

Simultaneous Measurement of Gastric Emptying with a Simple Muffin Meal Using [¹³C]Octanoate Breath Test and Scintigraphy in Normal Subjects and Patients with Dyspeptic Symptoms

MATTHEW Q. BROMER, DO,* STEVE B. KANTOR,* DAVID A. WAGNER, PhD,†
LINDA C. KNIGHT, PhD,‡ ALAN H. MAURER, MD,‡ and HENRY P. PARKMAN, MD*

The objective of this study was to determine how the [¹³C]octanoate breath test (OBT) using a muffin meal correlates with gastric emptying scintigraphy (GES) in normal subjects and patients with dyspeptic symptoms. Ten normal subjects and 23 patients with dyspeptic symptoms underwent simultaneous GES and [¹³C]OBT. After an overnight fast, a muffin labeled with [^{99m}Tc]-sulfur colloid and [¹³C]octanoate was ingested along with water labeled with [¹¹¹In]DTPA. Breath samples and scintigraphic images were obtained at baseline and at regular postprandial intervals over 6 hr. In the normal subjects, the mean GES T_{1/2} of solids and liquids were 64 ± 17 and 55 ± 27 minutes, respectively. The calculated OBT T_{1/2} using the 6-hr breath collection was 138 ± 15 min and correlated with T_{1/2} for solids by GES ($r = 0.664$; $P = 0.051$), but did not correlate with T_{1/2} for liquids by GES ($r = 0.13$; $P = 0.738$). In dyspeptic patients, the T_{1/2} for GES was 87 ± 53 min and 81 ± 70 min for solids and liquids, respectively. The mean OBT T_{1/2} was 155 ± 57 min and correlated with GES T_{1/2} for solids ($r = 0.86$; $P < 0.001$) and GES T_{1/2} for liquids ($r = 0.73$; $P < 0.001$). Delayed gastric emptying (GE) of the muffin meal was identified by scintigraphy in seven patients. The sensitivity and specificity for OBT identifying delayed GE were 86% and 94%. Use of the initial truncated 4-hr OBT results also revealed a significant correlation between OBT and GES T_{1/2} for solids ($r = 0.86$; $P < 0.001$) with sensitivity and specificity for detecting delayed GE of 86% and 94%, respectively. In addition, a linear regression model was able to reduce the number of collection points to four, while maintaining the same sensitivity and specificity. In conclusion, the OBT for GE, using an easily prepared muffin meal, significantly correlates with GES for solids. This muffin-based OBT is a sensitive and specific method to detect delayed GE in dyspeptic patients.

KEY WORDS: gastric emptying; functional dyspepsia; breath test; scintigraphy.

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From the *Gastroenterology Section, Department of Internal Medicine, and ‡Nuclear Medicine Division, Department of Diagnostic Imaging Temple University School of Medicine, Philadelphia, Pennsylvania; and †Metabolic Solutions, Inc., Nashua, New Hampshire.

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Address for reprint requests: Dr. Henry P. Parkman, Gastroenterology Section, Department of Medicine, Temple University Hospital, Parkinson Pavilion, 8th Floor, 3401 N. Broad Street, Philadelphia, Pennsylvania 19140.

INTRODUCTION

The [^{13}C]octanoate breath test (OBT) has been proposed as a noninvasive, nonradioactive technique for measuring gastric emptying (GE) (1–3). Following ingestion of a meal containing [^{13}C]octanoate, mixing occurs in the stomach, where the meal is triturated into small particles that can empty into the duodenum. The [^{13}C]octanoate is then easily absorbed in the proximal small bowel and metabolized in the liver to $^{13}\text{CO}_2$, which is expelled via the lungs. Breath samples, taken during the OBT at baseline and at regular intervals following meal ingestion, are assayed for $^{13}\text{CO}_2$ content. The rate-limiting step from ingestion to excretion of ^{13}C is GE (1). Thus, OBT is an indirect measure of GE. Previous studies have shown that the OBT, using an egg meal, is reproducible and correlates with scintigraphy for measuring GE (1, 2). Some investigators have suggested the test can be shortened from the conventional 6 hr, although this might be meal specific (2–4).

