Effect of Solids, Caloric Content on Dual-Phase Gastric Emptying

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The dual-phase gastric emptying technique is routinely employed to determine the differential emptying of solids and liquids in a wide spectrum of gastrointestinal diseases. Composition, acidity, volume, caloric density, physical form and viscosity of the test meals have been shown to be important determinants for the quantitative evaluation of gastric emptying. In this study, we have evaluated the effect of increasing the caloric content of the solid portion of a physiologic test meal on both solid and liquid emptying kinetics in healthy male volunteers. We observed that increasing solid caloric content delayed emptying of both solids and liquids. For the solid phase, the delay was accounted for by a longer lag phase and decrease in emptying rate; for liquids a longer emptying rate was also obtained. We conclude that modification of the caloric content of the solid portion of a meal not only affects the emptying of the solid phase but also alters the emptying of the liquid component of the meal.

Dual-phase gastric emptying studies using a solid meal labeled with technetium-99m-sulfur colloid (^{99m}Tc-SC) and a fixed amount of water containing indium-111-diethyltriaminepentaacetic acid (^{111}In-DTPA) have been routinely performed for more than 10 yr to evaluate gastric emptying of solids and liquids in a wide spectrum of upper gastrointestinal diseases (*1–2*). Some investigators have pointed out the importance of meal caloric content on the duration of solid and, to a lesser extent, liquid-phase emptying (*3–5*). Nevertheless, the influence of solid-meal caloric content on gastric emptying kinetics of both solids and liquids has never really been addressed. In this study, we have evaluated the effect of increasing the solid-meal caloric content of a physiologic solid-liquid test meal on both solid- and liquid-phase gastric emptying parameters in healthy subjects.

MATERIALS AND METHODS

Thirty male volunteers (mean age 29 ± 4 yr), assigned in two groups matched for age, underwent the same test procedure after an overnight fast. Fifteen volunteers (Group I) were given a standardized physiologic solid-liquid test meal consisting of one beaten raw egg labeled with 500 μCi of ^{99m}Tc-SC and steam-cooked in a hot water bath, two slices of white bread, and 150 ml of water with 100 μCi of ^{111}In-DTPA homogeneously mixed. The total caloric content of this meal was 231 Kcal, composed of 47% carbohydrate, 35% fat, and 18% protein, and weighing 260 g. Group II volunteers (15 subjects) were given the same test meal but with two eggs to increase the caloric content of the solid portion of the meal to 318 Kcal. The weight of this second test meal was 310 g and it consisted of 46% fat, 34% carbohydrate, and 20% protein.

Immediately following ingestion of the solid phase of the meal, each volunteer sat between the two heads of a dual-headed gamma camera fitted with medium-energy collimators and interfaced to a nuclear medicine computer system. One-minute simultaneous anterior and posterior images were acquired in the ^{99m}Tc window (140 keV ± 10%) to determine the maximum counts for the solid phase of the meal; the 247 keV ± 20% indium energy window was then set and, immediately after ingestion of the water, images were taken to determine the liquid-phase zero value. Images of the stomach were subsequently acquired in both windows for one minute every ten minutes during the first hour and every 15 min during the second hour. Images were stored on the computer and corrected for technetium decay and indium downscatter. Regions of interest were manually drawn around the stomach in order to determine gastric counts for both the anterior and posterior images for both the liquid and solid meal at all imaging times.

The gastric geometric mean counts, i.e., the square root of the product of the anterior and posterior counts, were then calculated for both meals. The fractional meal retention was obtained by dividing the geometric counts at each time interval by the maximum (time 0) value. The solid and liquid fractional meal retention values were analyzed using the previously described (*6–7*) power exponential function:

$$y(t) = 1 - (1 - e^{-kt})^{\beta},$$

where y(t) is the fractional meal retention at time t, k is the gastric emptying rate in min^{-1}, t is the time in minutes, and β is the extrapolated y-intercept from the terminal portion of the curve (Fig. 1). The k and β parameters are determined by

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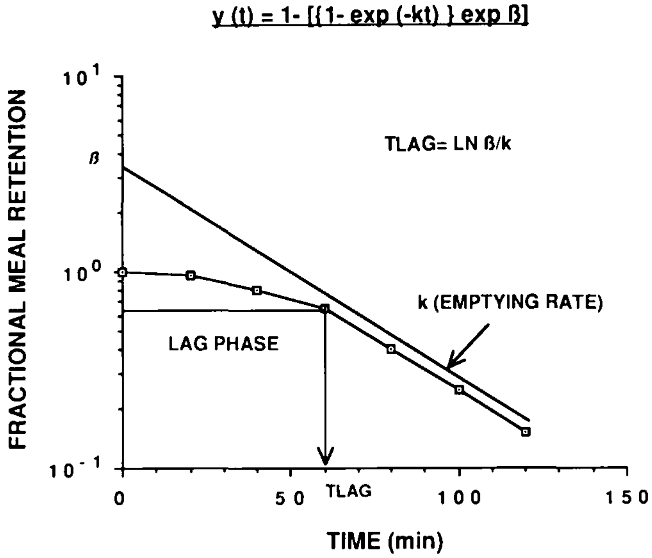

FIG 1. The power exponential fit to analyze solid and liquid data shown on a semi-log plot.

