. Cannon and Lieb were the first to observe the phenomenon of "receptive relaxation" of the stomach which occurs within seconds after gastric distension.[1] Jahnberg *et al* later demonstrated a second response ("adaptive relaxation") after food intake.[2] Gastric accommodation also occurs in response to duodenal distension or nutrient infusion. Thus the distribution of food within the stomach and the rate of gastric emptying vary according to which nutrients are ingested. A brain stem reflex is thought to mediate relaxation of the proximal stomach in response to a meal. Gastric tone (that is, accommodation and contraction) is therefore modulated by the central nervous system (CNS), vagal discharge, and a network of reflexes that arise from the stomach wall.[3]

Abnormal gastric accommodation occurs in functional dyspepsia,[4 5] in children with recurrent abdominal pain,[6] in rumination syndrome,[7] achalasia,[8] gastro-oesophageal reflux disease,[9] and diabetic vagal neuropathy, and post-vagotomy.[10 11] Despite widespread interest in the possible aetiology role of impaired postprandial accommodation in the pathogenesis of functional dyspepsia, there are relatively few published studies addressing this subject. This reflects the considerable technical difficulties faced in measuring the accommodation process. The current standard, barostat studies, and other existing methods such as conventional ultrasound, three dimensional ultrasound, and SPECT have significant disadvantages. The ideal technique would be non-invasive, widely available, convenient, reliable, and would not expose the subject to ionising radiation. It would allow the measurement of gastric accommodation in response to solid as well as liquid meals and would be able to differentiate between food, secretion, and air in the stomach. Gastric accommodation cannot be seen in isolation from gastric tone and tension, gastric motility, gastric emptying, or transpyloric

Abbreviations: CNS, central nervous system; MRI, magnetic resonance imaging; SPECT, single photon emission computed tomography; POM, position and orientation measurement.

flow. The ideal technique would allow simultaneous assessment of these factors. This review summarises the advantages and limitations of existing approaches to the measurement of gastric accommodation and presents preliminary findings from the development and validation of a new MRI technique that addresses many of the deficiencies of previous methods.

GASTRIC BAROSTAT

Gastric barostat studies are the best established methods of measuring gastric accommodation. However, the technique is invasive, involving the introduction of a balloon into the gastric fundus. The balloon, which is compliant up to a maximum volume of 1.0–1.2 litres, is attached to a barostat machine via a double lumen catheter. The barostat allows isobaric or isovolumic expansion of the balloon with continual monitoring of intraballoon volume or pressure. In this way the accommodation response of the gastric fundus or antrum to various interventions can be recorded.

Barostat studies have shown that postprandial gastric accommodation is reduced in a significant proportion of patients with functional dyspepsia, particularly those with symptoms of bloating, distension, nausea, early satiety, and weight loss.[5 12] The potential of drugs to modulate the accommodation reflex in healthy and dyspeptic subjects has also been demonstrated in barostat studies.[5 13] The procedure is however invasive, uncomfortable, difficult to use with solid food, and may in itself alter the intragastric distribution of a meal.[14] Another potential drawback of the procedure is that relaxation of the stomach wall is probably exaggerated due to the direct distension stimulus of the balloon. Despite these limitations, the barostat is the only technique that simultaneously measures intragastric pressure as well as volume. However, these parameters are only surrogate markers for gastric wall tone and tension, which are probably the most important determinants of gastric sensation.[15]

ULTRASOUND

Conventional ultrasound imaging of gastric antral accommodation is a non-invasive widely available method which also allows assessment of gastric emptying and transpyloric flow.[16] The technique is limited by the fact that the assessment of gastric accommodation is indirect, based on measurements of antral diameter. Another restriction is the fact that the costal margin and presence of air in the abdomen limits the view of the fundus. Gastric ultrasound imaging is also highly user dependent.

Berstad's group in Norway has combined conventional ultrasound with a position and orientation measurement (POM) device attached to the ultrasound probe.[17 18] This technique has significantly improved visualisation not only of the antrum but also the fundus and allows three dimensional reconstruction of the images to provide a volumetric assessment of gastric accommodation. However, three dimensional ultrasound cannot differentiate between food and secretion or solid and liquid phases in the stomach. It is technically demanding and POM devices are not widely available.