A variety of meals have been used for the OBT in previous studies (1, 5, 6). A standardized test meal that is easily prepared and inexpensive would be helpful for using [^{13}C]OBT as a clinical test for measuring GE. We have been investigating the use of an easily prepared muffin meal to use for OBT (7, 8). Our studies have shown that the OBT using a muffin meal correlates with scintigraphy in normal subjects (7), that this OBT can detect changes in gastric emptying in normal subjects given prokinetic agents (7), and that a 350-kcal meal rather than a smaller 250-kcal meal appears to be better in assessing gastric motility (8). How well this OBT performs in assessing GE in dyspeptic patients, who may have delayed GE, is not known.

The aims of this study were threefold: (1) to determine how well the [^{13}C]OBT, using a simplified muffin meal, correlates with emptying of the solid and liquid phases of the meal as determined by gastric emptying scintigraphy (GES) in normal subjects and patients with dyspeptic symptoms; (2) to determine the sensitivity and specificity of OBT in detecting delayed GE using simultaneous GES as the standard; and (3) to determine if shortening the OBT from the conventional 6-hr test duration affects the correlation with GES and the sensitivity and specificity of detecting delayed GE.

MATERIALS AND METHODS

Study Subjects. Ten normal subjects (6 women, 4 men; age range: 18–54 years; mean age: 34 years) without gas-

trointestinal symptoms and 23 patients (20 women, 3 men; age range: 20–72 years; mean age 43 years) with dyspeptic symptoms of upper abdominal pain and/or discomfort, nausea, vomiting, early satiety, or abdominal bloating underwent simultaneous GES and OBT. The main symptoms of the dyspeptic patients were nausea/vomiting (in 8 patients), bloating (in 7), abdominal pain/discomfort (in 3), regurgitation (in 3), and heartburn (in 2). Eleven of these patients also underwent GES using the conventional radiolabeled egg sandwich meal utilized at Temple University Hospital (9) as part of their clinical evaluation within four weeks of the OBT.

Study Design. All subjects signed an informed consent approved by the Institutional Review Board of Temple University School of Medicine.

Subjects fasted for 12 hr prior to the initiation of the study. This study used a 350-kcal muffin meal (carbohydrate: 63 g, fiber: 3 g, protein: 7 g, fat: 6.8 g) formulated as a powdered mix (Metabolic Solutions, Inc., Nashua, NH, USA) in a small, microwavable container (7, 8). This meal has 18.6% of calories as fat, similar to the fat content of egg meals used in prior breath test studies (1). One hundred milligrams of [^{13}C]octanoate in 60 cc of water were added to the power mix. For the purposes of this evaluation, 500 μCi of [$^{99\text{m}}\text{Tc}$]sulfur colloid was also added to the water. After mixing thoroughly with a disposable spatula, the muffin mixture was microwaved for 2.5 min at 80% power. The muffin was immediately removed from its container, sliced in half, and allowed to cool for 5 mins. The muffin was ingested with 100 cc of water and eaten within 10 min, at which time an additional 50 cc of water labeled with 125 μCi [^{111}In]DTPA was ingested.

Scintigraphic images (anterior and posterior) in both $^{99\text{m}}\text{Tc}$ and ^{111}In windows were obtained with a gamma camera immediately following completion of the meal, every 15 min for the first hour, every 30 min for the second hour, and then every hour for the next 4 hr. Breath samples were collected using a breath test kit (Quintron, Menomonee Falls, Wisconsin, USA) and transferred to breath storage tubes at baseline and at 15-min intervals following meal ingestion for 6 hr. At the completion of the study, the breath storage tubes were mailed overnight to the mass spectrometry laboratory (Metabolic Solutions, Inc.) to be analyzed.

