Gastric emptying of solids in man

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SUMMARY The influence of the type and size of solid particles on their emptying from the stomach was studied using isotopically labelled chicken liver and inert particles in normal subjects and in patients who had undergone gastric surgery. In normal subjects, initial emptying of the liver was slower than that of inert particles both for large liver cubes (1 cm) and small cubes (0·3 cm). Liver emptying subsequently accelerated to be faster than emptying of the inert particles. Overall emptying of the liver given as small cubes was faster than large cubes; 50% emptied in 50 minutes and 70 minutes respectively. In the postoperative subjects, emptying of the liver and of the inert particles was identical. The findings are consistent with the hypothesis that solid foods such as liver are ground down and ‘liquefied’ by the action of gastric peristalsis before being discharged to the duodenum. Ingested particle size appears to influence the rapidity of this process, which should be distinguished from the propulsive function of the stomach where small solid particles are concerned.

After the ingestion of a mixed liquid and solid meal, the liquid component empties from the stomach more rapidly than the solid. Although there is still debate about the relative importance of the proximal stomach and of gastric peristalsis in controlling the emptying of liquids, it is generally agreed that the emptying of solids is controlled by the distal stomach, where peristaltic activity also serves to grind and mix the gastric contents before their delivery to the duodenum. Recent interest in the gastric emptying of solids has led to the development of several radioisotopically labelled solid foods suitable for study by scintigraphic methods. Liver labelled with technetium 99m has been particularly favoured but emptying studies using bread and egg white, cellulose fibre, and bran have also been described.

We have previously reported studies of gastric emptying in man using small inert particles labelled with technetium 99m, which are added to a normal meal. These particles are emptied from the stomach in an approximately linear manner with time, corresponding to the pattern observed for solids which are normal dietary constituents. However, as the inert particles cannot be ground down within the stomach to produce the fine suspension of solid matter which normally enters the duodenum, their relevance to normal gastric function has been questioned.

One would expect that if the concept of grinding and ‘liquefaction’ of solid foods such as liver were correct, the pattern of gastric emptying of such food would differ from that of inert solid particles. A marked difference has been found in the dog, but, to our knowledge, Guller et al. have conducted the only published study in which emptying of the two types of solid has been directly compared in man and their results show linear emptying with time for both. The present investigation was therefore undertaken to repeat the comparison in man by performing simultaneous scintigraphic measurements of gastric emptying of chicken liver and inert particles which were both incorporated in a mixed solid-liquid meal.

Methods

Six normal male volunteers (aged 25–34 years) each underwent two studies of gastric emptying using a meal which consisted of isotopically labelled chicken liver (approximately 20 g) and mashed potato (approximately 150 g) to which 99mTc-labelled paper particles had been added. The particles consisted of 30 to 35 pieces of filter paper, each approximately 3 mm square which were impregnated with a total

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of 200 μCi 99mTc sulphur colloid. After drying, the
paper was coated with Perspex. Experiments in vitro
have shown that there is no significant elution of the
isotope from these particles.1 The chicken liver was
prepared as described by Meyer et al.,4 except that
113mIn sulphur colloid was used in place of 99mTc
colloid. One hour after intravenous injection of the
colloid (3mCi) the chicken was killed. The liver was
then removed and cooked by boiling in water for five
minutes. Checks on the water after cooking revealed
no detectable elution of indium.

Approximately half the cooked chicken liver (contain-
ing 200–300 μCi 113mIn) was cut into cubes, either
large (1×1×1 cm) or small (0·3×0·3×0·3 cm) and
thoroughly mixed with the potato and the Tc-labelled
particles. The subject was then given the meal
together with a warm (37°C) drink made up by
dissolving three Oxo beef stock cubes in 400 ml water.
The subjects were asked to consume the drink evenly
over the period during which they were eating the
solid food, but otherwise no instructions were given
concerning chewing or the speed of eating.

For one study, the subject ate the meal with the
larger liver cubes and, in the other study, which was
carried out on the following day, the subject was
given a meal containing the liver cubes of small size.
On each occasion gastric emptying of the two iso-
topes was measured using a rectilinear scanner set up
for bilateral count detection.15 After correction of
observed counts for physical decay of the radioisotopes, gastric emptying rates were calculated by
linear regression of intragastric 99mTc and 113mIn
against time. Comparisons of results were made us-
ing Student's t test for pair differences.

After the investigation of normal subjects was
completed, similar measurements were made on five
patients with diarrhoea attributed to previous gastric
surgery. The operations (four Polya gastrectomy,
one vagotomy and pyloroplasty) had all been carried
out because of peptic ulcer and had been performed
one year or more previously; diarrhoea was defined
as the production of fluid faeces with sufficient fre-
quency that the patient was classified in Visick grade
3 or 416 by an independent observer. After informed
consent had been obtained, these patients were
studied on one occasion only, using the large (1 cm)
and the small (1 cm) liver cubes and the Tc-labelled particles.

The simultaneous use of 113mIn and 99mTc in studies
of gastric emptying was approved by the local Advis-
ory Ethical Committee.