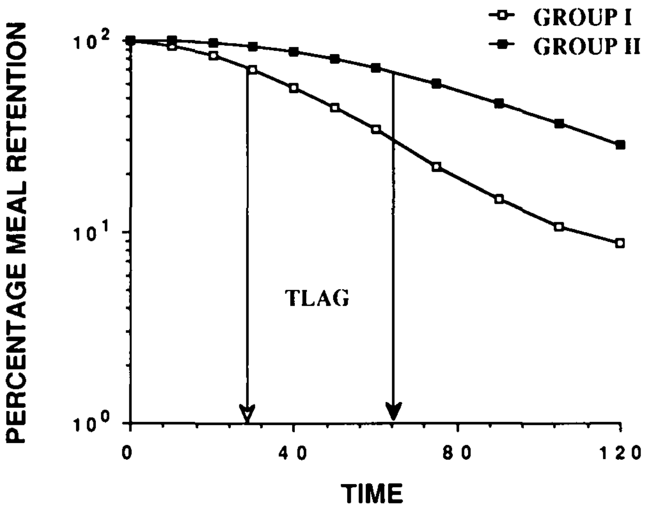

FIG 2. Percentage of solid meal retention in the stomach is figured on a semi-log plot to highlight the initial lag phase (TLAG indicated by the arrows) and the following constant emptying rate. Gastric emptying is prolonged in the two-egg test meal group compared to the one-egg group. The delay is accounted for by both a longer lag phase and a decrease in emptying rate.

a nonlinear least squares algorithm using the fractional meal retention, y(t), versus time, t as input data. This function can be used to determine the half-emptying time ($t_{1/2}$) of a meal and also allows for the characterization of the first portion of a biphasic curve. Indeed, a value of $\beta > 1$ indicates an initial delay in emptying while a value of $\beta < 1$ indicates an initial rapid emptying. When $\beta = 1$, the equation reduces to the mono-exponential function $y = e^{-kt}$. For solids, the initial portion of the curve is usually characterized by a lag phase period, TLAG in min, which is numerically equal to $1/k \ln \beta$ and corresponds to the time at which the second derivative of the gastric emptying curve is equal to zero (*7–8*).

Intergroup statistical analyses were done using Student's unpaired t-test; intragroup parameters for solids and liquids were compared by means of the Student's paired t-test.

RESULTS

Percent meal retention of solids after meal ingestion is shown in Figure 2 on a semi-log plot for both groups. The solid-emptying curves pattern was characterized by an initial lag period (TLAG) followed by a constant emptying rate phase. Both the lag phase and half gastric emptying time were prolonged in the two-egg test meal group (G II) compared to the one-egg group (G I). On a semi-log plot (Fig. 3), liquid emptying curves were linear. While the amount of water ingested by the volunteers was identical in both groups, liquid gastric emptying was faster in the one-egg test meal group.

Table 1 summarizes the gastric emptying parameters obtained by means of the power exponential function fit for both meals. All gastric emptying parameters were significantly prolonged in Group II volunteers. For solids, the half-emptying time delay was accounted for by a longer lag phase and a decrease in the equilibrium emptying rate. In Group I volunteers, liquid phase emptying was characterized by a rapid initial emptying. Emptying of water in Group II subjects was proceeded by a short lag phase ($\beta > 1$) and had a

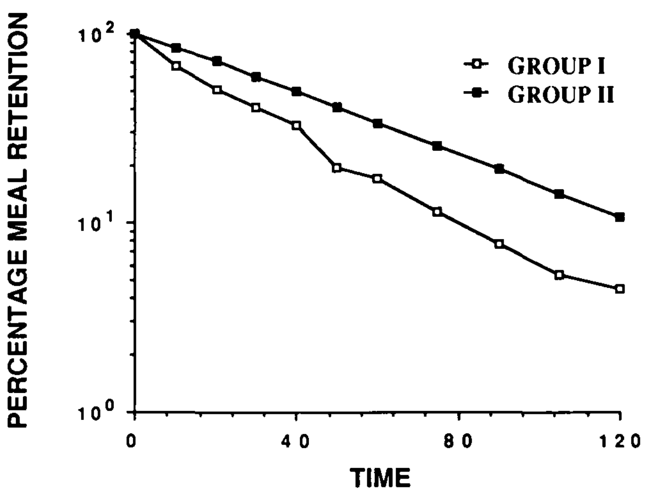

FIG 3. Liquid emptying retention curves are figured on a semi-log plot. While the amount of water ingested by the volunteers was identical, liquid gastric emptying was delayed in Group II compared to Group I.