Determination of GES $T_{1/2}$. Each scintigraphic image obtained was analyzed to determine the gastric counts for both solids and liquids (9, 10). The gastric region of interest (ROI) was manually drawn around the total stomach at each time interval. A geometric mean of the gastric counts was used to correct for depth changes [geometric mean counts = square root (anterior counts \times posterior counts)]. The counts were corrected for radioisotope decay.

The data, expressed as percent of the initial meal remaining in the stomach versus time, were fitted to a modified power exponential function (11): $y(t) = 100 [1 - (1 - e^{(-kt)})^\beta]$. The gastric half-emptying times ($T_{1/2}$) and lag phase (T_{lag}) were then determined from the fitted parameters for both solids and liquids using the following formulas (11): $T_{1/2} = -\text{Ln}(1 - 0.5^{(1/\beta)})/k$ and $T_{\text{lag}} = \text{Ln}(\beta)/k$.

Determination of OBT $T_{1/2}$. The breath samples were analyzed for $^{13}\text{CO}_2$ content at Metabolic Solutions, Inc. (NH), as previously described (7). The amount of $^{13}\text{CO}_2$ in

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the breath storage tubes was measured with a Finnigan BreathMat Plus gas isotope ratio mass spectrometer (Bremen, Germany). The ratio of $^{13}\text{CO}_2$ to $^{12}\text{CO}_2$ (mass 45 to 44) was measured in the sample and compared to a reference gas (5% CO_2 , balance 75% N_2 , 20% O_2). The reference gas was calibrated with international standards. The units of measurement were atom percent ^{13}C and defined by: atom % $^{13}\text{C} = \frac{^{13}\text{CO}_2}{(^{13}\text{CO}_2 + ^{12}\text{CO}_2)} \times 100\%$.

Standards of $^{13}\text{CO}_2$ at three different levels of enrichment were measured before and after each daily run to check instrument performance. The analytical precision of the instrument was 0.0001 atom % ^{13}C .

Data were expressed as the percent dose exhaled per hour and cumulative percent of dose over time. The carbon dioxide production was assumed to be 5 mmol/m² body surface area/hr (12). Body surface area was calculated according to the method of Boyd (13). Curves fitted to the percent dose per hour and cumulative percent of dose provided constants were used to calculate the gastric emptying parameters $T_{1/2}$ and T_{lag} according to the method of Ghooos et al (1). $T_{1/2}$ was calculated from the cumulative percent dose curve as one half the maximum cumulative excretion of $^{13}\text{CO}_2$ at infinite time. The R^2 coefficient obtained between the experimental and fitted $^{13}\text{CO}_2$ excretion curve was calculated. Only mathematical fits of R^2 coefficient >0.90 were used for analysis.

In Vitro Studies of Muffin Meal. The retention of the [$^{99\text{m}}\text{Tc}$]sulfur colloid label to the muffin was confirmed by testing *in vitro* (14). The muffin was prepared as described for the patient studies, and allowed to cool. A sample of approximately 1 g muffin (cut into pieces approximately 4 mm on each side) was suspended in 6 ml gastric juice aspirated from a human volunteer. Triplicate samples were prepared. The gastric juice–muffin suspensions were incubated in an orbital shaker (model 360, Precision Scientific, Chicago, Illinois, USA) at 37°C for 3 hr, after which each suspension was filtered through cotton to separate solids from liquids. The radioactive content in each fraction was assessed in a dose calibrator (CRC 30, Capintec, Ramsay, New Jersey, USA). The amount bound initially at $T = 0$ was assessed by suspending muffin pieces in phosphate buffered saline and filtering immediately. Greater than 95% of the $^{99\text{m}}\text{Tc}$ was associated with the solid particles, both before and after incubation for 3 hr. This compares to 98% and 94% binding of [$^{99\text{m}}\text{Tc}$]sulfur colloid label to an egg meal (14).

