# Section IV: Methods to study gastric emptying

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**REVIEW ARTICLE**

# Methods to Study Gastric Emptying

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**KEY WORDS:** gastric emptying; scintigraphy; ultrasonography; impedance epigastrography; magnetic resonance; breath tests.

Many techniques have been developed to study gastric emptying in humans (Table 1). The large number and great variety of techniques is perhaps the best indication that gastric emptying is complex and that no single technique is able to measure or visualize all aspects of the phenomenon.

## INTUBATION TECHNIQUES

Intubation techniques have been largely abandoned in clinical practice because they are invasive. In addition, gastric aspiration studies measure only liquid emptying. Nevertheless, the results obtained with Hunt's serial test meals (1, 2) are a good example of how expensive equipment is not always necessary to obtain important results. It suffices to replace breakfast, for some months or years, by a liquid meal, which is then aspirated before it leaves the stomach completely.

Duodenal dye dilution techniques are excellent as a research tool, but are time-consuming and require a good deal of expertise. Although solid emptying can also be measured with this technique, it is possible that transpyloric intubation may itself significantly delay emptying of solids into the duodenum (3).

## RADIOLOGICAL TECHNIQUES

Overall, radiological techniques are considered to be unsatisfactory for use in gastric emptying studies. It is therefore surprising to learn that gastric emptying of radiopaque spheres yields emptying patterns for solids that parallel those obtained with gamma camera scintigraphy (4), provided the spheres are of an appropriate diameter and density and are administered in adequate numbers. Radioisotopically labeled spheres 1.4 ± 0.3 mm in diameter, with a specific gravity of 1, empty at the same rate as [$^{99m}$Tc] liver (5). In the absence of intestinal feedback, gastric emptying of small spheres is determined by the number of spheres in the stomach (6).

## SCINTIGRAPHY

Scintigraphy has become the gold standard for gastric emptying studies in clinical research and clinical practice, as the technique shows not only the time course of gastric emptying of liquids and/or solids, but also allows the intragastric distribution of meal components to be followed. With special techniques, it is even possible to visualize gastric contractions together with emptying (7).

Most of the problems, pitfalls, and possible errors of scintigraphy have been identified, and solved (8, 9). Attenuation problems related to anterior passage of the meal when it moves from fundus to antrum have been addressed with techniques such as geometrical means with a dual-headed camera, frequent rotation of the patient, lateral imaging, or peak-to-scatter ratio.

One of the major achievements of scintigraphy has been to follow the time course of the emptying of liquids and solids separately and simultaneously by using specific markers. When there is no feedback slowing of gastric emptying from the entrance of material into the intestine, liquids show a first-order exponential emptying pattern. Solids, on the other hand, empty after a lag phase at a constant rate (0-order). Fats in the oil phase empty at a different rate to the aqueous phase (10).

## EMPTYING OF GAS

It is surprising that virtually no attention has been paid to the emptying of gas. Normal people swallow about once per minute between meals, but during a

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TABLE 1

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|---|---|
| Intubation techniques | Gastric aspiration |
| | Gastric dye dilution |
| | Duodenal dye dilution |
| Imaging techniques | Radiology |
| | Scintigraphy |
| | Ultrasonography |
| | MRI |
| Indirect techniques | Blood tests |
| | Breath tests |

20-min meal, some 100 swallows are taken. This means that about 10 liters of air is swallowed per day. It is of course possible to belch and burp in order to get rid of the air accumulating in the gastric fundus. All young mothers know that their baby has to belch a couple of times before he/she will digest well, and in some cultures loud belching at the end of the meal testifies to the pleasure of a good meal, but most of us must empty part of the swallowed air into the intestine. How is this emptying of gas achieved and how can it be studied? Are there disorders in gas emptying that cause symptoms? Perhaps these are problems that should be addressed.

## ULTRASONOGRAPHY

One of the most appealing aspects of imaging techniques is that they offer the possibility not only to measure the rate and pattern of gastric emptying, but they can also be used to visualize contractions of the gastroduodenal wall, and the movements of the gastric contents.

Ultrasonography is able to demonstrate antropyloroduodenal motility and flow of contents (11). Unfortunately, ultrasonic methods measure only changes in volume of the gastric antrum (they do not visualize the gastric fundus and corpus), and the gastric emptying rate measured by ultrasonography correlates with liquid emptying rather than with solid emptying, even following ingestion of a mixed meal (12). Perhaps the greatest disadvantage of this noninvasive and inoffensive technique is that it is time-consuming and requires an experienced and skillful operator.

## IMPEDANCE EPIGASTROGRAPHY AND APPLIED POTENTIAL TOMOGRAPHY

Recently, two new imaging techniques have been described, which are still under clinical evaluation. When the stomach is filled with a liquid meal of low electrical conductivity, the impedance of the epigastric region to a constant current increases. Measurement of this impedance can be used to follow gastric emptying of the meal. Impedance epigastrography uses a set of four electrodes and results in a tracing that shows the time course of gastric emptying (13). The needs to immobilize the patient during the entire study period and to suppress acid secretion with cimetidine in order not to change the electrical impedance of the gastric contents limit the practical application of this method.