Results

Emptying patterns of the labelled liver and paper
particles in the normal subjects are shown in Fig. 1.
Ten minutes after ingestion of the meal, more of the
particles than liver had been emptied from the stom-
ach, irrespective of the size of liver cubes ingested
(Fig. 1a and b). However, from 10 minutes onwards,
emptying rates of the liver were faster than those of
the paper particles (Table). Comparisons of the amounts
of liver emptied at 120 minutes show that significantly
more was emptied when it was given as small rather
than large cubes (Fig. 2a). The two measurements
made with paper particles give closely similar results
(Fig. 2b).

In the post-gastric surgery patients, the liver and
the paper particles emptied rapidly, 85% leaving the
stomach in the first 10 minutes after ingestion of the
meal (Fig. 3). Overall, there was no appreciable dif-
ference between the emptying of the two isotopes.

Fig. 1 Gastric emptying of 113mIn-labelled liver and
99mTc-labelled paper particles in six normal volunteers.
(a) Simultaneous study of large liver cubes (○) and paper
particles (△); (b) Simultaneous study of small liver cubes
(●) and paper particles. Data are means±SEM. *P<0.05.
**P<0.01.
Table  Gastric emptying rates of $^{113m}$In-labelled liver and $^{99m}$Tc-labelled paper particles during period 10–120 minutes after meal ingestion in six normal volunteers

<table>
<thead>
<tr>
<th>Liver cubes</th>
<th>Paper particles</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>0.58±0.07</td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>0.73±0.03</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.38±0.11</td>
<td>p&lt;0.05</td>
</tr>
<tr>
<td></td>
<td>0.41±0.05</td>
<td>p&lt;0.0025</td>
</tr>
<tr>
<td></td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Data are means±SEM. NS: not significant = p>0.05 (one tail).

Discussion

These results are consistent with evidence that ingested liver is 'liquefied' in the stomach before being passed through the pylorus. Emptying of the liver in the normal subjects was initially slower and then faster than the inert particles, which might be expected if the liver is progressively transformed from a solid to a more rapidly emptied 'liquefied' form. The fact that the liver emptied a little more slowly than the paper particles during the first 10 minutes may perhaps be attributable to differences in shape of the two solids (liver cubes compared with paper squares) but this explanation remains unproven. However, the subsequent faster emptying of the liver when presented as small rather than large cubes implies that 'liquefaction' was more rapid with the smaller pieces of liver. In the dog, finely, ground or homogenised liver empties more rapidly than liver given as discrete cubes and the same finding may reasonably be expected in man. The present results indicate that, in addition, the size of the liver cubes presented to the subject affects the rate at which the food is emptied from the stomach.

In the patients who had undergone gastric surgery, the liver and the inert particles emptied together. Rapid emptying took place during the first 10 minutes after meal ingestion, as observed in previous investigations. This abnormality in patients who have undergone gastric surgery tends to be greater in those with postoperative diarrhoea than in those without symptoms and the selection of patients for the present study was intended to maximise the abnormality. The results show that, in such patients, gastric emptying of the two types of solid is indistinguishable.

Fig. 3 Gastric emptying of $^{113m}$In-labelled liver (○) and $^{99m}$Tc-labelled paper particles (△) in five patients who had undergone gastric surgery. Data are means±SEM.

Fig. 2 Gastric emptying of $^{113m}$In-labelled liver and $^{99m}$Tc-labelled paper particles in six normal volunteers.

(a) Comparison of large (○) and small (◆) liver cubes.
(b) Comparison of the two studies of paper particles (△).

Data are means±SEM. *p<0.05.
The present results differ from those of Guller et al. who found that in normal subjects 99mTc-labelled liver emptied from the stomach more slowly than 99mTc-labelled paper particles. However, in Guller's study, the half emptying time of the liver was almost four hours, whereas other investigators using labelled liver in comparable meals have recorded half emptying times between 75 and 110 minutes. The reasons for this difference are not clear. In the present study, which used a larger volume of fluid in the meal, half emptying times for the large and small liver cubes were approximately 70 minutes and 50 minutes respectively. It is, however, of considerable interest that, despite some differences in meal size and composition, and much slower emptying of the liver, the mean emptying rate of the inert particles recorded by Guller (0.36% per minute) was very similar to the rates observed in the present study. This suggests that there are factors which influence the intragastric grinding of foods such as liver more profoundly than they influence the propulsive activity of the stomach for small solid particles. It would seem that these processes should be distinguished. Both these functions are usually attributed to gastric antral peristalsis, but more specific information about the mechanics of each is not available.

In normal subjects, the use of inert particles to study gastric emptying does not precisely represent the emptying of solid foods amenable to 'liquefaction'. Nevertheless, under the conditions of the present study, the differences between the liver and inert particles were small, indicating that liquefaction is not an essential precondition of the gastric emptying of solids. The present findings are consistent with our previous suggestion that simultaneous use of inert particles and a liquid phase marker in a mixed solid-liquid meal can provide physiologically relevant measurements which reflect aspects of the behaviour of liquids and solids in the stomach.

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References

ADDENDUM
Since this paper was accepted for publication we have learned of the investigation by Bertrand et al. (Gastroenterologie Clinique et Biologique 1980; 4:770–6) in which gastric emptying of inert radio-opaque granules and isotopically labelled rabbit liver were compared and found to empty from the stomach at similar rates.