Continuous monitoring of the effect of pentagastrin on gastric emptying of solid food in man

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SUMMARY By continuous monitoring of a solid meal labelled with a radiopharmaceutical it has been possible to determine the effects of drugs on gastric emptying and motility during a single study. Predictably hyoscine delayed, and bethanechol increased, the rate of gastric emptying. Pentagastrin initially produced marked antral activity resulting in a physiological stricture and subsequent delay in the overall rate of gastric emptying. Fundal motility was unaffected though reflux from the antrum occurred.

Gastric emptying tests have been used to assess physiological control mechanisms governing emptying from the intact normal stomach and to compare emptying rates in patients before and after surgery for gastroduodenal disease (Sheiner, 1975). By comparison, there are relatively few reports of studies assessing the effects of drugs on gastric emptying in the intact stomach, presumably because the established methods are relatively insensitive to intra-study manipulations. Hitherto, the actions of drugs on gastric muscle activity have usually been determined from isolated muscle preparations and from pressure and electrical studies in animals and humans.

The purpose of this study was to develop a sensitive, non-invasive technique for continuously monitoring gastric emptying in the intact human stomach, so that changes in rates and patterns of emptying could be determined after drug administration. In order to explain changes in the net rate of emptying from the whole stomach, an assessment of regional muscle activity was attempted by monitoring emptying from subareas of the proximal and distal stomach.

The project was developed in three parts: (1) establishment of the method and its reproducibility; (2) study of drugs with known effects on the intact stomach; and (3) study of the action of the drug pentagastrin which is reported to have apparently opposing effects on motility and emptying. (Hunt and Ramsbottom, 1967; Misiewicz et al., 1967; Kelly, 1970; Dozois and Kelly, 1971; Kwong et al., 1971; Cooke et al., 1972).

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Methods

TEST MEAL

Composition of meal

The meal consisted of 100 g cooked, lean, minced beef and 28 g of a proprietary potato whip (Edgell) added to 125 ml boiling water. This was lightly homogenized using a commercially available electric blender. One millicurie of Technetium-99 m labelled macro-aggregated ferrous hydroxide particles (99mTc-MAFH) (Boyd et al., 1969) was then added and the meal again homogenized. This produced a meal of low fat content (6 g), 2123 J (508 calories), of pH 7.0, volume 210 ml, and total weight of 250 g. It contained a moderate protein (100 g) and carbohydrate content (28 g).

Radionuclide label characteristics

The particles of 99mTc-MAFH (size 5-50 micra) were uniformly distributed throughout the meal phase as shown by counting random samples of equal weights taken from the meal. The distribution was unaffected by centrifugation and acidification to a pH of less than 1.0. Complete aspiration of gastric contents after studies resulted in less than 3% of the radionuclide in the supernatant. The remaining 97% of the activity in the aspirate was uniformly distributed throughout the meal phase.

Six hours after ingestion of the meal and after complete aspiration of the stomach, a gamma camera image failed to show residual radioactivity adsorbed onto the stomach wall. Serial images and counting performed over the thyroid, cardiac blood pool, liver, and spleen for the period up to 24 hours.
showed no detectable radioactivity in any of these organs. Urine collections performed over the 24 hour period after ingestion of the meal did not reveal any radioactivity.

In summary, the solid test meal provided a neutral, low fat preparation, uniformly labelled with a particulate radiopharmaceutical from which no significant dispersion, adsorption, or absorption occurred.

Target organ radiation absorption was low as calculated from published nuclear data on $^{99m}$Tc (Dillman, 1970) and data for absorbed fraction and organ masses (Snyder et al., 1969). The estimates were similar to previously published data using $^{99m}$Tc compounds for gastric emptying studies (Calderon et al., 1971; Chaudhuri, 1974) and significantly less than acceptable radiation exposure to the foetus upon abdominal radiography of pregnant women (Coates, 1971).

EQUIPMENT
Equipment consisted of a high performance, standard sized field of view Toshiba gamma camera (model GCA-102). A 1000 hole medium energy diverging collimator was used for all studies. The gamma camera was linked on line to a Digital Equipment PDP 11/40 computer. A Digital Equipment Gamma 11 Software package was used for data collection. The camera was equipped with a variable persistence storage oscilloscope and the computer terminals included a high resolution Tektronix 611 storage oscilloscope and a Tektronix 4010 key board visual display unit with a graphics capability.

PROCEDURE
All subjects were male medical students from whom consent was obtained in accordance with the proposals laid down by the Medical Research Council (Medical Research Council Annual Report, 1962-3).

The subjects were fasted for eight hours and then seated upright in front of the diverging collimator. As ingestion of the meal commenced, data collection started simultaneously. Therefore no initial data were missed. Consecutive 30 second frames were collected on a $64 \times 64$ matrix for one hour, 45 minutes (210 frames). A drug or placebo was given after one hour. At the end of the study, a flood field was collected for later correction of the data. This is essential, as there is inherent non-uniformity of response over the field of the gamma camera.