In applied potential tomography images of transverse sections of the stomach are obtained using a ringlike array of 16 electrodes arranged around the upper abdomen with a rotating pair of drive electrodes and the remaining 13 pairs of adjacent electrodes measuring the impedance (14). Measurements of gastric emptying of nonconductive liquids and simple meals like mashed potatoes recorded with impedance measurement show a fairly good correlation with the results obtained by scintigraphy or dye dilution techniques.

Once technical improvements allow simultaneous measurements of epigastric impedance at several levels in the epigastrium, gastric images may become sufficiently defined to follow both gastric volume and gastric contractions. This would be very useful, because the technique could be rather simple and inexpensive and perhaps the equipment might be portable.

## MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging of the gastric region using [Gd] DOTA as a liquid phase marker has recently been described (15). By performing multiple transaxial T1-weighted sections, three-dimensional images of the meal and the stomach can be constructed. Gastric emptying curves of liquid meals obtained with this technique correlate very well with scintigraphic curves. The advantage of the MRI technique lies in the possibility of simultaneously measuring gastric emptying and the total volume of gastric contents (gastric secretion + swallowed saliva and duodenal reflux). Now that echo planar magnetic resonance imaging is available (16), snapshot images requiring a data acquisition time of only 64–128 msec can be made, which may allow simultaneous recording of both gastric volume and gastric contraction.

## INDIRECT METHODS

Gastric emptying of a meal can be evaluated by measuring the part of the meal that remains in the

stomach, the part that enters the duodenum, or the part that is absorbed from the duodenum and appears in blood or in expired air. These latter indirect methods are based on several assumptions. The rate-limiting step in the appearance of the marker in blood or air should be gastric emptying; absorption, transport, and metabolism of the marker should be much quicker. The amount of marker appearing in blood or air sample should be a constant proportion of the amount absorbed from the intestine, and the amount absorbed in the duodenum should be related to the load of labeled nutrient entering the duodenum.

## BREATH TESTS FOR MEASURING GASTRIC EMPTYING

We have recently developed a technique based on breath testing using [$^{14}$C]octanoic acid as a marker to measure solid gastric emptying (17). Octanoic acid is easily dissolved in and firmly bound to egg yolk when baked, and the baked egg is only broken down by the hydrolytic activity of pancreatic enzymes in the duodenum. Following hydrolysis, [$^{14}$C]octanoic acid is rapidly absorbed and transported to the liver, where it is preferentially oxidized to $^{14}CO_2$. The test was evaluated by comparing results obtained from breath tests with those of simultaneously performed scintigraphy. Mathematical formulae were developed to calculate the half-emptying time, the duration of the lag phase, and an emptying coefficient, which provides a good indication of the overall emptying rate. There was a strong correlation between emptying parameters determined by scintigraphy and breath testing. A breath test has also been developed to measure liquid gastric emptying, using [$^{14}$C]glycine as marker of the liquid phase (Maes, unpublished observations), and there is also a good correlation between the results of this test and those obtained with scintigraphy.

The advantages with these techniques are the substantial reduction and, with stable isotopes, complete avoidance of radiation exposure, together with the possibility of performing the test at the bedside or at home. Such breath samples can be subsequently sent to a remote laboratory for automated analysis.

## PROBLEMS AND PERSPECTIVES

1. The first problem concerns the relation between clinical symptoms and gastric emptying disorders. There is no doubt that gastroparesis may cause pain, nausea, and vomiting. Not infrequently, however, when a gastric emptying disorder is suspected in a patient with so-called idiopathic dyspepsia, gastric emptying measurements are normal. It is also not unusual that treatment of a dyspeptic patient with a prokinetic drug improves the delay in gastric emptying but does not improve the patient's symptoms. It seems, therefore, that the relationship between symptoms and gastric emptying disorders is not very good. This is not surprising if it is realized that delayed gastric emptying may be due to a variety of gastric or intestinal motor disorders and that the symptoms may be related to disturbances in visceral sensation. Too little is known about motility disorders or disturbances of visceral sensation to predict the results of treatment. Gastroesophageal reflux disease is said to be a motility disorder, yet antisecretory drugs are far better than prokinetics for the treatment of reflux esophagitis. Dyspepsia may be due to a motility disorder, yet drugs that increase the sensation threshold may yield better results than prokinetics.

2. What can be done to improve the relationship between symptoms and test abnormalities? It is generally believed that a solid test meal is more sensitive than a liquid meal in detecting emptying abnormalities. However, tests of liquid emptying were more frequently abnormal than those of solid emptying in idiopathic dyspepsia (18), and it has been proposed that comparison of a nutrient and a nonnutrient liquid meal may provide the most useful tests of gastric emptying, because they may provide information on the intestinal feedback mechanism that delays gastric emptying (19). Volume and caloric load of current test meals, either solid or liquid, are currently not standardized. Now that easy-to-perform, noninvasive tests are becoming available, with little or no radiation burden, the time has come to investigate which test meal or combination of test meals yields the most useful diagnostic information.

3. Abnormal gastric emptying should be considered as a marker of a gastric or intestinal motility disorder (20). As it is often not possible to determine the nature of the underlying motility disturbance by performing gastric emptying tests, it seems logical to assume that a method that yields information on both the emptying pattern and the underlying motility disorder would be better than currently available techniques. Improved imaging

techniques or the combined use of manometry and breath tests is one potential solution.

4. A final suggestion is to perform studies on gastric emptying of gas.

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