The retention of [^{13}C]octanoate to the muffin was evaluated by incubating pieces of labeled muffin (total 1 g) in artificial gastric juice (Fisher Scientific, Fair Lawn, New Jersey) for 3 hr at 37°C. The pieces were dropped into a dialysis membrane (6000–8000 molecular weight cutoff; Fisher Scientific), bathed by gastric juice, and mixed continuously to simulate gastric motor activity. Samples of dialysate were taken every 30 min for 3 hr. Carbon-13 in the dialysate was determined in duplicate by combustion isotope ratio mass spectrometry (Europa Scientific 20-20, Crewe, England). Greater than 96% of the ^{13}C label was retained on the muffin in comparison to initial activity.

Statistical Analysis. All statistical analyses were performed using SPSS for Windows 7.5 (Microsoft). Gastric emptying results were expressed as the mean \pm SD. The correlations between half emptying times ($T_{1/2}$) obtained

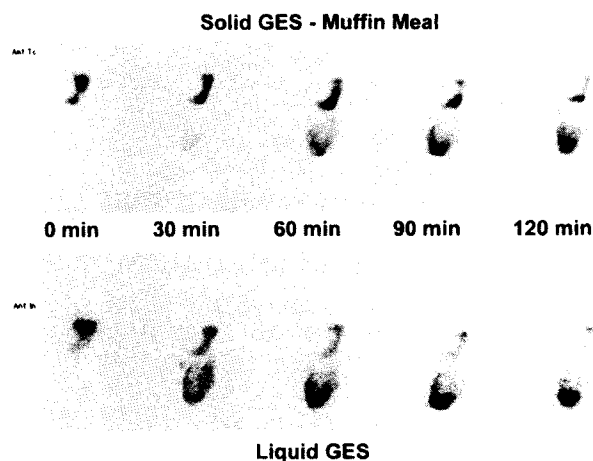


Fig 1. Dual-label gastric emptying scintigraphy for solid- and liquid-phase gastric emptying of the muffin meal and water in a normal subject. The left panels are the $^{99\text{m}}\text{Tc}$ images for solid-phase gastric emptying of the [$^{99\text{m}}\text{Tc}$]sulfur colloid labeled muffin. The right panels are ^{111}In images for liquid-phase gastric emptying of the [^{111}In]DTPA-labeled water. Only anterior images are shown.

by different methods (OBT and GES) were analyzed with the Pearson correlation. This was performed initially for the OBT for gastric emptying result using the entire 6 hr breath test results followed by a recalculation of the gastric emptying result from the OBT using an initial truncated 4-hr breath collection data set. In addition, linear multiple regression analysis with best subsets approach was used to further reduce the number of data points that could predict scintigraphic gastric emptying $T_{1/2}$ rates by the OBT. Minitab Version 13 software was used to select the smallest subset of predictors (OBT data points) that would predict scintigraphic gastric emptying rates with a clinically significant regression coefficient ($R^2 > 0.5$ and $P < 0.05$). Lee et al (3) initially described this approach of reducing the number of OBT data points.

RESULTS

OBT in Normals. An example of dual-label gastric emptying scintigraphy for solid- and liquid-phase gastric emptying of the muffin meal and water is shown in Figure 1. The mean $T_{1/2}$ for GES during simultaneous OBT for normal subjects was 64 ± 17 min and 55 ± 27 min for solids and liquids, respectively (Table 1).

An example of the excretion of [^{13}C]octanoate over time in a normal subject is shown in Figure 2A. One normal subject had a poor fit of the $^{13}\text{CO}_2$ excretion curve ($R^2 = 0.79$) and was not used in the statistical analysis. For the nine evaluable normal subjects, the mean $T_{1/2}$ for OBT was 138 ± 15 min and 150 ± 25 min for the entire 6-hr and an initial truncated 4-hr breath collection data sets, respectively. The 4- and 6-hr values for $T_{1/2}$ for OBT were significantly longer

TABLE 1. RESULTS OF $T_{1/2}$ FOR GASTRIC EMPTYING MEASURED BY SCINTIGRAPHY AND OBT IN NORMAL SUBJECTS AND DYSPLEPTIC PATIENTS*