SPECT

SPECT has recently been proposed as a new technique for measuring gastric accommodation.[19] It provides an assessment of the whole stomach volume and potentially enables gastric emptying to be assessed by radioactively imaging the gastric mucosa. ^{99m}Tc-pertechnetate 20 mCi is given intravenously and the isotope is taken up and excreted by parietal and mucous cells throughout the stomach. Within 10 minutes of administering the marker, multiorbit dynamic topographic studies can be obtained using a dual head gamma camera system. Images can be acquired in both the fasting and postprandial periods; the total duration of imaging is 30 minutes. In the initial feasibility study the intra- and interobserver variances suggested that SPECT provides a robust measure of gastric accommodation.[19] Validation studies against the gastric barostat have yet to be performed.

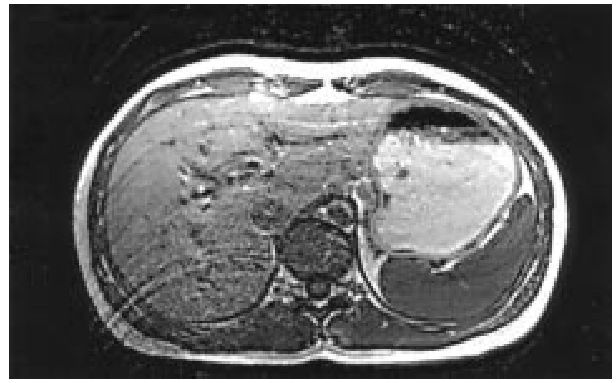

Figure 1 Transaxial magnetic resonance image 15 minutes following intragastric infusion of 500 ml of Ensure. The total stomach volume is outlined. Meal volume is seen as a white and air as a black area.

SPECT studies have indicated that impaired accommodation reflexes (defined by postprandial/fasting total gastric volume ratio <5) occur more often in patients with functional dyspepsia (five out of nine) than in patients who remain symptomatic postfundoplication (one in four) or in healthy controls (one in 10).[20]

However, SPECT has significant limitations. The technique involves high exposure to ionising radiation, and imaging can only be performed within a relatively short time interval after isotope injection. SPECT does not assess gastric content. Extensive and time consuming analysis of the raw data is required to produce transaxial images of the stomach and further image processing is required to assess gastric volume and accommodation. Spatial and temporal resolution is limited by current technology.

MRI

MRI allows measurement of gastric motility and emptying and has recently been proposed as a technique for measuring gastric accommodation.[21–24] The technique is free from many of the shortcomings of earlier methods. It is non-invasive, does not expose the patient to ionising radiation, allows simultaneous assessment of gastric anatomy, motility, and emptying, and can differentiate between an ingested meal, solid and liquid phases, gastric secretion, and air. Recent studies have validated the technique by demonstrating a close agreement between gastric emptying profiles as obtained by scintigraphy and MRI for liquid and solid meals,[21–23] and continuous measurement of postprandial proximal gastric volume measured by gastric barostat and MRI.[24]

The technique has been further developed for the measurement of postprandial volumes in different regions of the stomach with the objective of being able to assess postprandial gastric accommodation. Eight healthy subjects were studied on four occasions, separated by at least one week. Three 500 ml test meals of 10% Intralipid (a triglyceride emulsion containing mainly long chain fatty acids; 550 kcal), 20% glucose (400 kcal), and Ensure (protein 17%, fat 30%, carbohydrate 53%; 375 kcal) were given intragastrically and 500 ml of 0.9% saline was given as a volume control. Each meal was labelled with 500 µM Gd-DOTA (gadolinium tetrazacyclododecane tetraacetic acid; Dotarem). Patients were positioned supine in the MRI scanner (1.5 Tesla, Philips Gyroscan ACS NT). A scan was performed to assess the position of the stomach and preprandial gastric volumes. A multislice turbo spin echo technique (voxel resolution 10 µl) was used to image the whole stomach