At 60 minutes, a placebo (normal saline) was given as a bolus injection in three subjects. In a further three subjects a bolus injection was added to a continuous infusion of normal saline which had been commenced before the beginning of the study. Four other subjects in this control group did not receive any injections or infusions of normal saline.

The response by the stomach to the following drugs given at 60 minutes was studied.

1. Hyoscine-N-butyl bromide (hyoscine) 20 mg subcutaneously statim in four subjects.
2. Bethanechol chloride (bethanechol) 4 mg subcutaneously statim in six subjects.
3. Pentagastrin peptavlon (pentagastrin) 1.2 $\mu$g kg$^{-1}$ h$^{-1}$ by continuous intravenous infusion in normal saline in nine subjects. In three subjects the rate of infusion was doubled to 2.4 $\mu$g kg$^{-1}$ h$^{-1}$, 40 minutes after the commencement of the infusion.

ANALYSIS OF DATA

Flood correction
Each frame of the study was corrected for non-uniformity of response of the camera by means of a correction matrix derived from the flood field. This is automatically done under Gamma II Software.

Isotope decay and dead time correction
All data in the studies were corrected for radioisotope decay resulting from the six hour half life of $^{99m}$Tc. A correction was performed to allow for the 27 $\mu$s dead time of the camera-computer system.

Curve construction
Using the Gamma II Software, an integrated image of the stomach was displayed on the 611 oscilloscope screen by adding representative frames from the beginning through to the end of the study (Fig. 1a). The total stomach was outlined using an irregular region of interest marker controlled by a joystick. The study was checked to confirm that the stomach remained within the irregular region of interest outlined, throughout the study. Subareas were also defined to enclose the proximal and distal regions of the stomach (Fig. 1b). Then the computer was instructed to extract the counts in each region of interest from each frame in the study and the curves displayed (Fig. 2).

CURVE ANALYSIS
Using a specially written DOS programme, exponential fits were established for parts of the curve which the operator designated on the Tektronix 4010 screen (Fig. 3). The half emptying times for the curves were calculated and the results displayed on the screen. For the assessment of the effects of placebo and drugs, the half emptying times before and after 60 minutes were compared for groups of subjects. In this way, each subject acted as his own intra-study control. Obvious changes in patterns
Fig. 1 (Left) Integrated image of the whole stomach. (Right) Regions of interest enclosing the proximal and distal subareas of the stomach.

Fig. 2 Curves showing the raw data for the whole stomach; the proximal subarea; and the distal subarea. The subject received normal saline throughout the period of the study with a bolus injection at 60 minutes.

Fig. 3 Exponential fit for the whole stomach curve in a subject given subcutaneous hyoscine at 60 minutes. Note the marked delay in emptying which persisted for 20 minutes.

Results

Reproducibility

Reproducibility of the technique was assessed from the analysis of 31 separate studies performed on 11 subjects. There was significant variation between subjects (p < 0.05) but not between their replicates or meals. A histogram constructed from these data...
shows a skewed normal distribution (Fig. 4) and consequently analysis of the results of all the data was normalized using a logarithmic transformation. Then statistical validity was determined using Student’s *t* test.

**CONTROL STUDIES**
A comparison of the rate of emptying before and after one hour in the four subjects who did not receive either placebo or drug showed no significant difference (Table). When intravenous saline was used as a placebo no significant difference was observed in half emptying times before and after 60 minutes (Table).

**STUDY OF DRUGS WITH KNOWN EFFECT ON INTACT STOMACH**
The effects of hyoscine and bethanechol are shown in the Table. It can be seen that hyoscine significantly prolonged the half emptying time. A reverse situation was found with bethanechol.

**EFFECT OF PENTAGASTRIN**
As can be seen from the Table, the overall rate of emptying of the stomach was significantly delayed by pentagastrin. Visual inspection of the whole stomach curves showed an immediate decrease in counts suggesting a transient increase in the rate of emptying (Fig. 5). This was seen in all subjects to varying degrees. Towards the end of the study, when the rate of infusion of pentagastrin was doubled, an immediate but transient increase in emptying was observed again. Inspection of the ‘subareas’ revealed a marked, rapid initial decrease in counts in the distal region which was obvious in all nine

<table>
<thead>
<tr>
<th>Drug</th>
<th>Number of Subjects</th>
<th>Half emptying time (T½)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Before 60 min</td>
<td>After 60 min</td>
</tr>
<tr>
<td>Without drugs</td>
<td>4</td>
<td>61 ± 8</td>
<td>61 ± 15</td>
</tr>
<tr>
<td>Saline</td>
<td>6</td>
<td>74 ± 36</td>
<td>60 ± 25</td>
</tr>
<tr>
<td>Hyoscine</td>
<td>4</td>
<td>57 ± 22</td>
<td>631 ± 292</td>
</tr>
<tr>
<td>Bethanechol</td>
<td>6</td>
<td>54 ± 9</td>
<td>29 ± 8</td>
</tr>
<tr>
<td>Pentagastrin</td>
<td>9</td>
<td>73 ± 25</td>
<td>326 ± 415</td>
</tr>
</tbody>
</table>

Table  Mean T½ in all groups

subjects. A simultaneous slight increase in the proximal region was noted (Fig. 5).