	$T_{1/2}$ (min)			
	GES solids	GES liquids	OBT 6-hr data	OBT 4-hr data
Normal subjects ($N = 9$)	64 ± 17	55 ± 27	138 ± 15	150 ± 25
Range	(43-94)	(18-98)	(112-161)	(116-201)
Patients ($N = 23$)	87 ± 53	81 ± 70	155 ± 57	175 ± 96
Range	(36-306)	(16-350)	(85-334)	(78-488)

*Results expressed as mean \pm SD.

($P < 0.001$) than the $T_{1/2}$ for GES. In addition, the mean calculated $T_{1/2}$ for OBT using the 4-hr data set was significantly ($P = 0.028$) larger than that calculated from the entire 6-hr data set, as previously described (8).

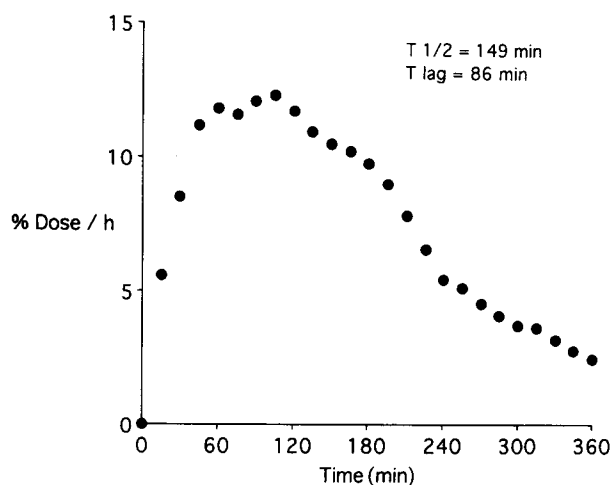
The OBT $T_{1/2}$ correlated significantly with $T_{1/2}$ of solids by GES using the 4-hr OBT data set ($r = 0.863$; $P = 0.003$) and the 6-hr OBT data set ($r = 0.664$; $P = 0.051$) as shown in Table 2.

The OBT $T_{1/2}$ did not correlate with $T_{1/2}$ of liquids by GES using either the 4-hr OBT data set ($r = 0.085$; $P = 0.828$) or the 6-hr OBT data set ($r = 0.130$; $P = 0.738$).

OBT in Dyspeptic Patients. The $T_{1/2}$ for GES during simultaneous OBT for the dyspeptic patient group was 87 ± 53 minutes and 81 ± 70 min for solids and liquids, respectively (see Table 1). An example of the excretion of ^{13}C over time in a dyspeptic patient is shown in Figure 2B. The $T_{1/2}$ for OBT was 155 ± 57 min and 175 ± 96 min for the 6-hr and 4-hr breath collection data sets, respectively. The OBT $T_{1/2}$ correlated significantly with $T_{1/2}$ for solids by GES using the 6-hr OBT data set ($r = 0.858$; $P < 0.001$) and the 4-hr OBT data set ($r = 0.860$; $P < 0.001$) as seen in Table 2. OBT $T_{1/2}$ also correlated with $T_{1/2}$ for liquids by GES, although the correlation was poorer than that for solids, using both the 6-hr OBT data set ($r = 0.725$; $P < 0.001$) and the 4-hr OBT data set ($r = 0.745$; $P < 0.001$).