prolonged half-emptying time, which was mainly due to a decreased emptying rate. No significant difference was observed between the solid and liquid emptying rate in both groups ($p > 0.4$ in Group II and $p > 0.1$ in Group I). Individually and compared to those in Group I, all volunteers in Group II had a prolonged emptying of solids and liquids.

DISCUSSION

Introduced by Heading et al. in 1976 (*9*), the dual-phase radiolabeled meal gastric emptying technique is now routinely performed to evaluate the differential gastric emptying of solids and liquids in various upper gastrointestinal tract diseases (*1–2*). In this technique, the assumption held is that the radiolabeled solids and liquids effectively represent the emptying of the solid and the liquid phases of a meal from the

TABLE 1. Solid and Liquid Gastric Emptying Parameters Obtained Using the Power Exponential Function $y(t) = 1 - (1 - e^{-kt})^{\beta}$

	Solids				Liquids		
	β	TLAG (min)	ER (10^{-2} min^{-1})	$t_{1/2}$ (min)	β	ER (10^{-2} min^{-1})	$t_{1/2}$ (min)
Group I	2.8 ± 0.4	31 ± 4	3.27 ± 1.15	49 ± 5	0.98 ± 0.1	2.8 ± 0.16	21 ± 5
Group II	4.3 ± 0.4*	66 ± 5*	2.13 ± 0.15*	87 ± 6*	1.2 ± 0.1*	2.1 ± 0.17*	44 ± 7*
*$p < 0.005$							

* β is the extrapolated y-intercept from the terminal portion of the gastric emptying curve; ER the gastric emptying rate, and $t_{1/2}$ the half gastric emptying time.

stomach. This implies first, that the radiolabel remains firmly bound to the solid food and that the liquid-phase isotope does not adhere to the solid and second, that the solid and liquid portion of the meal are emptied independently. If the labeling stability has been confirmed in most dual solid-liquid phase studies (*3*, *10–11*), the so-called solid-liquid discrimination, however, has remained controversial. It has been suggested that although the solid emptying curve looks different from the time course of liquid emptying, a slow nearly linear phase predominates after both types of meals; the major difference in the pattern of emptying being an initial rapid emptying phase for liquids and a long initial period of little or no emptying, called the lag phase, for solids (*12*).

Using an egg sandwich for the solid phase, water for the liquid phase and a power exponential function to fit both solid and liquid emptying curves, we have objectively and quantitatively confirmed first that the main difference between gastric emptying of solids and liquids is the existence of an initial solid lag phase and, second, that after this period solids are emptied at the same rate as liquids. The evaluation of the differential gastric emptying of solids and liquids using a mixed solid-liquid test meal appears therefore to be not suitable. This is confirmed by our recent observation that gastric emptying of water is much faster ingested alone than with solids.

Chemical composition and physical characteristics of food have been shown to be important determinants for the evaluation of gastric emptying in normals and patients (*4–5*, *10*, *13–16*). We have recently shown (*7*) that increasing the volume and the density of a test meal delays gastric emptying of solids by prolongation of the lag phase as well as the emptying of the liquid portion of the meal. In this study, we have quantitatively demonstrated that the increase of the caloric content of the solid portion of the meal prolongs the emptying of both solid and liquid portions of the meal. The delay in solid emptying is accounted for by both a longer lag phase and a decrease in emptying rate. The slowing of gastric emptying of solids by the increase of the caloric content of the meal is not a new concept (*3–4*) and it has already been shown that the lag phase of a solid meal is prolonged when water is replaced by a 10% or 25% dextrose solution (*3*). Our study not only confirms quantitatively these data but also demonstrates that increasing solid-meal caloric content reduces both solid and liquid emptying rates.

In conclusion, the caloric content of the solid portion of a mixed solid-liquid test meal not only alters the emptying of solids but also affects the liquid emptying duration in normal subjects. Strict standardization of meal caloric content is necessary for comparing gastric emptying data. The suitability of the dual-phase gastric emptying technique to evaluate simultaneously gastric emptying of solids and liquids in patients needs to be tested.

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