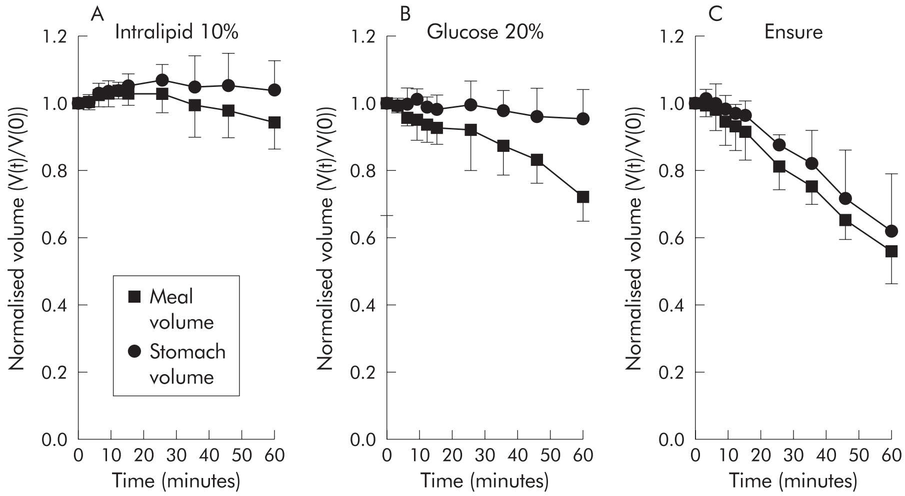

Figure 2 Normalised volume plots of total gastric volumes and meal volumes after intragastric infusion of 500 ml of 10% Intralipid (550 kcal) (A), 20% glucose (400 kcal) (B), and Ensure (protein 17%, fat 30%, carbohydrate 53%; 375 kcal) (C).

over a period of 30 seconds (30 slices, thickness 5 mm). Imaging was performed during three breath holds to minimise movement artefacts. The 500 ml test meal was then given by perfusion pump through a nasogastric tube at 100 ml/min (five minutes). MRI imaging was performed every three minutes for 15 minutes and then every 10 minutes until 60 minutes had elapsed. Total gastric volume, meal volume, gastric secretions, and swallowed air were identified and outlined on the screen (fig 1).

The volumes of the gastric contents were then determined by multiplying the sum of these areas by the slice thickness. Total stomach volumes were determined and gastric meal volume was calculated. Proximal and distal gastric regions were determined by drawing a line at right angles to the insicura. The study showed that immediately after infusion of all three meals, the 500 ml meal volume closely approximated total stomach volume (fasting to postprandial volume ratio 1:3–6). The greatest volume increase was observed in the proximal stomach. This presumably reflects receptive relaxation in response to increasing stomach volume. Subsequent scans revealed significant differences between the three meals that we consider to represent distinct and specific accommodation responses to different macronutrients (fig 2).

Following Intralipid infusion, total stomach volume and meal volume remained stable for the first 20 minutes and closely approximated the initial 500 ml meal volume. Thereafter, meal volume began to decrease slowly while total stomach volume remained elevated throughout the 60 minute experiment. Following 20% glucose infusion, total stomach volume remained elevated and essentially stable at the volume reached immediately after meal intake. However, meal volume decreased steadily over the same period. Following Ensure infusion, gastric volume and meal volume emptying curves decreased in paralleled with each other from the initial postprandial values. Saline emptied rapidly from the stomach within 15 minutes.

These data represent the first direct and non-invasive measurements of the effects of different macronutrients on gastric accommodation. Further studies will be necessary to interpret the results fully. Although gastric accommodation is closely associated with gastric emptying, both processes appear to be controlled and regulated independently of one another. This confirms the hypothesis that accommodation comprises more than a simple receptive relaxation of the stomach to volume loads, especially as the three nutrient meals had distinctly different effects on total stomach volumes and gastric emptying rates.

CONCLUSIONS

MRI techniques have been developed to assess gastric accommodation, gastric emptying, gastroduodenal and pyloric motility, and the relationship between gastric emptying, motility, and flow. MRI provides a unique opportunity to observe the intragastric distribution of nutrients, secretion, and therapeutic intervention.[25] Reconstruction of gastric volume is time consuming and technically demanding but suitable software is currently available for angiography and other well established clinical MRI techniques.

MRI probably represents the future in neurogastroenterology allowing in vivo, non-invasive, real time measurements of gastrointestinal functions in humans, including assessment of postprandial gastric accommodation.

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