In evaluating the raw data, there was an outlier data point representing a patient with severely delayed GE (GES $T_{1/2}$ of solids = 306 min and GES $T_{1/2}$ of liquids = 350 min). When this patient was excluded from the analysis, the correlation of OBT with GES of solids remained significant for the 6-hr data ($r = 0.76$; $P < 0.001$) and the 4-hr data ($r = 0.71$; $P < 0.001$) while the correlation with GES of liquids became insignificant for both the 6-hr ($r =$

A. Normal Subject (6 hour OBT)



B. Dyspeptic Patient (6 hour OBT)

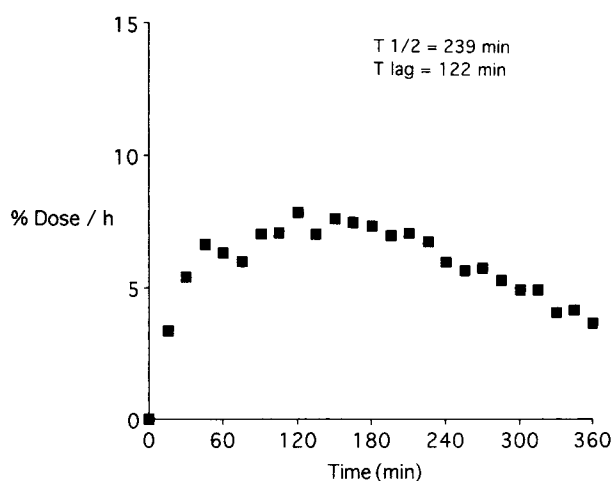


Fig 2. Examples of ^{13}C excretion curves in the breath samples during the OBT in two subjects. The data are expressed as percent dose exhaled per hour. (A) Normal subject with normal gastric emptying. (B) Dyspeptic patient with delayed gastric emptying. The $T_{1/2}$ is 239 min, above the upper of limit of normal of 167 min for the 6-hr breath test data set.

0.39; $P = 0.08$) and 4-hr ($r = 0.39$; $P = 0.08$) data sets.

Pooled OBT Data from Normal Subjects and Dyspeptic Patients. The data from normal subjects and dyspeptic patients were pooled to determine the correlation between GES and the OBT. When the data were combined, the correlation of the OBT to GES was $r = 0.86$ ($P < 0.001$), regardless of whether the 4-hr or 6-hr OBT data were used. The correlation equations to relate the OBT to GES were: $[\text{GES} = 0.49 \times (4 \text{ hr OBT } T_{1/2}) - 1.34]$ and $[\text{GES} = 0.812 \times (6 \text{ hr OBT } T_{1/2}) - 41]$.

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TABLE 2. CORRELATION OF GES RESULTS WITH OBT

	OBT			
	6-hr data set		4-hr data set	
	r	P	r	P
Normal subjects (N = 9)				
GES solids	0.664	0.051	0.863	0.003
GES liquids	0.130	0.738	0.085	0.828
Dyspeptic patients (N = 23)				
GES solids	0.858	<0.001	0.860	<0.001
GES liquids	0.725	<0.001	0.745	<0.001

Sensitivity and Specificity of OBT to Detect Delayed GE. The upper limit of normal for GE was taken as the mean + (2 × SD) from the nine normal subjects data (10). For GES *T*_{1/2} of solids, this was 97.4 min. For the 6-hr OBT *T*_{1/2}, it was 166.8 min, whereas for the 4-hr data set it was 199.4 min. Delayed GE of the muffin meal by scintigraphy was identified in seven patients. Delayed GE of the muffin meal by OBT was identified in six patients with both the 4- and 6-hr data sets. One subject with normal emptying (*T*_{1/2} = 94 min) but close to the GES *T*_{1/2} cutoff of 97.4 min was just misidentified by the 4-hr OBT (*T*_{1/2} = 201 min). The sensitivity and specificity for OBT correctly identifying delayed GE were 86% (6 of 7 patients) and 94% (15 of 16 patients) for both the 4-hr and the 6-hr breath test data sets.