**Discussion**
Since Griffith *et al.* (1966) first used an isotope labelled meal in conjunction with the scintiscanner, a variety of meals have been used together with either the scintiscanner or gamma camera (Harvey *et al.*, 1970). Our technique allows for the continuous acquisition of data from the commencement of the meal. Two advantages are apparent:
1. No initial data is missed and therefore an actual measurement of the ‘starting index’ initially postulated by Hunt and Spurrell (1951) may be obtained.
2. Intra-study manipulations can be made with each subject acting as his own control. Therefore, the action of a drug can be ascertained from a single study and its effect on net gastric emptying, as well as on antral and fundic emptying, can be monitored immediately after administration.

In the absence of any form of drug administration, there was no change in the rate of emptying before and after 60 minutes. This is in keeping with the
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The former, which is used to inhibit peristalsis in radiology (Solanke et al., 1969) was found to significantly delay gastric emptying. Bethanechol, a cholinergic, should stimulate gastric motility and emptying. Another cholinergic, carbachol, increased emptying in subthreshold doses in the postvagotomy patient (Tinker et al., 1970). This study, using a pharmacological dose, has shown a similar finding in the intact stomach.

The interpretation of the data using the half emptying time proved satisfactory for measuring the effects of both hyoscine and bethanechol. Visual inspection of the curves in these subjects added little useful information. The curves from the distal stomach, after injection of these drugs, reflected the overall changes in gastric emptying (Fig. 3). However, the fluctuations in counts between 30 second frames were insufficient to directly relate the changes in net emptying to antral muscle activity.

In this study, pentagastrin produced an overall delay in gastric emptying (as measured by \( T^b \)) which is in accord with previous reports using both gastrin II and pentagastrin with liquid meals in man (Hunt and Ramsbottom, 1967) and dogs (Dozois et al., 1971; Cooke et al., 1972). The only contradiction is that of Aylett et al. (1969) who found no change with pentagastrin. This may be attributed to the type of meal or the presence of duodenal ulcers in their patients. Despite the delay in gastric emptying, visual inspection of the curves showed a marked initial increase in emptying, most evident in the distal stomach (Fig. 5). This suggests strong antral contractions in response to pentagastrin. The slight reciprocal rise in counts noted in the proximal stomach area is interpreted as partial reflux of contents into the fundus. The subsequent delay in gastric emptying can be explained by the intense antral (and probable duodenal) activity producing a physiological stricture. This is supported by photographs of four consecutive 30 second frames showing virtually complete emptying of isotope from the distal stomach within two minutes of commencing the infusion—a situation not seen at any other time during these studies (Fig. 6; compare Figs. 3 and 5).

It is probable that this antral contraction is sustained (Dozois et al., 1971; Kwong et al., 1971) and this finding would not support the suggestion that delayed emptying is due to rapid weak antral contractions (Sugawara et al., 1969). The transient rise in counts in the antrum seen after the maximal response to pentagastrin is presumably related to rapid refilling from the fundus. The smaller rise in counts noted in the total stomach curve is a little more difficult to explain. It is possibly related to reflux back into the stomach from the

**Fig. 5** Effect of pentagastrin. The first arrow signifies commencement of the infusion at 1.2 \( \mu g \) kg\(^{-1}\) h\(^{-1}\) and the second arrow the doubling of the infusion rate to 2.4 \( \mu g \) kg\(^{-1}\) h\(^{-1}\). Note the immediate but transient decrease in counts in the distal stomach with simultaneous increase in counts in the proximal stomach. The whole stomach curve reflects the changes from the distal stomach, but to a lesser degree. The subsequent slow rise in counts in the whole stomach and distal area is presumably related to refilling after reflux (see text).

results of Cowley et al. (1972). Normal saline, whether given as a continuous infusion or by bolus injection, had no significant effect on the subsequent rate or pattern of gastric emptying (Fig. 2). The validity of applying this technique to drugs studies was shown using hyoscine and bethanechol.
maximal effect at 6 μg kg⁻¹ h⁻¹ (Kwong et al., 1971; Misiewicz et al., 1967). An infusion of pentagastrin at 3 μg kg⁻¹ h⁻¹ produced results identical with endogenously released gastrin (Sugawara et al., 1969). However, despite the effects of pentagastrin on gastric emptying shown in this study, it is not possible to extrapolate further and suggest that they are analogous to endogenous gastrin. The physiological role of gastrin on gastric emptying in man remains uncertain.

Conclusion

A non-invasive technique for the continuous assessment of the emptying of a solid isotope meal from the human stomach is described. Reproducibility of the technique was confirmed. Ability to assess the effects of drugs administered during a study was demonstrated using hyoscine-N-butyl bromide and betanechol chloride. Pentagastrin pentavlon (at 1·2 μg kg⁻¹ h⁻¹) delayed the overall rate of emptying of food from the normal stomach. There is marked initial increase in emptying due to intense antral contraction, subsequently resulting in a stricture. The proximal stomach is unresponsive and only passive reflux from the distal stomach is seen.

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