Comparison Between Egg Meal and Muffin Meal for GES and OBT. Eleven of the 23 dyspeptic patients had GES performed with both the muffin meal and an egg meal (two large scrambled eggs labeled with [^{99m}Tc]sulfur colloid and served between two pieces of toasted white bread), which is the standard clinical test meal at Temple University Hospital (9, 10). The two tests were performed within four weeks of one another. In these 11 patients, the *T*_{1/2} with the egg meal (90 ± 36 min) was slightly longer than the *T*_{1/2} with the muffin meal (76 ± 26 min; *P* = 0.015). There was a significant correlation between the GES *T*_{1/2} using the egg meal and the GES *T*_{1/2} using the muffin meal (*r* = 0.919; *P* < 0.001). In addition, there was a significant correlation between the GES *T*_{1/2} using the conventional egg meal and the OBT with the simplified muffin meal (*r* = 0.758; *P* = 0.007 for the 6-hr data set and *r* = 0.713; *P* = 0.014 with the 4-hr data set).

Linear Regression Analysis to Predict Scintigraphic Results. The linear regression model identified three postprandial time points as being significant predictors of OBT *T*_{1/2} namely 60, 75, and 180

min. Using the percent recovery per hour at each of the specified time points and subtracting out the natural baseline ¹³C using the fasting breath sample, the model predicted OBT *T*_{1/2} using the equation: OBT = 315 + 2.8 × (60 min) – 23.2 (75 min) + 9.89 × (180 min). The correlation of the reduced sample data to the full OBT data was significant (*r* = 0.81; *P* < 0.001). There was no difference in the sensitivity of specificity using the reduced number of time points when compared against GES, 86% and 94%, respectively.

DISCUSSION

This study has shown the following important findings on the use of a muffin meal for the [¹³C]octanoate breath test (OBT) to measure gastric emptying. First, the OBT, using an easily prepared muffin meal, correlates significantly with the gastric half-emptying time for the solid phase as measured by scintigraphy in both normal subjects and patients with dyspeptic symptoms. The OBT correlated poorly with the half-emptying times for the liquid phase as measured by scintigraphy. Second, the sensitivity and specificity of the OBT was good in comparison to scintigraphy in identifying delayed gastric emptying. Third, by shortening the breath collection data set from the conventional 6 hr to the initial 4 hr, the strong correlation between the OBT and GES was maintained. Fourth, a linear regression model with three postprandial collections did not reduce sensitivity and specificity compared to GES. Lastly, the muffin meal OBT correlates significantly with conventional GES using an egg sandwich meal.

The OBT was initially described by Ghos et al (1), who concluded that the [¹³C]octanoate breath test (OBT) was a reliable, noninvasive test to measure GE. Since then, several groups have showed that the OBT, using various meals, is reproducible and correlates with GES (2, 4, 15). OBT also appears useful for intraindividual treatment comparisons (5, 16). The OBT results for *T*_{1/2} are significantly longer than the *T*_{1/2} for GES, probably representing post gastric emptying processing of the [¹³C]octanoate (1, 5).

Meal content is known to affect gastric emptying (8, 17–20). Previous studies using the OBT have used meals with different caloric content and distribution including one or two eggs (baked, omelet, scrambled), one or two slices of toast (with or without margarine), and a glass of water or milk (1, 5, 6). Recently, a simple muffin meal was shown to have a strong correlation between OBT and GES in normal subjects

(7). A prior study of ours suggested that a 350-kcal muffin meal was a better "gastric-stimulating" meal than a smaller 250-kcal meal (8). Such a meal may be more sensitive in revealing abnormalities in gastric motility.

In the current study, we found a significant correlation between OBT, using this easily prepared 350-kcal muffin meal, and GES of solids. Our results demonstrate that in normal subjects, the OBT did not correlate with GES of liquids; it should not, at least theoretically, since the octanoate labels the solids. In the dyspeptic patients, the OBT did correlate with the GES of liquids, although less so than with solids. In our study, one patient had a severely prolonged half-emptying time of approximately 5 hr for solids and 6 hr for liquids. There was concern that this outlying point might strongly influence the correlation value. When this patient was excluded from the analysis, the good correlation with solids remained, whereas the correlation with liquids became insignificant. Prior studies have shown that measurement of solid-phase gastric emptying is more sensitive than liquid-phase gastric emptying for detecting gastroparesis (11); gastric emptying of liquids becomes abnormal only in advanced gastroparesis in which gastric emptying of solids is already abnormal (21).

Our study showed a good correlation between the half-emptying times of GES with both the muffin meal and the standard egg meal, which is conventionally used for scintigraphic gastric emptying studies of patients (9, 10). Furthermore, the OBT using the muffin meal correlated with GE of the egg meal. This further suggests that the simple muffin meal can be used to assess GE for clinical evaluation of patients with dyspeptic symptoms.

It has been suggested that the OBT be simplified by decreasing the number of intervals for collecting breath samples and/or shortened from the conventional 6-hr test duration (2, 3). The ideal intervals for collecting breaths for the OBT have not been determined and may be meal specific. Choi et al, using a meal of two egg whites, toast, and milk, found that using a subset of 11 sampling times there was sufficient information to characterize the whole breath-test curve (2). The test duration, however, remained at 6 hr. In a study of diabetic subjects, Lee et al found that breath samples at 0, 30, 120, and 150 min after the meal were needed to accurately measure GE in subjects with normal GE (3). The study, however, was not designed to assess GE in patients with delayed gastric emptying, where a longer duration of the test is often needed as there is a delay in the time to peak

^{13}C values (22). In the current study, we performed the OBT for a total of 6 hours, but analyzed both the 6-hr and a truncated, initial 4-hr data set. Our results show that the strong correlation between OBT and GES for solids is maintained with the 4-hour data set compared to the 6-hr data, both for normal subjects and dyspeptic patients, some of whom may have delayed GE. Scintigraphically, most of the emptying of the muffin meal occurs in the first 2–4 hr. The ^{13}C levels obtained in the breath after the stomach had emptied is probably expelled from a total body bicarbonate pool and may not reflect actual gastric emptying (1, 5). These late data points of ^{13}C may affect the shape of the curve and hence influence the calculated half-emptying times. Our results suggest that the OBT performed for 4 hr is sufficient for measuring GE. In the present study, we have also demonstrated with a muffin meal that collection of breath samples at 0, 60, 75, and 180 min after the meal achieves the same accuracy to detect delayed gastric emptying as the 4-hr or 6-hr collections. Studies using [^{13}C]spirulina as the substrate for breath testing have also shown that only intermittent samples are needed over 2–3 hr to objectively measure normal gastric emptying (4).

The OBT, using varying test meals, has been used to quantify gastric emptying in patients with dyspepsia (1, 6, 16). This study and these others have shown that patients with dyspepsia have longer gastric emptying rates using the OBT as compared to controls (6, 16). Maes et al, using [^{13}C]OBT with an egg omelette meal, studied 344 patients with dyspeptic symptoms and found 25–30% had delayed gastric emptying of solids (6), similar to previously published data of other studies using different methods to measure gastric emptying (23–26). The results of our study are similar to those of Maes et al (6): seven of our 23 (30%) patients had delayed gastric emptying of solids using GES as the standard. Of these seven, six patients (26%) had delayed gastric emptying by OBT. The sensitivity and specificity of OBT, using the muffin meal, for detecting delayed gastric emptying was 86% and 94%, respectively, regardless of test duration. It is possible that the normal range for OBT may be narrower if larger numbers of normal subjects are used, and delayed GE may have then been detected by OBT in the one patient misclassified but close to the cutoff for delayed gastric emptying. The sensitivity and specificity of our study compares favorably with the 67% sensitivity and 80% specificity reported by Delbende et al (15) and the 86% sensitivity and 80%

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specificity reported by Viramontes et al using drug-induced delay in gastric emptying (27).

In summary, this study has shown that the OBT, using an easily prepared muffin meal, can be used to reliably assess gastric emptying of solids in normal subjects and dyspeptic patients with either normal or delayed gastric emptying. The OBT, using the muffin meal, is both a sensitive and specific method to detect delayed gastric emptying and correlates with the "gold standard" gastric emptying scintigraphy test.

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